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Land-Use Mix and Urban Sustainability: Benefits and Indicators Analysis

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Abstract: Sustainable development is one of the biggest challenges for the future of our cities. With this in mind, eco-districts are essentially designed to respond to four challenges that place emphasis mainly on complexity and resilience by acting on aspects such as urban green spaces, mobility, energy, water management and waste management. In this study, the focus is on the concept of mixitè, from both a functional and social perspective, which is seen as a tool to increase the sustainability of urban settlements and bring benefits to the social, environmental and economic system. Despite the growing interest of research into the impacts of an urban land-use mix, there have been few methodological analyses on how to measure the functional mix in an urban environment. Therefore, the goal of this study is to define one or more indicators that are able to represent the diversity of the soil through their application to different areas. It is therefore possible to define a tool that helps to design, evaluate and support decision makers in urban planning choices. Indeed, it is important to understand how the soil mix, and subsequently the social mix, affects sustainability and how planners can take it into account in planning and developing urban policies. In this document: (a) we will highlight the theories and concepts underlying both functional and social mixitè; (b) the benefits it brings both to the city and to the individual; (c) a review of the main methods of measurement of the mixitè; (d) application and a subsequent comparison of the methods identified in case studies represented by three areas related to the establishment of the University of Salerno, in Italy, consisting of its two campuses as well as an adjacent site. The results obtained show that some of the indicators analyzed are more effective at representing the phenomenon of mixitè than others. Therefore, widening research, especially for those concerning the social mixitè, is advisable. Despite this, the results show that proper planning and management of urban devices bring about a series of advantages by increasing the sustainability and urban efficiency of settlements.

Keywords: urban planning; land-use mix; urban indicators

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1. Introduction

The need for a greater mix of land use, through the integration of residential with commercial, civic and recreational uses, has become a dominant approach in urban planning [1]. In fact, urban theorists believe that land mix use is considered a very important component of the urban development paradigm compared with smart growth, new urbanism and sustainable urban development paradigms [2–5]. In fact, land mix use is prevalent in many of the urban planning concepts around the world [6]. Dynamic processes of urban change, in particular the enormous worldwide expansion of the urban population and urbanized area, affect natural and human systems on all geographical scales [7]. The worsening of crowded conditions, the shortage of housing and insufficient or obsolete infrastructure, as well as the increase in urban climate and ecological problems and the issue of urban security, highlight the need to rethink the city and its spaces through effective planning and management so that they can adapt to new urban, environmental and social needs [8]. One of the fundamental aspects of sustainability is resilience, defined by the Italian National Plan of Adaptation to Climate Change (PNACC) of the Ministry of the Environment in

2017 as "the ability of a social, economic or environmental system to cope with a dangerous event, or anomalies, responding and reorganizing itself so as to preserve its essential functions, identity and structure, while also maintaining the capacities for adaptation, learning and *transformation.*" In general, in order for a system to be *resilient*, it should be, among other characteristics, [9] *diversified*. This implies a number of components with different functionalities in order to protect the system against different hazards. It should also be *independent*, with different components of the different systems connected in order to support each other. The more the urban system is equipped with the above characteristics, the quicker it will be able to resume normal activities with a view to improvement and awareness. Innovative approaches to urban spatial planning and management are currently proposed and discussed as adaptation and smart growth [7].

Urban and territorial planning have already made use of *zoning* as a technical tool, which is useful for regulating the uses of a territory by dividing it into macro-areas, even before being officially ratified by urban planning law, each with a precise function. Functionalist monotony determined by functional zoning practices has been highlighted by various scholars [10,11]. Historically, this tool was introduced with the affirmation of the modern city and multiple needs. It was intended to give order to the cities hit by the migratory waves caused by the industrial revolution, to eliminate the inconveniences derived from the original mixture of incompatible functions located in the same area (such as, for example, polluting industries and homes), to avoid overcrowding and to equip the city with essential services [12]. Zoning is essentially concerned with separating the three main dimensions that interact in urbanization: the *functional* one (with respect to uses and activities), the *morphological* one (with respect to density and building types) and the *social* one (with respect to different categories of inhabitants recognized above all with respect to their professions and their belonging to certain classes) [13]. Sectoral, monofunctional zoning has long since disappeared, canceled by the very complexity of the city [14]. In fact, by separating land uses too rigidly through zoning, it has had a number of undesirable consequences over time that planners and other policy makers are now trying to undo through a shift towards the promotion of mixed uses, thus replacing the concept of separation with the concept of mixitè [4–15]. It is essential to counteract the denied effects caused by urban sprawl due to high land consumption in the face of low population density with high energy consumption and damage to the environment. In fact, urban planning, through regeneration plans and projects on different scales, can help to tend towards the city of short distances, working on the connection between multifunctionality and sustainable mobility. It can propose social housing projects integrated with free housing, widening the spectrum of possibilities and diluting the most disadvantaged social categories into a wider and more varied social fabric.

There are now many cases of sustainable neighborhoods or eco-neighborhoods that seek to respond to environmental challenges, to new forms of living, work and mobility, which represent the current challenges for urban planners. Among the essential aspects of these neighborhoods, such as urban green spaces, mobility, energy, water management, waste management, complexity and, finally, resilience, attention is drawn to the concept of both functional and social mixitè, seen as a means of increasing the sustainability of urban settlements and bringing benefits to the economic, social and environmental system. Substantial progress has been made over the past two decades in the ability to measure and analyze the characteristics of urban form [16,17]. Land-use mix is a fundamental part of urban form, and it is essential to understand how it affects sustainability and how planners can take it into account when planning and developing urban policies.

