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A Strategic Multidirectional Approach for Picking Indicator Systems of Sustainability in Urban Areas

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Abstract: In a global context, the identification of frameworks and assessment tools for achieving sustainable development requires the study of urban sustainability at different scales. While sustainability can be quantified more precisely on a larger scale, it is challenging to adapt these accounting techniques to smaller sites. Measuring becomes more challenging when researching urban sustainability from several viewpoints, especially when constructing an acceptable set of measurements while taking into account the several issues of the unique decision-making apparatus from theoretical and geographical perspectives. Which sorts of indicators should be prioritized above others? How many indicators should be used? Which criteria should be employed to choose the best indicators for the location of interest? This study addresses the aforementioned research problems by proposing a systematic, multidirectional approach to defining an adequate collection of indicators for sustainability accounting in urban situations. A top-down strategy, which provides a literature study to identify regularly used indicators in essential sustainability categories, is joined by a bottom-up approach, which creates indicators based on real-world circumstances. The combination of these two methodologies seeks to produce a set of relevant sustainability measurements. A neighborhood rehabilitation project for public housing in Le Lignon (Switzerland) serves as a pilot case for calibrating the proposed multidirectional technique. The final findings can support the public and private parties involved in sustainable urban planning procedures in assessing urban projects based on location-specific features.

Keywords: sustainable development; urban regeneration; top-down approach; indicators system

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1. Introduction

Cities play an important role in sustainable development due to their rising urbanization and evident environmental, social, and economic implications due to pollutant emissions, resource employment, and other barriers including waste production and urban heat islands. Quick urbanization exacerbates economic and social inequality, reducing low-income households' access to services and increasing social exclusion [1,2].

Current urban transformation models have placed a strong emphasis on regeneration as a means of mitigating these negative effects. In order to model sustainable development assessment procedures, it is crucial to highlight the potential for creating co-creative multidimensional frameworks.

The significance of a sustainability analysis in regeneration initiatives is shown by its extensive inclusion in global policies and agendas [3–7]. International organizations adopted mechanisms for evaluating sustainability at both the territorial and urban levels in the last ten years of the twentieth century. The frameworks covered in the worldwide scenario provide an overview to help decision-makers in the adoption of policies that meet sustainable standards from several perspectives (environmental, social, and economic ones) [8].

The scientific community frequently uses various sustainability accounting methods. Some of these are appropriate for urban evaluation, as they capture the fundamental features of sustainability across multiple schemes of indicator-based techniques. Understanding the urban component through the application of an indicator system requires a comprehensive strategy that considers the interconnection of the social, economic, and environmental components of the development area [9,10].

The potential of indicator-based systems to minimize the complexity of sustainability assessments makes them more useful for evaluating the performance of sustainable development policies and initiatives. Quantitative and qualitative indicators address various challenges at different geographical scales, but it is difficult to determine which ones are most successful in reflecting the characteristics of the urban sustainability setting [11–16]. Cairns J. (2003) stated that there is an ethical issue when we refer to sustainability accounting with the mention of a twofold visual of the issue—"top-down" and "bottom-up"—in accordance with the desirable point of view on sustainability. Sustainable development requires both a worldwide plan ("top-down approach") and a bottom-up strategy that takes into account the particular concerns and ecosystems of each region [17].

Interpreting sustainability from two perspectives has led researchers to return to indicators as tools for accountability. E.g., Salati et al. (2022) developed metrics of sustainable urban design through a review of the most applied urban sustainability evaluation tools [18]. Feleki et al. (2018) analyzed over twenty sustainability tools, including indicator systems and building indices [19]. According to Berardi et al. (2011), research should be carried out on how to modify the current methods to fit different geographical settings, and the evaluation criteria should be modified to take the viewpoints of the citizens who are taking part into account [20]. These serve as illustrations of how the top-down and bottom-up approaches to sustainability may be applied separately and differently, particularly when it comes to the stage of selecting and determining which indicators to employ in order to evaluate sustainability performance.

This could pinpoint "in-depth investigation windows" that still require more exploration and pertain to conceptualizing difficulties that may be summed up in the following main points: (i) synergy among indicators; (ii) the correlation of indicators and stakeholders' interests; (iii) multi-scaling indicators; (iv) data availability across time/space. Each point is better specified as follows:

(i) Creating appropriate methods for assessing urban settings overall depends on the interlinkages between the sustainability triad. The interdependence of social, environmental, and economic issues makes it tricky to create issue-specific indicators relevant to decision-making contexts. To entirely realize the relevance of indicator interactions and the synergy between dominant fields in a particular decision–framework system, further investigation needs to be performed.
(ii) A mismatch can be detected between the objectives and expectations of all those engaged in the urban sustainable development procedure and the process itself. When the metrics for sustainability and interest are not equal, there is less confidence in employing one kind of signal over another.
(iii) The effectiveness of indicators is directly impacted by the settings in which they are used. Many tools and indicator frameworks that function at the building, neighborhood, city, region, national, and international levels serve a range of geographic scales and provide data pertinent to their reference scale [21,22]. Indicators at the city or metropolitan level typically focus on broad issues that affect the urban area, such as economic productivity, environmental value, and social equality. National or worldwide indicators of urban sustainability address wider concerns and trends that extend beyond specific city boundaries, providing a more comprehensive view [2,12]. When the inquiry is expanded to the local level, a number of connected problems

concerning the arrangement of various components occur [23,24]. The interoperability indicators create on multiple geographic analytic scales turn out to be challenging.

(iv) Evaluation is determined by the quantity and the quality of accessible data across several geographical dimensions. Smaller analytical contexts create more challenges for data collection since accessible data are typically aggregated. This problem might make it more difficult to holistically assess sustainability. Metropolitan areas may have varying levels of data accessibility; although some may have large databases, others may not have well-documented data. Because of these distinctions, evaluations may be skewed to favor decisional settings with greater access to data, excluding a number of locations from the comparison [6].

Furthermore, various datasets may only provide information for a certain number of years or time periods, making it impossible to analyze long-term patterns and the sustainable performance accounting of metropolitan regions over time [25,26].

