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Interplay between Land Use Planning and Functional Mix Dimensions: An Assemblage Approach for Metropolitan Barcelona

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Abstract: The concept of mixed-use urban planning is gaining recognition as a crucial element in the development of sustainable and vibrant urban environments. In contrast, many 20th-century cities were designed with segregated land uses and monofunctional zones, following the principles set out in the 1933 Athens Charter. Over time, this approach has been widely criticized, and in the present era, mixed-use environments are praised for fostering social interaction, generating economic synergies, and reducing environmental impacts. This article explores the complex relationship between urban activities, morphology, and planning, with a particular focus on the Barcelona metropolitan area. Utilizing GIS mapping and morphological drawings, this research offers innovative perspectives by analyzing a series of selected urban fragments, highlighting the differences and similarities among various urban fabrics. After a review of the evolution of mixed-use planning regulations and plans since the mid-20th century, a threefold analysis was conducted: examining planning standards and codes, assessing the ground floor activities in promoting urban mixticity, and defining the characteristics of urban patterns' vitality. Through mapping and indexes, the research offers both qualitative and quantitative evaluations, uncovering new tools to better understand functional mix as a critical element in addressing the challenges of contemporary urbanization.

Keywords: Barcelona; urban activities; mixed-use; functional mix; diversity

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1. Introduction

Although mixed-use is widely regarded as one of the most desirable urban qualities, many cities that were developed during the 20th century consist of a series of distinct, monofunctional areas. The genesis of these zoning arrangements can be traced back to the drafting of the Athens Charter in 1933. This document determined that for modern cities to function optimally, the separation and distance of living, working, and leisure uses should determine urban form. However, these views were soon challenged by those who argued that such segregation was not necessarily beneficial. One notable example is the debate between two opposing theories. The first, advocating for a "fine-grained mix of diverse uses" to create vibrant and successful neighborhoods [1]. The second argued that a more integrated approach was necessary to achieve urban renewal, advocating for a greater commitment to integrating planning with other disciplines, with the view that "the physical environment is an important determinant of society and culture" and that "only an environment based on professional planning principles can provide the good life" [2].

Consequently, mixticity has progressively emerged as a pivotal constructive attribute within compact cities. An urban environment that exhibits a greater diversity of urban fabrics is inherently more resilient. The concept of sustainability being inherent to mixed settings can be evaluated at both the social and economic levels: it fosters social interaction and creates synergies between adjacent economic activities [3]. From an ecological standpoint, mixed-use developments contribute to reduced energy consumption through the minimization of everyday movements and the promotion of active transportation modes, such as walking and cycling.

In recent years, a number of surveys have been conducted to investigate the relationship between sustainability, compactness, and a more health-centric urban design. The combination of higher densities and shorter travel distances not only encourages the formation of healthier mobility habits but also facilitates the development of efficient public transport networks. This results in a reduction in air and noise pollution, heat island effects, and overall carbon emissions [4]. Furthermore, from the perspective of emerging mobility trends, it is evident that diversity in land use, characterized by a combination of residential, commercial, educational, and workspaces within a specific area, encourages walking and cycling [5].

The concept of the '15 min city' has recently emerged as a slogan, synthesizing the values of the sustainable city. It promotes urban policies and designs that enable residents to meet six basic needs—living, working, commerce, healthcare, education, and entertainment—within a 15 min distance—walking or cycling—from their homes, which ensures a higher quality of life [6]. A review of the literature on this trending topic reveals that the 15 min city is not a mere novelty, but rather has its roots in a long tradition of 20th-century urban planning theories and practices. However, there are evident pitfalls and risks of the oversimplification associated with this concept [7].

At the institutional level, the New Urban Agenda, endorsed by the United Nations General Assembly following the Conference on Housing and Sustainable Urban Development (Habitat III) in Quito in 2016, establishes the Sustainable Development Goals (SDGs). It emphasizes the importance of more inclusive, safer, more resilient, and more sustainable cities (SDG 11) and triggers the development of evaluation systems, including metrics and indicators. A variety of disciplines are being called upon to contribute to the achievement of the SDGs, with numerous studies being conducted in the social sciences to support this common objective. Although there is a general consensus on the crucial role of spatial planning and design in urban development, the morphological dimension is often absent from the debate due to a lack of specific contributions. This absence has been the subject of criticism by some scholars [8] on the grounds that morphology makes a decisive contribution to the description, explanation, and prescription of contemporary urban form.