In more detail, this paper will summarize the theories and principles based on the desire to increase the sustainability of urban settlements. The results of recent research on the impacts of the urban land-use mix will be described, mainly in three fields: transportation, public health and urban economics. There is a lack of methodological analysis in the scientific literature on how best to measure the functional mix in an urban environment. For this reason, a dedicated section presents a review of various land-use mix and social mix measures, including their mathematical formulas, and discusses their conceptual and computational differences. A simulation is then carried out on some urban contexts to understand which of the identified indicators is best suited to represent the described phenomenon. Finally, the discussion of the results allows us to understand the limits and perspectives for research in this specific field of interest (Figure 1).

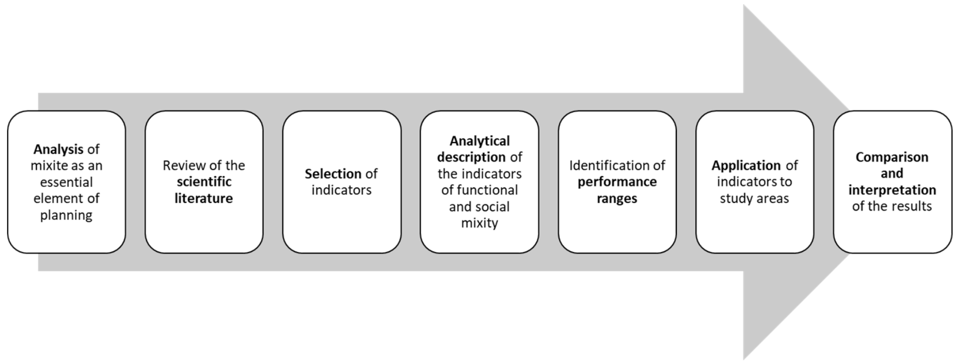

Figure 1. Methodological flowchart.

2. Benefits of the Functional and Social Mix

The term mixitè refers to a design strategy, which is now consolidated in the contemporary world, aimed at creating a network of relationships and transversal links between functional, social and morphological dimensions. Pursuing the functional mixitè means designing an antizoning city, a plan that encourages synergies and benefits from the phenomena that are generated on the territory due to the integration of different activities [16]. There are various design principles and theories that developed over time between 1973 and 2005 based on the desire to increase the sustainability of cities. The concept of land-use mix is one of the fundamental aspects of eco-cities [18], of the compact city [19,20], of the car-free city [21,22] and those designed specifically for cyclists [23]. In addition, it becomes part of a series of planning strategies [24] (Figure 2), including transit-oriented development (TOD) [25,26], which means placing a node of the public transport network at a point of urban density. Thus, TOD means designing urban places to bring people, activities, buildings and public spaces together with easy walking and cycling connections between them and a nearby excellent transit service to the rest of the city that can connect the neighborhood to other parts of the city or other urban centers effectively. This is closely linked to the "15-min city" model [27], which emphasizes the concept of planning in which all distances between residences, workplaces, facilities and services are as short as possible and as interconnected as possible between slow or soft mobility routes. These modern approaches in urban planning emphasize the problem based on sustainable development [28,29].

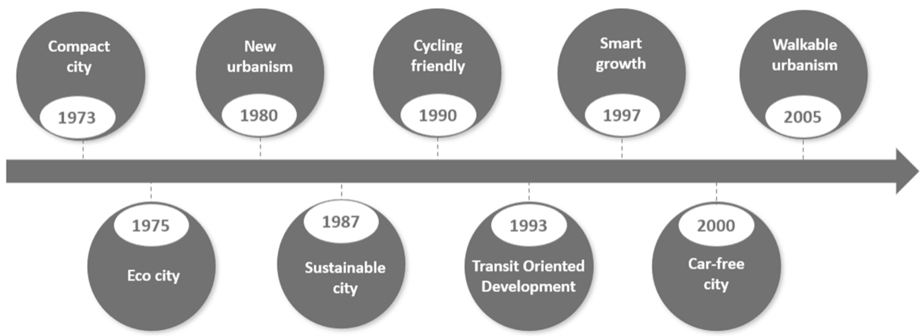

Figure 2. Principles and philosophies of urban planning related to the mix of land use, starting from the compact city in 1973 up to walkable urbanism in 2005 (revisited by [22]).

Through the functional mixitè, it is possible to counteract the phenomenon of urban sprawl and the consequent negative effects of modernist planning such as single-use zoning, traffic congestion and loss of quality in public spaces [30] with a lower consumption of land, preservation of green spaces and permeable surfaces and a lower use of the means of transport that produce climate-altering gases, leading to [31] a reduction in environmental pollution [32]. From a social point of view, it guarantees the realization of the concept of multiple and intelligent uses of the land by providing for the simultaneous presence of several functions with a consequential lower economic, technical and organizational use for the provision of services. The benefits of the urban land-use mix have been studied in several fields, particularly in transportation, public health and urban economy [1,33–37]. From a transportation perspective, the benefits of mixed uses come mainly from bringing together a variety of origins and destinations, thus allowing travel to non-motorized modes and/or shorter travel distances. From a public health perspective, bringing a variety of interesting destinations closer to residential areas is a means of encouraging active travel modes [38,39]. Finally, from the point of view of the urban economy [40,41], the appropriate combination of complementary uses of urban land has the potential to encourage higher density development through the provision of urban services and to induce an increase in land values. Achieving an efficient mix of land use has become a conventional practice for urban planners by providing complementary functions placed mutually in the immediate vicinity, which encourage residents to walk or cycle [42,43].