These kind of challenges occur notably when considering a project's sustainability, particularly in metropolitan areas. To solve these difficulties, a comprehensive methodology that integrates both top-down and bottom-up sustainable analytical areas has become cogent. The lack of alignment with the interests and needs of stakeholders involved in the real urban planning process becomes clearer. In addition, there is a unique problem in assessing indicators for which it is possible to refer to international banks but not to local ones. By focusing on these two major issues, sustainability indicators can be better defined and possibly implemented if they are conceptualized as part of a co-knowledge process of urban sustainability, taking into account a two-way research path that aims to align international content with local specificities (a top-down vs. bottom-up approach) [27–30].

As a consequence of these considerations, the key Research Questions (RQs) underlying this study are as follows:

RQ1: What are the key measures used to assess the condition of sustainability at the urban scale?

RQ2: Given the available indicators for measuring urban sustainability, how can we link them in a sustainability assessment exercise at the local urban scale with the needs of those involved in the design process?

This study describes an exhaustive approach with the purpose of establishing a suitable panel of performance indicators tailored to the evaluation problem in urban areas. A double-operative strategy is offered, based on two separate research activities, a literature assessment and content analysis, aimed at providing an indicator suite for sustainability accounting. Both aim to provide a comprehensive review of key sustainability indicators at the urban scale, with a focus on economic–financial, environmental, and socio-cultural categories, through the integration of a top-down and bottom-up plan.

The top-down approach begins with a literature study to identify the frequently used indicators in the key areas of sustainability. The bottom-up method focuses on more particular considerations gleaned from the study of a pilot case, which serves to make the indicator suite territorially specific so that it can be taken into account in appropriate evaluation procedures in urban settings. This method employs indicators from a real-world example to demonstrate the intervention's sustainability by comparing pre- and post-intervention situations. The neighborhood scale, namely that of Le Lignon in Switzerland, acts as the pilot case that emerges as a case study from the perspective of selecting and then verifying the indicator suite. Neighborhoods, as fundamental units of urban analysis, have unique characteristics and dynamics that influence overall sustainability. They refer to a distinct geographic area within a city or urban region, characterized by a combination of physical, social, economic, and environmental attributes. A consideration of the neighborhood scale is critical to addressing the localized challenges and opportunities inherent in urban redevelopment.

This work is organized as follows: Section 2 outlines the materials and methods used in identifying acceptable indicators for sustainable accounting on an urban scale, as well as the pilot case conducted via the bottom-up approach; Section 3 describes the outcomes of the two approaches, as well as the scenarios for defining an appropriate indicator set from a holistic perspective; Section 4 discusses the proposed results and analysis methods; and Section 5 summarizes the methodological apparatus's findings and practical implications for urban sustainability.

2. Materials and Methods

2.1. Methods and Tools for Tracking the Indicator Suite of Sustainability

A sustainability assessment in urban settings is essential for environmental planning processes at the local (city or neighborhood) and micro (street or parcel) levels. Its goals are to (i) define targets for sustainable development and assess how well they have been met; (ii) assess the effectiveness of current planning policies and help make the necessary adjustments in response to changing realities; and (iii) compare the differences over time and space using performance evaluations, which will serve as a basis for organizing future actions. In other words, a sustainability evaluation is an effective instrument for linking past and present efforts to long-term development objectives [31].

Urban sustainability is assessed using several methods and tools, from specific related models to indicator systems. Three categories were established to structure sustainability evaluation techniques:

(1) The first category includes instruments for product-related evaluations that examine the creation and usage of products and services. Environmental laws and regulations are influenced by evaluating a product's resource consumption and environmental impact throughout its lifespan.

(2) The second type includes integrated assessment tools that provide scenarios for project implementation or policy changes. To reduce externalities, terms such as "Environmental Impact Assessment" and "Strategic Environmental Assessment" are commonly used to examine how development projects or strategic decisions may affect the environment.

(3) The third one is about urban sustainability indices and indicators, which are becoming more commonly recognized as effective instruments for evaluation [31].

Indicators are statistical measures of significant phenomena that depict present situations or changes towards the definition of goals, strategies, and solutions [32]. Indicator-based sustainability assessments have several applications: (i) they can be used to analyze pertinent issues, current conditions, and emerging trends; (ii) they can serve as a foundation for the information needed to define objectives, goals, and necessary actions; (iii) they can orient the monitoring and evaluation and predict the decision-making processes behind the development of a territory; and (iv) they can be used to facilitate communication between public and private subjects, starting conversations and raising awareness [32].

Selecting the right indicators is an essential step in the management of an indicator system. There are a few drawbacks, though. In a group setting, choosing and defining indicators can be challenging since it may be easy to ignore opposing viewpoints and come to a consensus. Moreover, researchers may prioritize some elements of sustainability above others when choosing indicators because there is not a single reference system that is widely relevant in the context of decision-making [33].

International organizations have developed Urban Sustainability Indicator Frameworks (USIFs) to measure urban sustainability [34]. Among these, for example, are those of the United Nations (2015) on sustainable urban development, as well as the New Urban Agenda (NUA), which was adopted by the United Nations General Assembly on 23 December 2016. For further information on existing USIFs, see Michalina et al.'s (2021) review [2]. It is a set of references that are generally valid and potentially applicable in decision-making contexts that vary in terms of objectives and analyses.

To be able to develop more sustainable metrics related to the territorial context, strategies for tracking sustainability indicators have been proposed based on information sources relevant to the study's urban environment. Text mining techniques may be used to measure a variety of sustainability-related issues. This is a qualitative method that recognizes the keywords that best capture the sentiments expressed about the topic of the research based on their weight and the repetition of text in a particular sample [35].

The "Trends in Sustainability" Web application looks for pre-specified keywords relating to various sustainability-related topics in 115 newspaper sources from 41 different countries [36]. The program's output shows the trend in the quantity of news articles using the keyword over time. An analogous tool "Carbon Capture Report" looks for pertinent content on social media sites including blogs, Twitter, YouTube, and news sources using preset keywords. On the other hand, sentiment analysis and natural language processing methods are used in the "Carbon Capture Report" to further evaluate the data and provide additional information. The program displays a time series analysis of the data, color-coded based on the individuals' locations, activities, and overall data contribution (positive, neutral, or negative). Media Watch on Climate Change is a comparable resource. It is a publicly accessible website that compiles vast archives of digital news and social media content about climate change and related subjects [37].