In consideration of the aforementioned issues, this article proposes an investigation into the inter-relationship between sustainable mixed-use functionality, land management, and planning. To this end, the Barcelona metropolitan area, a compact and dense urban context, was selected as a case study to test a methodology that measures and, in the long term, aims to predict the balance of uses in relation to the urban planning that has determined the built environment that accommodates them.

Following an overview of the evolution of urban planning in Barcelona in relation to the regulation of land use (Section 2), this article then presents the selected case study areas (Section 3.1), the databases on which the analysis is based (Section 3.2), and the methodology used in the analysis of the mixticity within them (Section 3.3). In Section 4, the current planning regulations are compared with the mixed-use reality in twelve areas of diverse morphological features, subject to different planning regulations. Here, the measures and expressions of the mix balances are tested and defined through mapping and quantification.

2. Mixed-Use in Metropolitan Barcelona through the Urban Plans and Regulations

Barcelona represents the second-largest Spanish metropolitan area, with a total population of 3.3 million people distributed across 36 municipalities, occupying 636 km². The metropolis's natural territory encompasses a region extending from the Mediterranean Sea to the coastal mountain range of Collserola, situated between the Llobregat and Besòs rivers. These distinct geographical boundaries shape the metropolis's dense and compact character.

A succinct examination of the pivotal elements delineated in the urban development plans of the 1950s and 1970s, which established the legal framework that has shaped the

metropolis's growth, is crucial to comprehend how planning in the Barcelona area has regulated the distribution of uses in the urban territory up to the present.

The current arrangement of land uses and activities in the Barcelona metropolitan area is deeply influenced by both historical and current regulations. Notably, the Plan General Metropolitano [Metropolitan General Plan] from 1976 [9], which remains valid, although it has undergone over a thousand specific amendments over time. The plan is influenced by its predecessor, the Plan de Ordenación de Barcelona y su zona de influencia [Development Plan for Barcelona and its area of influence], commonly known as the Plan Comarcal [Land Use Plan or County Plan] of 1953 [10], which represents a crucial milestone in the local planning culture and provides the insights to understand the fundamental principles that guide urban planning that were inherited from the 20th century. Additionally, the general planning in force today is superimposed on the nuances provided by different derived plans, reformation, or urban improvement plans.

A substantial corpus of the literature has addressed the evolution of urban planning at the metropolitan scale, with a considerable number of studies focusing on the city of Barcelona, its urban renewal practices, and the concept of the 'model Barcelona' [11–15]. In addition, other studies have emphasized the significance of transformations at the metropolitan scale [16–20]. In sum, these studies, and numerous others with a thematic or sectoral focus, have delineated the evolution of urban growth up to the present day. They have alternated between more structural and comprehensive views on planning, mobility, and green systems, and provided numerous detailed studies on the distinctive formation of residential spaces (mass housing, low-density spaces, and suburban extensions), as well as on economic activities, services, and so forth.

2.1. Land Use and Zoning: From the County Plan of 1953 to the Metropolitan General Plan of 1976

In 1953, the County Plan (officially known as "*Ley de 3 de Diciembre de 1953, sobre Ordenación Urbana de Barcelona y su comarca*" [law of 3 December 1953, on the urban planning of Barcelona and its region]) established for the first time in Barcelona a new urban regulation at the scale of the whole city and entailed the importation of the zoning principles of the first modern plans in Barcelona [21]. The need for a new plan arose from the existing "urban disorder, resulting from the diversity and contrast of uses, the lack of organic communication systems within the city and its surrounding area, the conservation of agriculturally significant zones among others, that made it necessary to study a County Plan 'that includes Barcelona's capital and the towns in its periphery that coexist and develop with it'(. . .)". Consequently, one of the main objectives of the plan was to settle on appropriate zoning for each urban area or sector, properly segregating residential areas from industrial ones, adequately distributing open spaces, and preserving agriculturally significant zones [22].

The plan defined a total of 39 areas with specific nomenclature and grouped them into urban areas, green areas, and parcs and rural areas. The first group defined 17 different zones, melting together different types of housing and industries, characterized by a diversity of patterns, densities, and compatibilities: (1) old town; (2) intensive grid; (3) semi-intensive grid; (4) intensive residential urban area; (5) semi-intensive residential urban area; (6) semi-intensive suburban area; (7) extensive suburban area; (8) detached suburban area; (9) detached suburban area with industry; (10) intensive garden city; (11) extensive garden city; (12) urbanized park; (13) urbanized forest; (14) industrial housing tolerance; (15) large industry; (16) mid-size industry; and (17) sanitary area with housing tolerance. In addition to the previously mentioned categories, other land uses related to services and facilities were defined as special zones which encompass various specific purposes, including commercial, leisure, sports, healthcare, military, or railroad, among others.