Similarly, it is important to ensure an adequate level of social mix. Indeed, various experiences prove that the coexistence of different social groups improves general urban well-being, especially the social and institutional component, and stimulates socio-economic development. When we speak of social mixitè, we are referring to a territorial arrangement that favors a heterogeneous mix of socially different groups within the same urban area. It improves social cohesion as well as satisfying different housing needs by ensuring a varied housing offer with different household compositions and mixes of functions. From an urban planning point of view, this is assessed through social housing. The European Coordination Committee for Social Housing (CECODHAS) has proposed a common definition for all EU countries, according to which the term social housing means all activities aimed at providing housing and services with a strong social connotation, suitable for those who have difficulty in meeting their housing needs on the market for economic reasons, because they are unable to obtain credit, because there is no adequate supply or because they suffer from particular problems [44]. The social dimension, when not expressly regulated, is closely linked to the other dimensions of urbanization previously identified, in particular to the residential housing use of some areas and to the differentiation by building density of the same type. Different types of buildings often correspond to different social categories due to the different economic possibilities of the population.

3. Method

3.1. Selection of Indicators

In order to design a smart, welcoming and quality city it is necessary to consider the functional mixitè, a parameter that measures the degree of organization of the urban system by providing information on the diversity of uses and services, the presence of certain infrastructures and spaces dedicated to sociality, leisure and sport. For the definition of this indicator, different methodologies found in the literature are proposed. The measures of the urban land-use mix examined here come from a range of social science research papers related to the concepts of mixing, segregation or concentration. These are measures that capture the basic concepts of distance (or proximity) and quantity and that can be applied to a context of urban land use on a local scale. There are various studies in the scientific literature that analyze urban indicators that can represent the mix of land use [22,34,36,38,45–52] and this willingness of the literature to use and compare different indices in order to quantify mixed land use demonstrates the importance of this factor for research. However, despite the popularity of mixed land use, none of the identified indicators are adopted as a standard of measurement [34,50,53,54]. The indicators are divided into soil measurements of *integral* type, that is, applicable to small geographical areas such as neighborhoods, and soil measures of *divisional* type, which are applied to larger geographical areas such as cities, which are then further divided into districts [34]. These include the dissimilarity index (DIS), which can be applied when the area concerned has two or more land uses, and the exposure index (EXP), which, on the other hand, refers to only two types of land use. The focus will be on integral measures, in particular the Gini–Simpson index (I_{GS}), the Gini index (I_G), the Shannon–Wiener index (H'), the entropy index (ENT), the Herfindahl–Hirschman index (HHI) and the balance index (BAL), which are added to the indicator of social mixitè (N_{ash}), described synthetically (Table 1) through their mathematical formulation and subsequently analyzed in detail.

Table 1. Methods for calculating the land-use mix.

Indicator	Formula
(a) Gini–Simpson Index	$I_{GS} = 1\sum\left(\frac{n}{N}\right)^2$
(b) Gini Index	$I_G = 1 - \sum_{i=1}^{N} f_i^2$
(c) Shannon–Wiener Index	$H' = -\sum_{i=1}^{N} Pi \times \log_2 Pi$
(d) Entropy Index	$ENT = -\frac{\sum_{j=1}^{N} P^j \ln(P^j)}{\ln(N)}$
(e) Herfindahl–Hirschman Index	$HHI = \sum_{j=1}^{N} \left(P^j\right)^2$
(f) Balance Index	$BAL = 1 - \frac{\lvert X - aY \rvert}{(X + aY)}$
(g) N_{ash}	$N_{ash} = \frac{N_{all(sh)}}{N_{all(tot)}}$

3.2. Measure of Fuctional Mixitè

It is appropriate to specify that the term "*services*" refers to the different functions present in the analyzed area, which are therefore the types of land use including residential (e.g., university residences), commercial (real shops where an asset is sold, e.g., clothing store), offices, public establishments (e.g., bars, restaurants, tobacconists) and equipment (e.g., school equipment, sports equipment, etc.). These services are identified by visually evaluating the affected areas through a physical analysis.

(a) The Gini–Simpson index [55,56] is defined as follows:

$$I_{GS} = 1 - \sum\left(\frac{n}{N}\right)^2 \quad (1)$$

where:

- n is the number of services/land type use present referring to a specific function;
- N is the total number of services/land type use offered related to all functions.

(b) The Gini index [56] is defined as follows:

$$I_G = 1 - \sum_{i=1}^{N} f_i^2 \quad (2)$$

where:

- f_i is the relative frequency of the N services/land type use offered related to all functions of the considered distribution. It is calculated as the ratio of the number of services present (n) and the total number of services (N); if such data are not available, the relationship between the area of the service considered and the total area can be considered.

The Gini index is a value between 0 and 1, where low values of the coefficient indicate a homogeneous distribution. In particular, the value 0 corresponds to the pure equidistributional; high values of the coefficient indicate instead a more heterogeneous distribution. In particular, the value 1 corresponds to the maximum concentration.

(c) The Shannon–Wiener index (H') is a diversity index used in statistics in the case of populations with an infinite number of elements [57,58] and it is used in statistical ecology to assess the biological diversity (biodiversity) of a population of individuals [59].

This index is defined as follows:

$$H' = -\sum_{i=1}^{N} Pi \times \log_2 Pi \quad (3)$$

where:

- N is the number of different types of services/land type use (richness of 'species');
- P_i is the relative abundance of each species, i.e., the proportion of a species (entity or type of services) to the total number of species (existing services); it has the same meaning as the term f_i in Equation (2);
- $Log_2\ (P_i)$ is the logarithm (base 2) of the relative abundance of each species.