Textual analyses allow us to identify relevant variables to depict the sustainability of an urban area across several objectives. In the study of Vázquez and Escamilla (2014), opinions regarding the primary determinants of old health were sought to be identified by a textual analysis process using the Nvivo program [38]. Textual analysis was utilized in the study of Saito et al. (2008) to forecast retweets based on the significance of the user-generated material on Twitter [39]. Similarly, Jiang et al. (2016) examined the basic characteristics that influence the idea of "re-tweetability" for each tweet when employing a predictive filter for user cooperation, linkages, and keyword repetition in tweets [40]. As a result, textual analysis may be used to discover and quantify the keywords with the most weight in a particular sample, as well as to investigate their impact on the text [41]. When evaluating sustainability in urban environments, a text mining analysis may be helpful in finding sustainability traces by searching through publications or other readily accessible sources of information pertaining to the context of the reference. This requires proof of the projects and/or program that are being looked at. However, this approach is characterized by a considerable degree of subjectivity in its operational methodology, and its sustainability track record may or may not be in line with the metrics used in general contexts.

The aforementioned explanation of how the indicator selection process is structured (Section 3.2) seeks to control subjectivity in text mining and encourage conformity with global sustainable criteria. It does this by fusing a bottom-up strategy—through the text analysis of relevant documents of interest—with a top-down approach through a literature research on sustainable components.

2.2. Methods

The main objective of this study is to provide local and case-specific relevant performance indicators to be referred to for developing assessment exercises. Two methodologies can be applied in an integrated manner: a top-down systematic literature review (Section 2.2.1) and a bottom-up content analysis (Section 2.2.2). Figure 1 illustrates the qualitative functional link between the two proposed methods. It is feasible to follow a clear and unambiguous relationship between these two methods in order to connect the essential components of the literature review—performance indicators and categories—with the structural components common to a content analysis—core sentences and keywords. The ideal collection of indicators is then found by combining these two approaches with their structural components. While a top-down strategy creates a larger group and a bottom-up method may uncover indicators more specific to the pilot case under investigation, combining the two methods results in a collection that has the most indicators to refer to the context of the decision-making process. Determining the coordinates of the starting point, for the sustainability indicator groups' consistency with respect to the configuration of the urban landscape, is the aim. The following Section 3 provides a demonstration of the double-operative process based on the integration of the two previously mentioned methodologies.

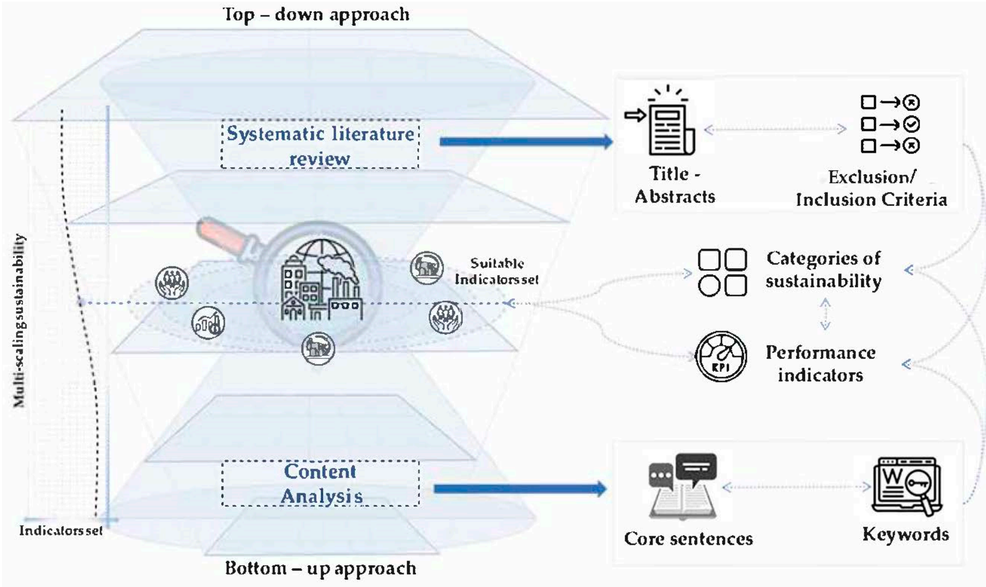

Figure 1. Qualitative functional link between systematic review and content analysis for suitable indicator suite definition.

2.2.1. Top-Down Systematic Literature Review

The notion of sustainable development gives rise to complex and conflicting issues due to the coexistence of fundamental values at odds with one another. Sustainability is thus defined as the capacity to reach a dynamic balance between diverse and opposing polarities, culminating in the idea of preserving or conserving current conditions over an extended period of time.

Many measurement systems and form-based design codes focus on urban neighborhoods rather than the city as a whole, emphasizing the neighborhood as a fundamental component of the urban system to achieve sustainability goals [42]. They (measurement systems and form-based design codes) are configured as tools that, by stabilizing a set of indicators related to various aspects of sustainability, govern the urban processes at different scales of analysis.

Indicators, borrowing the words of Peter Bosselmann (2008), are teaching instruments that help communities to identify, monitor, compare, evaluate, measure, model, and change alternative initiatives in their performance accounting [43]. Indicator systems constitute a basic framework for evaluating an urban project or a current state: they transform complex physical and social systems into simple information units, allowing them to be evaluated and guiding projects towards better a performance valuation.

The number of performance indicators to be taken into account during the impact analysis phase, in the territorial context of reference, makes it possible to conceptualize the urban process in an *n*-dimensional space of action when sustainability indicator systems are used at the urban scale. The primary indicator systems used to evaluate sustainability in urban contexts at multiple scales are to be identified by a comprehensive examination of the national and international literature. To define the primary indicator systems currently (2024) in use, a top-down approach must be taken to conduct a thorough literature review.