The definition of this significant number of zones, subject to different codes of use and building regulations, was aligned with the intention to validate the existing urban fabrics at that time, which necessitated differentiation among the various built realities. While

some municipalities adopted the rules of this plan for the distribution of the uses, in other cases, as in the city of Barcelona, the metropolitan rules would serve as guidelines for the Ordenanzas Municipales de la Edificación [Municipal Building Regulations], which were later approved in 1958 [23].

2.2. Land Use Regulation in the Metropolitan General Plan of Barcelona

On the basis of urban regulations from the 1950s, an additional step forward was made by the 1976 General Metropolitan Plan (PGM), which was adopted in parallel to a new ley sobre régimen de suelo y ordenación urbana [law on land and urban planning], setting the foundations for the current regulations in the metropolis. (The Metropolitan General Plan, approved by the Provincial Urbanism Commission of Barcelona on 14 July 1976, regulated the urban area of the former Metropolitan Municipal Entity of Barcelona, which included a total of 27 municipalities and today encompasses 36 municipalities and an area of 600 km^2). Among the many contributions of the PGM, the distinction between zones and systems stands out, based on the general regulation law, setting a series of parameters that are still in force with the specific modifications. Whereas, in the County Plan, each zone included blocks and streets, as well as public and private areas. The PGM—while maintaining some relationship with the categories of the former—detailed the specific conditions at the block and even at the plot scale, so that new urban planning developments and instruments were put on the table, providing a much more precise definition. The PGM regulations establish common provisions for building—alignments and isolated, specific volumes—and the regime of uses, which in turn controlled the activities classifying them into housing, residential, commercial, sanitary, leisure, industrial, cultural and religious, parking, or sporting functions; the regulations also addressed situations of overlapping uses and prohibited uses and limited certain activities in certain situations by establishing the categories of compatible, conditional, temporary, or provisional usage. Next, the zones were regulated and were given an identification code, a number common to all municipalities: (1) old town, was code 12; (2) intensive and semi-intensive urban densification, 13a and 13b; (3) urban and building structure conservation, 15; (4) volumetric development, 18; (5) isolated building development, 20a; (6) protected private green, 8a; (7) industrial, 22a; (8) redevelopment, 14a and 14b; (9) urban renewal: rehabilitation, 16; and (10) urban renewal in the transformation of use, code 17.

Over forty years, the PGM has regulated the establishment of activities in the city of Barcelona and throughout the entire metropolitan area, strictly controlling the development of new sectors as well as the regeneration and upgrading of the existing areas. The significant changes in the habitat and built environment in recent decades have resulted in hundreds of modifications to the initial regulations. However, in essence, the determinations regarding the compatibility and incompatibility of uses, densities, built areas, or occupancy have remained unchanged.

2.3. Current Regulations and Planning Amendments since 1976

In order to adapt to new ways of life, over the last three decades the different municipalities have implemented thematic plans and regulations to model the deployment on the territory of some specific uses or to define the synergies needed or to be avoided between more than one type of activity, with the city of Barcelona taking the lead in this process of drafting derived plans.

In this respect, it is worth highlighting some administrative interventions, especially with regard to the planning and compatibility of commercial uses with other urban uses: the Ordinance for the Rehabilitation and Improvement of the Eixample district, with a vocation to promote commercial uses—over other invasive activities—in the use of street-side premises; the Urban Landscape Ordinances; the Special Interior Reform Plans; and the "New Downtowns" Plans in 1987 [24]. They are all urban planning instruments that base a large portion of their articles on the distribution of activities, as do similarly derived plans that apply on an ad hoc basis for the rest of metropolitan municipalities, which shape the permitted uses in certain fragments of the coherent fabric that overlaps with the PGM.