The index refers to the relative frequency of each individual species detected in the sample area and is a spatially unexplained index [60]. As illustrated in the European project Change Mediterranean Metropolises Around Time (CAT-MED) [61], it is first necessary to identify the different types of activities relying on the European standard classification, the National Classification of Economic Activities (CNAE) codes. Next, you can group all the listed activities according to their similarities, and then assign one of the *species* (or type of activity) to each entity based on the type and description. Finally, the Shannon index is applied. If low values close to 0 are obtained, it means that the sample has little diversity or at least, the number of individuals is poorly distributed among the species. The Shannon–Wiener index, not having values between 0 and 1, can be difficult to interpret, so the entropy index (*ENT*) is proposed as an alternative.

(d) The Entropy index (*ENT*) [50] is defined as follows:

$$ENT = -\frac{\sum_{j=1}^{N} P^j \ln(P^j)}{\ln(N)} \quad (4)$$

where:

- P^j represents the percentage of each land type use j in the area; it has the same meaning as the term f_i in Equation (2);
- N is the total number of services/land type use present in the area in question.

It can have a value between 0 and 1. A score of 0 corresponds to a condition of minimum heterogeneity and diversity of services, for which there will be a single land use for the entire spatial unit. A score of 1 corresponds to a condition of maximum variety of functions in which all types of land use are equally present.

(e) The Herfindahl–Hirschman index (*HHI*) [34] is a concentration index used mainly to measure the level of competition in a certain market, but which, at the same time, can also be used to assess functional mixitè. It is defined as:

$$HHI = \sum_{j=1}^{N} \left(P^j\right)^2 \quad (5)$$

where:

- P^j represents the percentage of each land type use j in the area; it has the same meaning as the term f_i in Equation (2);
- N is the number of services/land type use in the area in question.

Its minimum value over the range [0, 1] is $1/N$. In fact, if there is only one type of land use in an area, *HHI* will be equal to 1, and if all types of land use are equally present, then *HHI* = $1/N$. Therefore, the higher *HHI* values correspond to a lower combination of land use.

(f) The balance index [34] can be used to assess the relationship between residential and non-residential areas ($N = 2$). It is defined as:

$$BAL = 1 - \frac{|X - aY|}{(X + aY)} \tag{6}$$

where:

- X is the amount of land intended for residential use;
- Y is the quantity of land intended for non-residential use;
- $a = X^*/Y^*$ is an adjustment factor, since X^* and Y^* represent land uses on a wider geographical scale, which is used as a benchmark for an acceptable equilibrium level.

This index allows you to measure the degree of balance between two different types of soil uses or activities within an area.

The index ranges from 0 to 1. Values close to 1 are more balanced. The lower the index value, the less balanced the two types of land use; this indicates that one type dominates in terms of percentage coverage [17]. The equation is established to compare only two types of land use but can be modified to include a larger number [34].

For the sake of completeness, the methodology illustrated in the UNI-ITACA reference practice [62] concerning the application of the area functional mix indicator is reported However, it will not be used in the following sections due to the unclear application of this indicator in real urban contexts. Since the analysis has an urban approach, by adopting the appropriate changes, non-residential buildings and their external areas of relevance are evaluated, then the location of the commercial, service, sports and cultural structures present in the vicinity of the building/area under analysis is identified. Subsequently, the average distance in meters measured from the main entrance of the building/area of relevance to the entrance of the structures selected for the verification of the indicator will be calculated. The value of the performance indicator is calculated using the following formula:

$$d_{average} = \frac{\sum_{i=1}^{5} d_i}{5} \tag{7}$$

where:

- $d_{average}$ is the average distance that can be expected on foot, considering the shortest journey between the pedestrian entrance of the building (or its area of relevance) and the five selected structures;
- d_i is the distance between the building (or its surrounding area) and the i-th structure.

As mentioned, the following will not be used for the uncertainties related to the correct mode of its application.

3.3. Measure of Social Mixitè

There are few studies analysing the relationship between land-use mix and social diversity [63], including for its analytical measurement. This study proposed to evaluate the social mix, as well as the functional mixitè, through the Gini–Simpson index, the Gini heterogeneity index, the entropy index, the HHI and the balance index by considering three different residential types, namely: the free residential construction (ERL), that is to say, private-initiative construction for the free market; social housing (ERS), i.e., private initiative construction intended for specific targets of users in very disadvantaged economic and/or social conditions, in an agreement with the public administration; and, finally, the public residential building (ERP), i.e., the building of public initiative intended for specific targets of users in very disadvantaged economic and/or social conditions, in agreement with the public administration [64]. These three types of housing can correspond to high, intermediate and low socio-economic classes, respectively. It is therefore a proxy indicator, i.e., an indicator that does not measure a phenomenon directly, but measures it indirectly on the basis of the basic assumption that a certain type of residence also corresponds to a certain socio-economic class.

(g) As an alternative to the indicators listed above (indicators a, b, c, d, e, f), social mixitè can be assessed through the following formula:

$$N_{ash} = \frac{N_{all(sh)}}{N_{all(tot)}} \quad (8)$$

It relates the percentage of social housing ($N_{all(sh)}$) present in the total number of dwellings ($N_{all(tot)}$).

3.4. Performance Ranges

To understand the results of each indicator in the best possible way, we follow the performance bands already identified in other studies [65], which are essential in order to be able to define the definition of a synthetic judgment on the performance of each device, to monitor the progress and adequacy of design choices and verify, therefore, the effectiveness of certain decisions.

In order to obtain a range of reference values, reference was made to the results obtained from the Change Mediterranean Metropolises Around Time (CAT-MED) project [61], to the social housing average extrapolated from the case studies and to some European normative references, such as the land law in force in Spain, which foresees a minimum 30% of public housing for urban interventions related to new developments, or the French law, which establishes 20% as a minimum percentage of public housing for municipalities with a population above a certain number of inhabitants.

The construction of the performance bands presents several critical issues related above all to the absence of regulatory and scientific parameters.