This involves the following steps:

1. The formulation of research questions: the identification of the main questions that need to be researched in connection to urban sustainability [44]. These questions are precisely tailored to align with the objectives of the study.
2. Database building and literature sources' identification: databases relevant to the field are selected to facilitate a comprehensive literature search. A selection of keywords is made to find research articles that support the objectives of the study. Examples of these keywords are "sustainability indicators", "urban sustainability assessment",

and "urban indicator systems". The initial collection of articles gleaned from the literature is then sifted using relevant inclusion and/or exclusion criteria, most often based on the existence or absence of a sustainability indicator list and the adaption of the indicators to an urban framework.

3. Information gathering: the next step is the collection of key data from the selection of literature sources. This includes the article's year of publication, title, primary goal, sustainability categories taken into consideration, variables/indicators employed, and, for each indicator, the kind of methodology used (e.g., qualitative or quantitative), measurement method/unit, and spatial scale [45–50].

2.2.2. Bottom-Up Approach

A bottom-up strategy looks at various parts or unique situations to have a thorough grasp of the issue at hand [51–53]. A more comprehensive and equitable perspective is attained by constructing the overall reference set of indicators utilizing top-down and bottom-up approaches in a synergic way [54–65].

The bottom-up approach involves the following steps of a content analysis:

1. Examine pilot case-specific documents for thorough information, highlighting significant lines with keywords that convey contextual factors and/or intervention characteristics. The resources under investigation have to be focused on a compelling analytical pilot case that will function as a prototype for further study. By identifying the indicators to assume based on valuation approaches within the same analysis environment, the pilot case aids in the customization of the analytical framework.
2. Identify the important variables required for establishing a set of sustainability indicators across a number of dimensions using the highlighted keywords.
3. By exploring these key variables, one can gain insight into a variety of sustainability-related topics (categories), including the technological, typological, social, and environmental aspects that are monitored in the analysis document.

Following the content analysis, the indicator suite has to be validated by ensuring that it is applied appropriately in the research location. This can be achieved, for example, by having people or other stakeholders (politicians, technologists, professional societies) participate and provide feedback on whether or not each indicator is actually implemented in assessment practices. The Pilot Case Section provides a description of the pilot case that is used as the benchmark in the work.

Pilot Case

Le Lignon, a modernist housing complex in Vernier, Switzerland's canton of Geneva, is the pilot case for customizing the indicator pool in line with international sustainability standards while dropping in more context-specific practices of assessment at the territorial level. Built between 1964 and 1966, this complex is one of the most monumental neighborhoods in the world and the first in Switzerland. Between 2017 and 2021, the complex underwent a multi-phase renovation. Despite covering 28 hectares, only 8 percent of the district's total area is built up. With impressive structures, including two towers of 26 and 30 stories and an additional building, its Y-shaped design spanning 1065 m ensures dual orientation, maximum sunlight for each apartment, and the integration of numerous amenities. This arrangement facilitates the development of large green spaces, preserving the forest along the Rhone and the Nant des Grebattes. In recognition of its importance, Le Lignon was included in the Federal Inventory of Swiss Settlements to be Protected (ISOS) in 2021, under the auspices of the Swiss Conference and the Federal Law on Nature and Landscape Protection. This pilot study area was delimited based on administrative boundaries and its significance as a distinct functional unit within the city context. The neighborhood, in fact, is home to approximately 6000 residents, representing approximately 20% of the total population of the city of Vernier. This area functions as a major satellite settlement, with 2780 individual housing units. It also has a variety of amenities, including a school, shopping center, medical facility, church, cultural and sports facilities, and an urban farm with vegetable gardens. A map illustrating the distribution of land use within the neighborhood is presented in Figure 2.