Getting closer to the specific approach of this research and looking in a holistic way and at smaller urban fragments, it is worth mentioning the Pla Especial d'Establiments de Concurrència Pública i Altres Activitats [the Special Plan for Public Establishments and Other Activities], a planning tool that regulates the implementation of certain activities in specific neighborhoods, with the aim of balancing the uses they generate and thus minimizing their impact. The old town of Barcelona, Ciutat Vella, was, in 1992, the first district to draw up a plan of these characteristics—which was successively redrafted or modified in 1997, 2000, 2005, 2010, 2013, and 2018—which was aimed at addressing conflicts of coexistence in public space, firstly with prostitution and drug trafficking in public space, and then in relation to the bars and guesthouses (meublés) as spaces for the private development of these activities [25].

In general terms, the plans of uses have the following aims: (1) improving the balance between the needs of residents and the maintenance of commercial activity; (2) ordering and limiting activities that generate negative consequences; (3) promoting economic activities that help to dynamize the area; (4) promoting economic and commercial diversity in all neighborhoods; (5) achieving greater precision in the regulation of establishments, plot by plot and building by building; (6) allowing the implementation or restriction of activities depending on whether or not the urban fabric admits them, in order to guarantee a mix of activities and services; (7) ensuring that all stakeholders understand the regulatory instruments; and (8) creating a tool for monitoring commercial and environmental developments in the urban environment [26].

These planning tools relate activities to the morphological composition of each area [27] and have become more sophisticated over time, starting with their attention to, among other things, the densities—in units or surface area—of certain activities and the street widths. The more recent versions look at locations in relation to housing, to certain uses of facilities, to the public space in front of the access points to the facilities and to other premises, to their zonal location in relation to planning, and to the minimum and maximum surface areas of the premises. A further set of regulations pertains to the control of specific activities within the city, including those relating to commercial premises and tourist accommodation.

2.4. Mixed-Use and Planning: A Literature Review

Despite the existence of a substantial body of urban studies on the Barcelona metropolis, which have been conducted from a variety of perspectives, including morphological and geographical, the complex issue of functional mix has not been adequately addressed from the specific perspective and level of detail that this research proposes. In addition to the value of the aforementioned references, other research and approaches are of particular interest for their complementary perspectives: (1) research on the morphological configuration of various urban fabrics [28] and (2) parametric approaches that establish vitality indexes [29,30].

The initial group of works, despite their diversity, exhibit a notable degree of overlap in terms of their approach, which intertwines the morphological perspective with the logic of planning and certain quantitative methods. Regardless of these apparent similarities, they diverge significantly from the present research in that they focus on more homogeneous urban fabrics—those with less mixed land uses—and give less emphasis to the discussion of activities.

With regard to the second group of works, their approach is noteworthy for its complexity, which was designed to elucidate the concept of "urban vitality" as a combination of diverse, quantifiable qualities. These include concentration, diversity, contact opportunity, the necessity for aged buildings, accessibility, and distance from border vacuums, in an approach consistent with the methodology proposed by Jane Jacobs [1].

In addition to the existing literature on urban studies in Barcelona, there is a paucity of investigations that employ measurements and graphical representations to examine urban diversity. One particularly noteworthy study compared the functional mix in "dispersed areas" across Europe, focusing on what it termed the "territories in between" [31]. The

study offered a vision of the phenomenon at three different scales—from 50 × 50 kms to 500 × 500 m. However, it did not include an instrumental development of a particular complexity at the closest scale. Another pertinent study proposed a case study analysis and endeavored to elucidate the concept of "functional mix", noting the dearth of thematic references. The research proposed five complementary categories: "entropy, dissimilarity, destinations, proxies, and mixed-use index" [32]. This final measure (MXI) was directly linked to one of the three indexes that formed the basis of the results chapter (R-NR, the most elementary of the three, which established the proportion between residential and non-residential uses). The work proposed a methodology based on the "live–work–visit triangle", which has been applied to the central areas of three cities—New York, Barcelona, and Bogotá—using a trans-scalar analysis. This approach is complementary and offers interpretive results at a fairly general scale of detail.

Other concepts such us urban diversity, urban vitality, or vibrancy have certain concomitances with mixed-use and are more frequently used for the social sciences and tested in different metropolises. To cite only few examples, the notion of urban diversity has been measured and related to "economic benefit" at the neighborhood scale in diverse cities [33]; the relationship between urban vitality and social cohesion, through population-based surveys and statistical analyses has been explored in Oslo [34]; the relationship between urban form and neighborhood vibrancy has been explored in Beijing [35]; the assessment on urban vitality has been tested in Chicago and Wuhan [36]. In all these cases, the results and methodology were tied to statistical and geographical scales, relying on available aggregated data, which makes their approach and results substantially different from the present research. Other studies are closer to the present study in terms of their scale and morphological scale and also their use of the concept of "urban vitality", as related to the street or neighborhood fragments [37,38].