The performance ranges are as follows:

- Insufficient: compared to the criterion analyzed, the calculated value is zero or in any case insufficient with respect to the sustainability objectives;
- Sufficient: with respect to the criterion, a minimum desirable value derived from the case studies and from the data present in the literature is reached;
- Good: the criterion shows an improvement compared to the minimum expected, but in any case, not such as to achieve excellence (intermediate level);
- Excellent: compared to the criterion analyzed, the performance most consistent with the sustainability objectives has been achieved.

The performance bands reached for each indicator are provided in Table 2.

Table 2. Performance ranges.

Indicator	Formula	Performance Ranges	
(a) Gini–Simpson Index	$I_{GS} = 1 - \sum\left(\frac{n}{N}\right)^2$	<0.25	Insufficient
		$0.25 \leq I_{GS} < 0.50$	Sufficient
		$0.50 \leq I_{GS} < 0.75$	Good
		≥0.75	Excellent
(b) Gini Index	$I_G = 1 - \sum_{i=1}^{N} f_i^2$	<0.25	Insufficient
		$0.25 \leq I_G < 0.50$	Sufficient
		$0.50 \leq I_G < 0.75$	Good
		≥0.75	Excellent

Table 2. *Cont.*

Indicator	Formula	Performance Ranges	
(c) Shannon–Wiener Index	$H' = -\sum_{i=1}^{N} Pi \times \log_2 Pi$	<4	Insufficient
		$4 \leq H' < 5$	Sufficient
		$5 \leq H' < 6$	Good
		≥ 6	Excellent
(d) Entropy Index	$ENT = -\frac{\sum_{j=1}^{N} P^j \ln(P^j)}{\ln(N)}$	<0.25	Insufficient
		$0.25 \leq ENT < 0.50$	Sufficient
		$0.50 \leq ENT < 0.75$	Good
		≥ 0.75	Excellent
(e) Herfindahl–Hirschman Index	$HHI = \sum_{j=1}^{N} \left(P^j\right)^2$	>0.75	Insufficient
		$0.75 \leq HHI < 0.50$	Sufficient
		$0.50 \leq HHI < 0.25$	Good
		≤ 0.25	Excellent
(f) Balance Index	$BAL = 1 - \frac{\lvert X - aY \rvert}{(X + aY)}$	<0.25	Insufficient
		$0.25 \leq BAL < 0.50$	Sufficient
		$0.50 \leq BAL < 0.75$	Good
		≥ 0.75	Excellent
(g) N_{ash}	$N_{ash} = \frac{N_{all(sh)}}{N_{all(tot)}}$	<0.20	Insufficient
		$0.20 \leq N_{ash} < 0.40$	Sufficient
		$0.40 \leq N_{ash} < 0.60$	Good
		≥ 0.60	Excellent

4. Application

In this section, we apply and compare the methods for calculating soil mixes to three urban-type settlements in Italy (Figure 3). As regards the boundaries of the areas identified in the case of area one, the perimeter is dictated by the area of the municipal urban plan of Fisciano, while in the case of areas two and three the borders derive from the property of the University of Salerno (Figure 4):

- A1: ARUCT zone [65] in the municipality of Fisciano (SA);
- A2: University of Salerno, Campus of Fisciano, in the municipality of Fisciano (SA);
- A3: University of Salerno, Campus of Lancusi, in the municipality of Baronissi (SA).

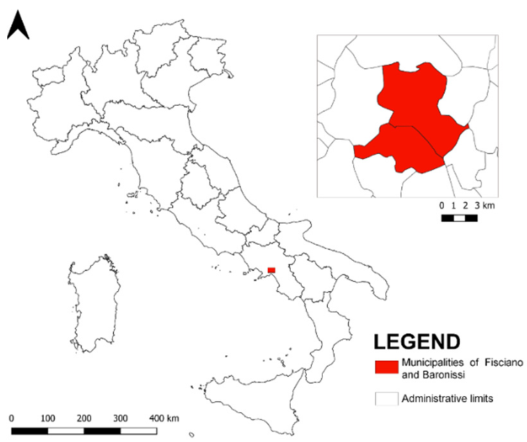

Figure 3. The study area in the Italian context.

Settlement A1 is an area in the municipality of Fisciano, with a surface area of 245,166 m^2, attended by 35,000 students and 2000 employees, which, according to the PRG zoning plan, falls within the commercial tourist urban renewal zone D (parts of the territory intended for new settlements for industrial plants and for new commercial and managerial settlements with related equipment). The intervention area consists of a part occupied by the transformed lots, which are mainly residential, and to a larger extent by uncultivated land and cultivated vineyards, orchards and citrus groves.

Figure 4. Territorial classifications A1, A2 and A3.

The intervention area consists of a part occupied by the transformed lots, mainly residential, and to a larger extent by uncultivated land and cultivated vineyards, orchards and citrus groves. On the basis of the calculations of sizing and proportioning [65] carried out in compliance with regulations, the design of the area provides for the construction of surfaces for tourism represented by student residences and association offices as well as commercial areas represented by retail stores, shopping centers and entertainment equipment. The addition of additional services, plants and infrastructures aimed at increasing the sustainability of the settlement are expected and are explicitly provided for by the technical standards implementing the plan. They consist of the provision of an ecological island, an intermodal transport hub and, finally, the provision that 25% of the accommodation is reserved for off-site students based on merit and economic condition.

The main functions of the area, therefore, are residential, tertiary and facilities, each of which corresponds to the respective surface area and is transformed into a percentage, which is necessary to apply the indicators (Table 3).

The measurement and quantification of the functions are carried out in terms of gross usable surface areas, and their processing is carried out on the plan volumes with the support of QGis software.