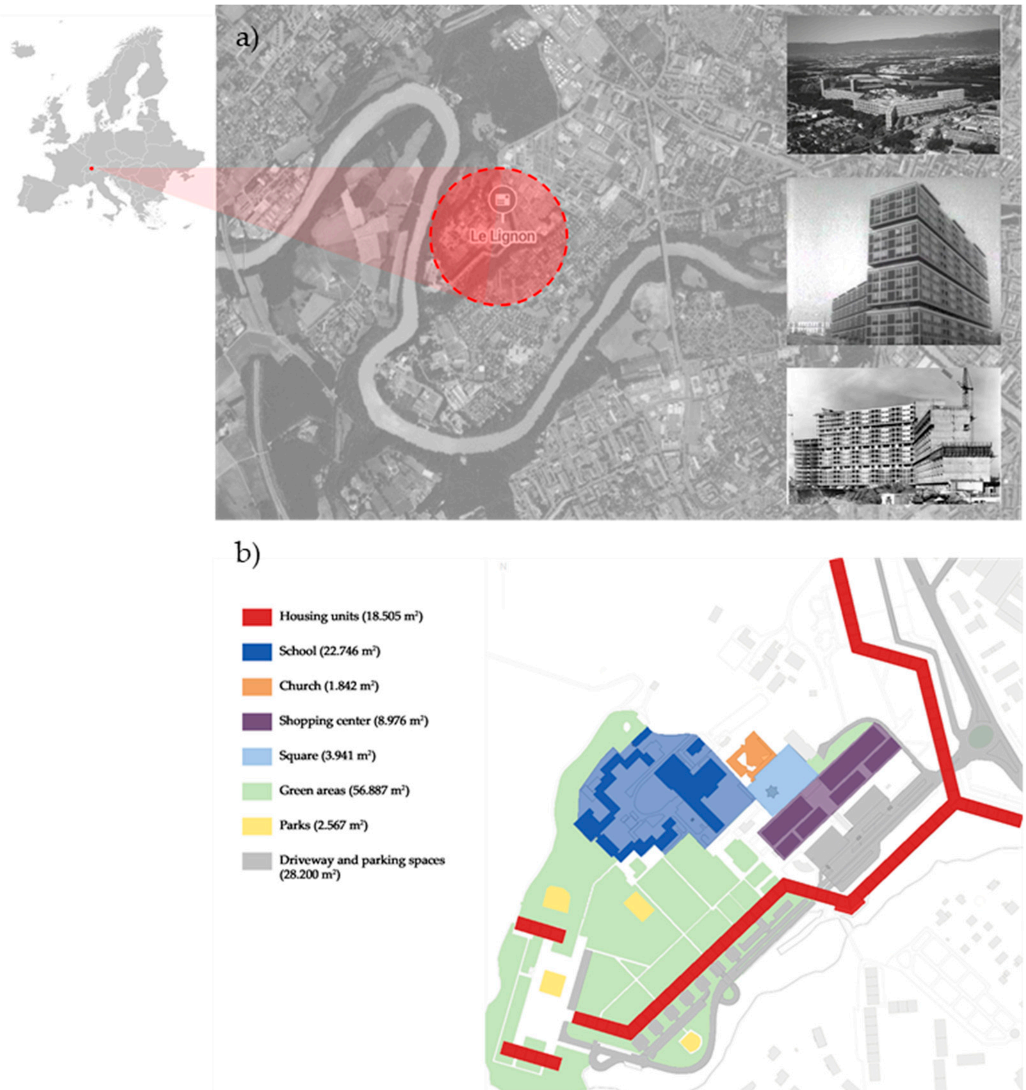

Figure 2. Determining the Le Lignon pilot case's (**a**) territory and (**b**) intended uses.

3. Results

The following section describes the results of the top-down (Section 3.1) and bottom-up (Section 3.2) techniques, followed by a comparison of their sustainability metrics (Section 3.3).

3.1. Top-Down Analyis

In the Elsevier Scopus bibliographic database (last accessed on 6 February 2024), three keywords—"indicator", "sustainability", and "urban"—made it easier to locate peer-reviewed research. A significant number of publications were located using their titles, abstracts, and keywords; of these, 20 were assessed due to their fields of application, topic affinity, and recent publication date [66–85]. Articles that provided an indicator set for the foundation of sustainable accounting and had some bearing on the process of making the indicators more useable were specifically chosen for additional analysis. Articles that were theoretical, review-based, or unrelated to any particular city were not considered. Details on the 20 analyzed articles are included in Table 1. Information on the categories and types of indicators are provided for each publication.

Table 1. Indicator system derived by literature review practice using Scopus database.

No	Year	Authors	Scale of Analysis	Categories	Indicator Set
I	2023	Samuel M., et al.	City	Access to City Credit facilities Consumption patterns Economic prosperity Environment Environmental knowledge Equity/justice Hospital network services Livable communities Place shaping Population Quality of life Building resilience Safety Social	n.a.
II	2023	Yue Z., et al.	Global scale	SDG11.6.2	PM2.5 concentrations
III	2023	Zhou-Qian G., et al.	River	Land dataset Natural environmental data Socioeconomic data Pressure on urban expansion Pressure on the food supply Pressure on ecological degradation Pressure on landscape pattern	Built-up land expansion intensity Proportion of built-up land Land use composite index Proportion of agricultural land Decrease rate of agricultural land Ecological service value Ecological carrying capacity Shannon's diversity index Landscape disturbance index Landscape vulnerability index
IV	2023	Fusaro L., et al.	City	ES supply and demand	O3 and PM10 removal
V	2023	Qu J., et al.	City	Water resource system Socioeconomic system	Water quantity Water quality Water efficiency Economic development level Social development level
VI	2023	Keshtkar M., et al.	Biome	Environment Socioeconomic system	Bio-physical data Socioeconomic data
VII	2023	Raquel Calapez A., et al.	Urban	Ecosystem services	Provisioning Regulating Cultural
VIII	2023	Zhou Y., et al.	Greater Bay Area	Urban ecological network	Water conservation Habitat quality Soil conservation Carbon fixation
IX	2023	Cheng M., et al.	Country	Urban areas Urban greenness	Nighttime data Enhanced vegetation index
X	2023	Abu-Rayash A. and Dincer I.	City	Environment Economy Society Governance Energy Infrastructure Transportation Health	
XI	2023	Mylonakou M., et al.	City	Public satisfaction with transport	Access to mobility services Active mobility Affordability Quality of public space Air pollution emissions Energy efficiency Greenhouse gas emissions Commuting travel time Congestion and delays Road deaths Security Traffic safety active mode
XII	2022	Prieto-Curiel R., et al.	City	Urban	Building footprint density
XIII	2023	Zafar Z., et al.	Megacity	Vegetation	Enhanced vegetation index

Table 1. *Cont.*

No	Year	Authors	Scale of Analysis	Categories	Indicator Set
XIV	2023	Anwar Uddin Md., et al.	City	Density Diversity of land use Destination accessibility Design	Population density Commercial density Employment density Land use diversity Land use mixedness Length of walkable/cyclable paths Intersection density Parkin utilization Open/green spaces
XV	2022	Pukowiec-Kurda K.	City	Urban ecosystem	Number of ecosystem services provided by forests Percentage of forests Number of ecosystem services provided by wetlands Percentage of wetland Percentage of recreational area Number of ecosystem services provided by recreational area
XVI	2022	Zhang H., et al.	City	Economic scale Economic structure Economic vitality	GDP per capita Disposable income of urban residents per capita Net income of rural residents per capita Primary industry output Secondary industry output Financial income per capita Retail sales of consumer goods per capita Residential savings deposit balance per capita
XVII	2022	Valencia A., et al.	Metropolitan area	Environmental aspects Social aspects Economic aspects	Carbon footprint Water footprint Sea level rise Food consumption index Unemployment index Crime rate index Crop production index Water reuse potential
XVIII	2021	Effat H. A., et al.	City	Shelter degradation Social degradation Environmental degradation Economic degradation	Habitat quality Overcrowding Rate of illiteracy School enrolment Social status Quality of society Population growth Pollution High-voltage pressure area Average price of residential land Utilities Road density
XIX	2022	Han Z., et al.	Province	Provisioning ecosystem services Supporting ecosystem services Regulating ecosystem services Cultural services	Food supply Habitat quality Soil conservation Carbon sequestration and oxygen production Water conservation Landscape esthetics
XX	2022	Cardenas-Mamani and Perrotti D.	n.a.	Ecosystem services	Provisioning Regulation and maintenance

A total of 95 performance metrics that relate to 64 affiliation categories are relevant, according to this review. These are mostly indicators used in urban settings and connected to ecological–environmental issues. Because they are used and referred to in the study of city performance, the task is to examine the possibility of utilizing and linking the same indicators at lower scales of analysis, such as those of urban communities. As a result, it is necessary to cross-reference broad information like this with the data produced from an information system analysis, which is more relevant to the urban setting of interest. In this regard, it is appropriate to conduct a bottom-up study, as outlined below.

3.2. Bottom-Up Analysis

Applying a bottom-up methodology to the Le Lignon pilot case study enables the identification of preliminary indicators that facilitate the capturing of the particularities inherent in a real case study.

By retracing the stages associated with the development of a content analysis, it was possible to examine historical, social, environmental, and economic analyses of the relevant interest case documents, as well as relationships pertaining to the building technology of neighborhood houses. Every available document has a few key phrases that can be easily identified, as well as phrases that can be further broken down into smaller units, for an analysis to determine the sustainable performance of the intervention. The supplementary files include a document (Figure S1) that illustrates the pilot case study, with phrases underlined in yellow that may provide suggestions for keywords to be used as potential analysis variables. Table 2 provides a detailed overview of the pilot case study, expressed through various variables. This table can be used to describe and understand the interventions to be evaluated both ex ante and ex post, in addition to using the set of indicators identified with the proposed methodology (see Table 3). For this purpose, for each variable, the unit of measurement is indicated, as well as the type of variable, whether it is numeric/continuous, categorical/nominal, or whether it is a variable to be calculated.

Table 2. Descriptive table of pilot case study information. (Source: research working document "*Post-COVID future cities. Methods and tools to design and assess, healthy, sustainable and resilient suburbs*", Sapienza University of Rome, August 2022).

Source/Information for the Definition of A Variable	Description of the Rationale of Each Variable	Type of Variable	Unit of Measure
Location: Vernier, Switzerland Original Project Georges Addor, Dominique Julliard, Louis Payot, and Jacques Bolliger	1. Are the architects a reason for the project having an element of identity?	Categorical/ordinal	Yes or no
Renovation Project Jaccaud Spicher Architectes Associés	2. It is the project an "example" of the traditional architecture of the place?	Categorical/ordinal	Yes or no
Academic Research Project Directed by Franz Graf and Giulia Marino (TSAM)	3. It is the project a masterpiece?	Categorical/ordinal	Yes or no
Timeline 1971 original | 2021 renovation Research Project 2008 | 2011 Renovation: Design Phase 2010 | 2017 Construction: 2017 | 2021			
Typology Upcycling	4. Does the upcycling involve the residents? 5. Are the architects specialists in upcycling? 6. Is the project appropriate for upcycling?	Categorical/ordinal Categorical/ordinal Categorical/ordinal	Yes or no Yes or no Yes or no
Technology Concrete PreFab	7. Is this type of construction usual in the area?	Categorical/ordinal	Yes or no
Clients Anlagestiftung Pensimo, Bellerive Immobilien, Comité Central Du Lignon, Immobilien Anlagestiftung Turidomus, Imoka Immobilien Anlagestiftung, La Fondation HBM Camille Martin, La Rente Immobilière, and Marconi Investment	8. Are the clients private or public?	Categorical/ordinal	Yes or no

Table 3. Indicator system retrieved using the bottom-up approach.

			Indicator Set				
No.	**Indicator/Data**	**No.**	**Indicator/Data**	**No.**	**Indicator/Data**	**No.**	**Indicator/Data**
1	Gross internal floor area	22	Land density of suburb	43	Shape of the building and information about its main dimensions (height, length)	64	Maintenance costs of the building
2	Green surfaces	23	Inhabitants of suburb	44	Distance from university, school, train station, city center, and parks	65	Commercial rental values for this typology
3	Built area	24	Land density of the Cantone	45	Analysis of urban standards	66	Dwellings for non-self-sufficient people
4	Built density	25	Inhabitants of the Cantone	46	Pervious surfaces	67	Access to the building
5	Residents	26	Original construction typology	47	Impervious surfaces	68	Access to nearby spaces
6	Composition of households	27	Time of maintenance	48	Garden surfaces	69	Per capita housing surface
7	Population density	28	Is the building preserved?	49	Facilities (schools, shops, medical center, church, and cultural and sports areas)	70	Public aggregation areas
8	Age of inhabitant	29	Where is the project located?	50	Average summer temperature perceived internally and average summer temperature measured externally	71	Distance from the underground, train station, and bus services
9	Number of houses	30	Is it a prestigious location?	51	Average winter temperature perceived internally and average winter temperature measured externally	72	Distance from the university, postal offices, hospital, schools, and supermarket
10	Commercial activities	31	Elements of the building that are going to be renovated	52	Air pollution	73	Distance from car–bike sharing points
11	Parking lots	32	Type of housing tenure	53	Construction technologies for minimizing natural risk	74	
12	Number of *garages*	33	Market value of residential buildings	54	Sources of renewable energy	75	Average cost of water supply
13	Building typology	34	Rental value of residential buildings	55	Systems for water recycling	76	Investment costs of the entire renovation of the building
14	Residential typology	35	Average period of possession for residents	56	Frequency of ordinary and extra-ordinary maintenance interventions in the last 5 years	77	Maintenance costs of the building
15	Average climate temperature	36	Average income of residents	57	CO_2 quantity produced by the green areas and construction elements of buildings	78	Commercial rental values for this typology
16	Humidity	37	Average income of suburb	58	Transmittance of walls and window frames	79	Number of dwellings for non-self-sufficient people
17	Wind conditions	38	Average income of Cantone	59	Transmittance of rooftop and midline ceiling	80	Number of access points in the building
18	Rain precipitation	39	Type of education	60	Are any materials being reused?	81	Number of access points to nearby spaces
19	Local radiation	40	Employment status of residents	61	Average cost of heating and cooling		
20	Exposure of the apartments	41	Average age of residents	62	Average cost of water supply		
21	Land density	42	Information about criminality	63	Investment costs of the entire renovation project of the building		

Based on this content analysis of the available documents, 130 core phrases have been identified, from which 130 keywords may be extracted. Due to certain words being synonymous, a subset of variables equal to 101 has been identified from the 130. The 101 indicators discovered during the document analysis have been divided into categories, including environmental resilience, economic–financial appropriateness, and socio-cultural suitability, according to the thematic affinities and correlation of some keywords.