The Gini–Simpson index is not calculated, as the extent of each function is expressed directly in percentage and not in absolute number of services present.

The other two areas are part of the university system of the University of Salerno in particular:

- A2: campus of Fisciano with 1,200,000 m^2 of surface, 1,015,838 m^3 of volume;
- A3: campus of Baronissi with 150,000 m^2 of surface and 180,615 m^3 of volume.

In both cases, the functions envisaged in the optimal scenario are proposed, i.e., a long-term scenario in which actions aimed at progressively improving the energy and environmental performance of the settlement are implemented.

In these two cases, unlike the previous case, for each function there is an absolute number of elements present in the area (and not the gross useful area) (Tables 4 and 5) for which it was possible to correctly apply the Gini−Simpson index. The numbers associated with each function were transformed into a percentage in relation to the total number of services present in the area, and this allowed the application of the other indicators.

Table 3. Application of indicators to the ARUCT zone (Zone A1).

Functions	**Definition**	**Area (m^2)**	**%**	**(b) I_G**		**(c) *H′***			**(d) *ENT***			**(e) *HHI***		**(f) *BAL***		
				f_i	f_i^2	P_i	$log_2(P_i)$	P_i $log_2(P_i)$	P^j	$ln(P^j)$	P^j $ln(P^j)$	P^j	$(P^j)^2$	X	Y	a
Residential	ERL [1]	6060	13	0.13	0.02	0.13	−2.92	−0.39	0.13	−2.03	−0.27	0.13	0.02			
	ERS [2]	1509	3	0.03	0.00	0.03	−4.93	−0.16	0.03	−3.42	−0.11	0.03	0.00	16		
	ERP [3]	0	0													
Tertiary	Tourist	4526	10	0.10	0.01	0.10	−3.34	−0.33	0.10	−2.32	−0.23	0.10	0.01			
	Commercial	15,095	33	0.33	0.11	0.33	−1.61	−0.53	0.33	−1,11	−0.37	0.33	0.11			
	Offices (executive)	0	0													0.72
	Public establishments	2209	5	0.05	0.00	0.05	−4.38	−0.21	0.05	−3.03	−0.15	0.05	0.00		84	
	Service craftsmanship	0	0													
Equipment	Equipment for entertainment, associative and cultural activities	7138	16	0.16	0.02	0.16	−2.69	−0.42	0.16	−1.86	−0.29	0.16	0.02			
	Sports equipment	9391	20	0.20	0.04	0.20	−2.29	−0.47	0.20	−1.59	−0.32	0.20	0.04			
	10	45,928			0.80			2.50			0.75		0.20			0.43

[1] ERL: free residential construction; [2] ERS: social housing; [3] ERP: public residential building.

Table 4. Services present in the A2 settlement.

Functions	n	Functions	n	Functions	n
University residences	3	State police station	1	Museum/Exhibition space	1
Canteens	3	Chapel	1	Coworking room	1
Bar	7	Bus terminal	1	Legal support desk	1
Press center	2	Heliport	1	Everyday products and hygiene shop	1
Multi-specialist health center	1	Club house: restaurant/cafeteria	1	Ecological island	1
Psychological counselling center	1	Orientation/tutoring/placement office	1	Multi-religious hall	1
Language center	1	International relations office, Erasmus	1	Shopping center	1
Company crèche	1	Public/private technological district	1	Gymnasium	1
Study rooms	208	Indoor swimming pool	1	Wellness center	1
Research laboratories	13	Indoor and outdoor tennis courts	5	Pub	1
Library	2	Indoor and outdoor football pitches	7	B&B	1
Internet point	3	Multipurpose sports area	1	Theatre	1
Classroom	1	Bicycle path, can also be used for jogging	2	Newsstand/Tobacconist's	2
Post office	1	Pharmacy	1	Cinema	1
Bank/counter	1	Laundry	1		
Stationery shops	3	Cinema	1		
					N = 292

Table 5. Services present in the A3 settlement.

Functions	n	Functions	n	Functions	n
Canteens	4	Post office	2	Ecological island	2
Bar	8	Bank/counter	3	Multi-religious hall	2
Multi-specialist health center	2	Stationery shops	7	Pharmacy	1
Psychological counselling center	2	State police station	2	Laundry	1
Study rooms	214	Chapel	2	Cinema	1
Research laboratories	43	Heliport	1	Shopping center	1
Library	3	Orientation/tutoring/placement office	2	Wellness center	1
Classroom	2	International relations office, Erasmus	2	Pub	1
Bus terminal	2	Public/private technological district	1	B&B	1
Club house: restaurant/cafeteria	2	Gymnasium (weight room)	2	Language center	1
University residences	3	Indoor and outdoor tennis courts	8	Multipurpose sports area	4
Press center	4	Indoor and outdoor football pitches	10	Theatre	1
Company crèche	1	Indoor swimming pool	1	Newsstand/Tobacconist's	4
Internet point	7	Bicycle path, can also be used for jogging	1		
					N = 373

We then move on to apply the same indicators used to measure functional mixitè to social mixitè for A1 (Table 6), A2 (Table 7) and A3 (Table 8), in addition to indicator g. It should be noted that to apply the balance index to assess social mixitè, X refers to the quantity of ERL, while Y refers to the quantity of ERS.

Table 6. Application of indicators to A1 to measure social mix.