3.3. Comparing and Validating Sustainability Metrics

A comparison of the indicators in Tables 1 and 3 was carried out in order to identify the panel of minimum reference indicators through which to conduct ex ante and ex post evaluations of the urban environment. The comparison operation was performed using a sentiment analysis, which is the act of computationally recognizing and categorizing the ideas indicated in a piece of text, particularly to determine whether the author's attitude towards a specific topic is positive, negative, or neutral [86]. Sentiment analysis has been implemented through the Orange Data Mining software (version 3.36.1). Figure 3 depicts the workflow of the algorithm used for identifying possible semantic correlations between the indicators of Tables 1 and 3.

Figure 3. Sentiment analysis algorithm.

The sentiment analysis findings are returned as a heat map, as seen in Figure 4 below. In the same image, clustering is emphasized to demonstrate the potential inter-linkages between the indicators recorded by both methodologies (bottom-up and top-down).

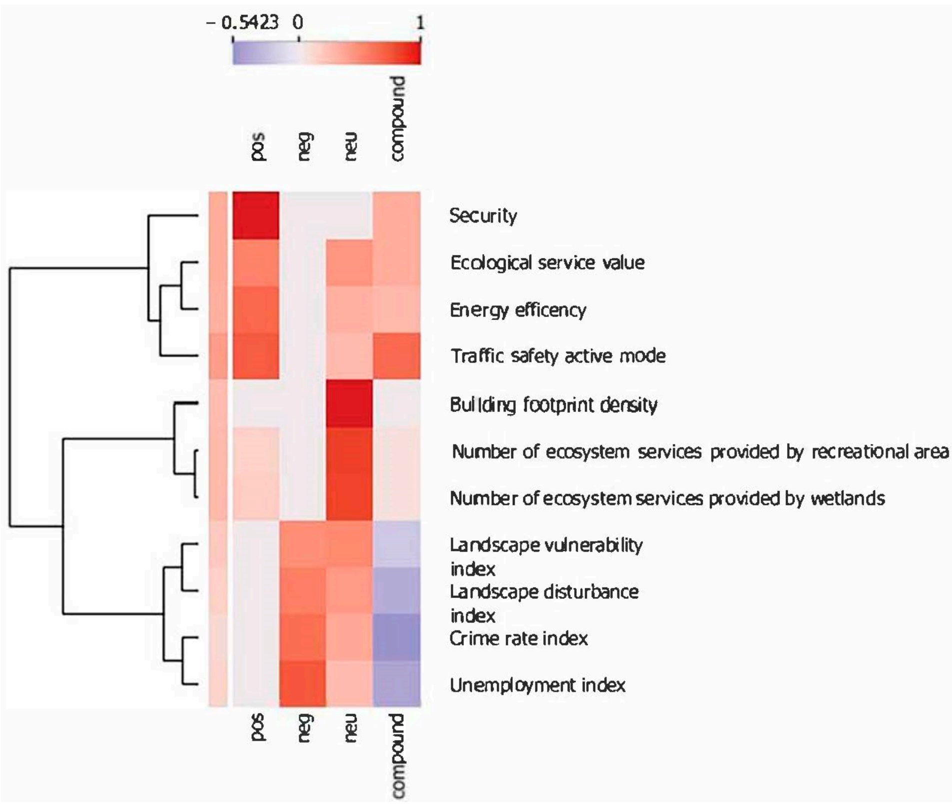

Figure 4. Heat map with clustering structure.

The degree of interconnectivity between the proper coupling conditions was shown by the correspondence between the fluid indicators from the top-down analysis and the metrics obtained from the bottom-up approach's implementation. For example, the content analysis of the documents relevant to the Le Lignon pilot case, using the bottom-up approach, has provided a set of metrics that show a positive connection with the security indicator (1.00) and the notable negative influence of the building footprint density indicator (−1.00). Other notable values also match the indicators for measuring the ecosystem services provided by wetlands (0.843) and recreational areas (0.822).

Clustering activity, on the other hand, generates three broad groupings of indicators from which the most relevant sentiment-analysis-derived components may be determined. The three dimensions that emerge are those of (i) security and health (security, ecological service value, energy efficiency, traffic safety); (ii) building and ecosystem services (building footprint density, number of ecosystem services); and (iii) landscape and economy (landscape indices, deployment rate):

(i) These metrics offer an evaluation of metropolitan areas' overall environmental quality in terms of resource sustainability and ecosystem health. As an illustration, temperature-related indicators that shed light on the condition of the air environment have been added. This category also includes land use indicators, which help to evaluate the environmental effects of various land uses by providing data on the geographical distribution of built and undeveloped areas relative to the entire region under study.

(ii) These indicators provide insight into cultural variety, social dynamics, and people's overall well-being in an urban setting. A variety of important factors are included in this group of indicators, such as the caliber and the accessibility of educational institutions, the accessibility of health care, and the level of safety, as determined by crime rates. Furthermore, metrics like the quantity of green space in the city and proximity to public transit and services shed light on the accessibility of these areas and their impacts on the connectivity and well-being of city dwellers. The socio-cultural compatibility category also encompasses metrics pertaining to the regeneration project, which offer insights into attitudes towards the project among the local population. The indicators of building technologies that shed light on their potential effects on the environment are also included here.

(iii) This category covers employment-related factors, such as unemployment rates, job openings, and the development of jobs locally. Indicators of the residential market, rental prices, and typical expenses for water supply, heating, and cooling services are also included in this area. This category contains indicators pertaining to the redevelopment project that quantify the costs of interventions such as investments and provide details on building upkeep, such as the price and frequency of such upkeep.

In order to allow for the clear organization of the indicators to be used as tools for assessing the sustainable performance of urban areas at different scales and according to the main categories of analysis (environmental resilience, socio-cultural adequacy, and economic and financial sustainability), an initial comparison of the obtained results has been validated. In order to authenticate the identified indicators resulting from the simultaneous application of the two approaches, and to verify their credibility and widespread usefulness, surveys will be circulated among professionals from various disciplines, including construction and real estate experts and environmental and social specialists.

4. Discussion

Territorial sustainability should take into account the evolutionary capacity of urbanized contexts through the employment of measures of targeted interventions. Given the specificities of the type of intervention proposed, as well as the characteristics of the context of reference, the identification of which evaluation methods may be most appropriate for the case in point, in order for us to be able to appreciate the benefits of the project in terms of ensuring the territory's environmental, social, and economic development, is necessary.

For these reasons, of the several existing sustainability assessment tools, indicator-based methods and frameworks are often suitable but the problem lies in the consistent and logical adaptation of the chosen indicators to various analytical design scales. Even if the selected techniques employed for choosing a final set of indicators exist, they require several in-person meetings with whole groups of experts. This procedure can last a long time, decreasing the level of control and affecting the reliability of the results.

Unlike previous research [17,18,87], which has often struggled to integrate comprehensive data across different urban contexts, this study uses a multi-directional systematic approach. By combining top-down and bottom-up approaches, it seeks to improve the robustness and relevance of sustainability indicators in tracking urban planning and design. Furthermore, while previous studies have highlighted the importance of stakeholder engagement, they often do not fully consider the range of perspectives involved [19,20,88]. Instead, this study seeks to provide a basis for promoting the participation of a diverse range of local stakeholders, thereby providing a more comprehensive view of community priorities and needs and adapting indicator systems to specific local conditions.

This study has proposed a multifaceted method to address the measurability gap in sustainability at multiple territorial layers.

This process has been tested and recorded as being both time- and cost-effective. This time-bound condition should encourage more willing participation from experts and from marginalized groups, as well as those with vested personal interests in the outcome.

In fact, the process of the suggested analysis offers more chances for discussion with individuals who might be involved in urban decision-making procedures than the text mining techniques used in the literature, making it possible to create a framework that is more flexible and resilient in meeting the strategic and programmatic requirements of the referenced context. If required, the procedure could be adjusted to achieve tighter group standardization by giving set weights to each choice criterion. At the cost of being unable to obtain individual feedback on the importance of each choice criterion, this would enable more equitable comparisons across the suggested indicators in accordance with defined decision criteria. On the other hand, with this modification option, the decision criteria might be entirely generated and selected by agreement during the in-person workshop. If necessary in a particular area or application, the method might also be changed by giving greater weight to the representative opinions of major stakeholders or to the opinions of certain experts.

In terms of urban interventions, their features and demands are particular, influencing both the scale of the building and the larger urban context, which must answer the neighborhood's current needs. It is critical to note that the proposed methodology, while tailored to the specific factors of the analyzed pilot case study, is replicable for other urban regeneration initiatives and territorial contexts, thanks to its ability to systematically capture the specificities in different market locations. The information data initially gathered from the in-depth analysis of one particular instance may be mutually validated using the more general information gathered from the literature research by first comparing the outcomes of the simultaneous implementation of the two methodologies.

5. Conclusions

This approach is easily adaptable to different contexts and other procedures that require group consensus to prioritize viable possibilities or recommended alternatives in order to make a decision. This method scores indicator opportunities based on their suitability with respect to given criteria, combining qualitative and quantitative factors to find the greatest match. This process can be used to identify indicators for ecological restoration, environmental impact monitoring, alternative spatial planning, and other assessments that require urban management decisions, for example. In the pilot case of Le Lignon, the process of defining appropriate indicators allowed for the identification of which targets to pursue in the process of sustainable territorial development: the environmental resilience and socioeconomic augmentation of the territory's systems. These aims relate to programming objectives based on the efforts provided by Swiss urban planning tools, which aim to preserve existing natural assets rather than increase the territory's infrastructure. Certainly, the process of determining the appropriate collection of indicators to support suggested sustainable practice evaluation methodologies has its methodological and computational hurdles; the majority of them are connected to the text mining phase. The holistic component of the procedure has a significant impact on the process's end results, according to the arbitrator of the inclusion and exclusion criteria for defining performance indicators.

This methodology has provided the development of a dual-work approach. A top-down method is utilized to identify critical sustainability indicators based on current studies. Then, a bottom-up technique is employed to discover an initial set of elementary variables based on the case's unique properties. The bottom-up approach involves a content analysis, which can be qualitative or quantitative depending on the accuracy of the available indicators and data, as well as the object of analysis (project, urban analysis area, or functional relationship). A comparative examination of the data obtained from these two techniques has resulted in a collection of indicators that create a framework for assessing urban sustainability, as well as a viewpoint tailored precisely to the instance under discussion.

Although this work provides a realistic approach to selecting indicators, one disadvantage is the absence of comprehensive empirical validation across varied urban environments. The effectiveness and applicability of the system may change depending on different socioeconomic or geographic circumstances. Therefore, to ensure the pathway selection's longevity and adaptability, future research should concentrate on using and assessing this method in a variety of urban contexts. This strategy will improve sustainability evaluations in urban environments and indicator systems.

Future research endeavors will incorporate a validation step to verify the information derived from this comparison's general validity. This would entail sending out questionnaires to specialists in the fields of the environment and social sciences, as well as to technicians and operators in the building and real estate industries. This phase's goal is to increase the results' dependability and applicability by further defining a case-specific subset of indicators chosen in accordance with stakeholders' interests. In the end, it also seeks to establish a stable hierarchy of priorities among the sustainability factors connected to the study intervention, leading the sustainability assessment into an increasingly long-term perspective. A decision criteria matrix might be used to measure and verify the ability of distinct recognized management scenarios to satisfy the defined criteria. This alternate usage would capitalize on the objectives and possible trade-offs of the suggested management measures.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/urbansci8030107/s1. Figure S1: Extract from the pilot case study document used to identify the bottom-up set of indicators (source: research working document "*Post-COVID future cities. Methods and tools to design and assess, healthy, sustainable and resilient suburbs*", Sapienza University of Rome, August 2022).

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