Functions	Area (m^2)	%	(a) I_{GS}			(b) I_G		(c) H'			(d) ENT			(e) HHI		(f) BAL			(g) N_{ash}	
			n	n/N	$(n/N)^2$	f_i	${f_i}^2$	P_i	$\log_2(P_i)$	$P_i \log_2(P_i)$	P^j	$\ln(P^j)$	$P^j \ln(P^j)$	P^j	$(P^j)^2$	X	Y	a	$\frac{N_{all(sh)}}{N_{all(tot)}}$	
ERL	6060	80	512	0.80	0.63	0.80	0.64	0.80	−0.32	−0.26	0.80	−0.22	−0.18	0.80	0.64	6060		0.72	$N_{all(sh))}$	132
ERS	1509	20	132	0.20	0.04	0.20	0.04	0.20	−2.33	−0.46	0.20	−1.61	−0.32	0.20	0.04		1509		$N_{all(tot)}$	644
ERP	0	0																		
	7569				0.33		0.32			0.72			0.45		0.68			0.30		0.20

Table 7. Application of indicators to A2 to measure social mix.

Functions	n	%	(a) I_{GS}			(b) I_G		(c) H'			(d) ENT			(e) HHI		(f) BAL			(g) N_{ash}	
			n	n/N	$(n/N)^2$	f_i	${f_i}^2$	P_i	$\log_2(P_i)$	$P_i \log_2(P_i)$	P^j	$\ln(P^j)$	$P^j \ln(P^j)$	P^j	$(P^j)^2$	X	Y	a	$\frac{N_{all(sh)}}{N_{all(tot)}}$	
ERL	156	80	156	0.20	0.04	0.20	0.04	0.20	−2.32	−0.46	0.20	−1.61	−0.32	0.20	0.04	156		0.72	$N_{all(sh))}$	624
ERS	624	20	624	0.80	0.64	0.80	0.64	0.80	−0.32	−0.26	0.80	−0.22	−0.18	0.80	0.64		624		$N_{all(tot)}$	780
ERP	0	0	0																	
	780				0.32		0.32			0.72			0.46		0.68			0.52		0.80

Table 8. Application of indicators to A3 to measure social mix.

Functions	n	%	(a) I_{GS}			(b) I_G		(c) H'			(d) ENT			(e) HHI		(f) BAL			(g) N_{ash}	
			n	n/N	$(n/N)^2$	f_i	${f_i}^2$	P_i	$\log_2(P_i)$	$P_i \log_2(P_i)$	P^j	$\ln(P^j)$	$P^j \ln(P^j)$	P^j	$(P^j)^2$	X	Y	a	$\frac{N_{all(sh)}}{N_{all(tot)}}$	
ERL	156	80	156	0.20	0.04	0.20	0.04	0.20	−2.32	−0.46	0.20	−1.61	−0.32	0.20	0.04	156		0.72	$N_{all(sh))}$	624
ERS	624	20	624	0.80	0.64	0.80	0.64	0.80	−0.32	−0.26	0.80	−0.22	−0.18	0.80	0.64		624		$N_{all(tot)}$	780
ERP	0	0	0																	
	780				0.32		0.32			0.72			0.46		0.68			0.52		0.80

5. Results

Before analyzing and interpreting the results obtained (Tables 9 and 10), it is advisable to specify that for the present study the size of the areas is relatively important, since what is considered is how the services are distributed over this area. Furthermore, the comparison is not made between areas A1, A2 and A3 but within the same area in order to understand the result of the different indicators. Therefore, the difference in surfaces aims to highlight how the identified indicators can be applied and are efficient regardless of the size of the neighborhood.

Table 9. Comparison of results: functional mix.

Indicator	Formula	Value			Performance Ranges		
		A1	A2	A3	A1	A2	A3
(a) Gini−Simpson Index	$I_{GS} = 1 - \sum\left(\frac{n}{N}\right)^2$	-	0.49	0.65	-	Sufficient	Good
(b) Gini Index	$I_G = 1 - \sum_{i=1}^{N} f_i^2$	0.80	0.49	0.65	Excellent	Sufficient	Good
(c) Shannon−Wiener Index	$H' = -\sum_{i=1}^{N} Pi \times \log_2 Pi$	2.50	2.27	2.91	Insufficient	Insufficient	Insufficient
(d) Entropy Index	$ENT = -\frac{\sum_{j=1}^{N} P^j \ln(P^j)}{\ln(N)}$	0.75	0.41	0.53	Excellent	Sufficient	Good
(e) Herfindahl−Hirschman Index	$HHI = \sum_{j=1}^{N} \left(P^j\right)^2$	0.20	0.51	0.35	Excellent	Sufficient	Good
(f) Balance Index	$BAL = 1 - \frac{\lvert X - aY \rvert}{(X + aY)}$	0.43	0.03	0.03	Sufficient	Insufficient	Insufficient

Table 10. Comparison of results: social mix.

Indicator	Formula	Value			Performance Ranges		
		A1	A2	A3	A1	A2	A3
(a) Gini−Simpson Index	$I_{GS} = 1 \sum\left(\frac{n}{N}\right)^2$	0.33	0.32	0.32	Sufficient	Sufficient	Sufficient
(b) Gini Index	$I_G = 1 - \sum_{i=1}^{N} f_i^2$	0.32	0.32	0.32	Sufficient	Sufficient	Sufficient
(c) Shannon−Wiener Index	$H' = -\sum_{i=1}^{N} Pi \times \log_2 Pi$	0.72	0.72	0.72	Insufficient	Insufficient	Insufficient
(d) Entropy Index	$ENT = -\frac{\sum_{j=1}^{N} P^j \ln(P^j)}{\ln(N)}$	0.45	0.46	0.46	Sufficient	Sufficient	Sufficient
(e) Herfindahl−Hirschman Index	$HHI = \sum_{j=1}^{N} \left(P^j\right)^2$	0.68	0.68	0.68	Sufficient	Sufficient	Sufficient
(f) Balance Index	$BAL = 1 - \frac{\lvert X - aY \rvert}{(X + aY)}$	0.30	0.52	0.52	Sufficient	Good	Good
(g) N_{ash}	$N_{ash} = \frac{N_{all(sh)}}{N_{all(tot)}}$	0.20	0.80	0.80	Insufficient	Excellent	Excellent

A comparison of the results obtained for each indicator analyzed for the three areas of the study (Table 9) shows the consistency between the various values and the corresponding performance bands, except for two indicators. In particular, as the Shannon−Wiener index does not have a value between 0 and 1, it is not immediately interpretable. Moreover, following the performance bands provided for in the CAT-MED project [61], the results that are obtained are not consistent with the real capacity of the three areas, far from an insufficient performance related to both functional and social mixitè.

Instead, as regards the Balance Index, in general, there is a mismatch in representing the phenomenon described, as it considers only two uses of the land, that is, what is residential and what is not, by neglecting the sub-functions that are in any case fundamental to be able to speak of a sustainable neighborhood. This is particularly evident for the A2 and A3 settlements, where the subdivision of the territory is determined by the number of services present, from which it can be seen that non-residential functions lead to very small values for the balance index (equal to 0.03), as they are more detailed than residential ones.

Such a small value corresponds to a bad balance between the functions on the territory, in particular between what is residential and what is not; these results, however, do not correspond to reality, as can be seen from the values obtained from the other indicators.

On the other hand, for settlement A1, since the non-residential functions are less detailed and represented as a percentage, the value of the indicator increases (equal to 0.43) but is not consistent with the other indicators, which are considered more reliable since they include all the single functions.

6. Discussion

The study conducted seeks to expand the scientific research hitherto focused on the application of mixitè indicators on entire cities [22–34] and not on neighborhoods with different characteristics, demonstrating how attention must be shifted from a larger scale to a smaller one. In fact, the main technique for measuring and analyzing mixed use found in the literature considers a geographical scale from the building level to the city level [66,67]. This study, on the other hand, focuses on neighborhoods, whether large or small. It can be understood that the most critical part of mixed land use is its measurement, as there is a lack of a solid theoretical basis and capacity to use it in different cases and scales, which can improve its efficiency and interpretation [68].

The comparison of the results also shows that the values obtained between the Gini−Simpson index and the Gini index are equal so that the two indicators can be grouped into a single indicator, as the resulting value is indifferent. The entropy index, on the other hand, containing within its formula the number of soil types (k), turns out to be the one that best adapts to the reality of a territory, also considering the way in which the initial data are presented, and therefore best represents the phenomenon being described. The HHI is the only index among those proposed that must be read in reverse. More specifically, while for the others, the higher the value obtained, the higher the performance and thus the land-use mix of the settlement, for the HHI higher values the exact opposite is expressed. Thus, a value hypothetically equal to one corresponds to a single soil type.

In summary, on the one hand it can be said that the Gini−Simpson index (alternatively the Gini index), the entropy index and the Herfindahl−Hirschman index represent the functional mix well and can be interchangeable for this reason. On the other hand, the other two indicators (indicator c and indicator f) are not recommended because they lead to results that are not consistent with reality.

Considering only the four indicators (a, b, d, e), the performance obtained for the three areas is, respectively, excellent for area one, sufficient for area two and good for area three.

Similar considerations can be made for the social mixitè (Table 10), where it is evident that the Shannon−Wiener index is not able to express the phenomenon (for the performance bands that are not adequately constructed), and the same is true for the Balance index (probably due to the parameter a (6) whose determination does not follow precise rules). While there is an analogy of the results obtained through the Gini−Simpson index, the Gini index, the entropy index and the Herfindahl−Hirschman index. However, these results do not converge with the one obtained by considering the ratio between the number of dwellings dedicated to social housing and the number of total dwellings.

Therefore, while the indicators identified are considered valid for measuring the land-use mix and thus the research carried out is exhaustive, as far as the social mix is concerned, it is necessary to carry out new studies and continue with the research in order to identify indicators that allow us to achieve consistent results and that can therefore represent well the phenomenon to which they are associated.

The difficulties encountered are mainly related to the work of selecting indicators, aimed at defining those that best meet the requirements of the research. Even the definition of the performance bands is not easy, given the absence of adequate examples in the technical/scientific literature; some choices, in fact, enjoyed a certain arbitrariness that, in the light of the results obtained, could be subject to modifications and improvements.

7. Conclusions

Despite the growing research interest in sustainability and the impacts of urban land-use mix on both the environment and the population, there has been little methodological analysis of how best to measure functional mix in an urban environment. Therefore, in this research, six indicators were proposed to measure the functional mixitè obtained from the technical/scientific reading, and the intention of our study was to use the same indicators to also measure the social mixitè, which is fundamental for sustainability. These indicators were applied to three different areas to verify their validity and efficiency.

The overall results of this research would indicate that only some of the indicators selected from the technical/scientific literature are able to describe the land-use mix in an appropriate way (such as the entropy index, HHI and Gini–Simpson index), while with regard to the social mix, it is necessary for further research to be carried out in order to identify indicators that make it possible to achieve consistent results and are able to clearly represent the phenomenon that they are associated to.

Finally, this study aimed to enhance the concept of both social and functional mixitè as a spatial planning strategy, considering how efficient planning and management of the urban devices within an urban settlement determine a series of advantages in terms of urban quality, resilience, inclusion and economic, social and environmental sustainability. It is necessary, however, for the definition of a sustainable neighborhood, to put in place multiple strategies that embrace different themes (mobility, energy, water management, waste management, urban endowments and natural resources), abandoning the strictly urbanistic approach and moving to a multidisciplinary and interdisciplinary approach to obtain feedback from other expert knowledge on specific design solutions and, at the same time, to ensure an exchange and a relationship between the different disciplines.

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