3. Materials and Methods

In this paper, the methodology for mixed-use interpretation, measurement, and representation is presented through the selected urban fragments in the metropolis of Barcelona. The objective was not only to provide a new urban interpretation of the 12 specific areas, but also to test a methodology that allows the following: (1) the composition of an image of the whole metropolis, concerning the diversity of mixed uses in relation to the basic differences in planning codes; (2a) the establishment of a series of graphic representation tools that illustrate the dimensions of the mix in morphological terms at the block, street, and plot levels; and (2b) the establishment of three indices related to the mix of uses, which are connected to the mapping and also enable a parametric comparison between urban fabrics of different natures.

3.1. Case Study: The Selection of Twelve Coherent Metropolitan Fragments

In light of the insights gleaned from the metropolitan area and the findings of studies on the correlation between mixed-use development and proximity in Barcelona [39], as well as the scale of the metropolis [40], the research team identified a set of twelve regular, square fragments, each measuring 500 by 500 m, encompassing a total area of 25 hectares within the metropolitan territory.

Displayed in Figures 1 and 2 and located in seven different municipalities, the fragments correspond to diverse morphological conditions with characteristic patterns related to old towns, modern regular grids, traditional irregular extensions, garden cities, mass housing areas, and industrial estates. In terms of urban planning, the various urban codes trigger different balance situations between built space and open space, different housing densities with different heights, and differentiated intensities of use according to urban structure and the role of centrality within the metropolis. Four-letter abbreviations were assigned to each of the areas in order to simplify the toponyms that describe them, so that they are named as follows, and ordered in the figures according to this criterion: Castelldefels (BCAM); Muntanyeta (BSBC) and Fonollar (BSBI) in Sant Boi de Llobregat;

Pallejà (BPAC); Badia del Vallès (BBAV); Cerdanyola (BCER); Badalona (BBDN); Poblenou (B22@), Sagrada Familia (BSFE) and Tres Torres (BTRT) in Barcelona; Poligon del Mig in L'Hospitalet de Llobregat (BLHI); and Sant Ildefons in Cornellà (BCSI).

Figure 1. Aerial image of the Barcelona metropolitan area. In red, the 12 fragments detailed in Figure 2. Source: Authors' elaboration, after Google Earth.

Figure 2. Aerial of the twelve selected case studies at the same scale. Source: Authors' elaboration, after Google Earth.

3.2. Data Sources and Processing

Two major public databases were central to the research. First, the research utilized data from the Spanish Land Registry [41], which provided insights into private activities on the ground floor, such as housing or private parking, and helped identify the uses of upper floors.

Additionally, data from the National Institute of Statistics [42] offered a comprehensive demographic and socioeconomic dataset at the census section level, covering aspects such as the age, gender, origin, income, and education of the population, as well as tracking the fluctuation of people throughout the day within the area. This data enabled the research not only to generate socioeconomic profiles for the cases studied but also to integrate this information with other datasets.

For specific cases within Barcelona, the research incorporated the Inventory of Commercial Premises in the City [43], which provided a geolocated overview of non-residential, ground-floor activities, which were categorized into 86 activity types. This dataset served as a basis for fieldwork, with the existing categories being reorganized into the seven groups defined in the research.

3.3. Methods

The analyses employed GIS tools and integrated the automated processing of the aforementioned databases with a bespoke plot-by-plot correction. This methodology is based on the value of mapping as a form of empirical knowledge, which can be considered analogous to textual description or numerical parameterization.

Activities were quantified in terms of number and area on the ground floor and the upper floors. The analysis was conducted from two perspectives. Activities on the ground floor and upper floors were analyzed on a block-by-block basis to compare the proportions between the various uses and identify the mean block size. Activities on the ground floor were also analyzed to observe the concentration and continuity of each type of activity along a street, and to evaluate the mixture of uses at the pavement level.

Once the initial data collection and processing were complete, the fieldwork phase was initiated with the objective of updating and refining the baseline information in order to identify and confirm the specific category of activities. During the fieldwork phase, activities were categorized into seven groups, and represented by distinct colors. These were food retail (orange), other retail (red), hospitality (yellow), services (maroon), industry and logistics (purple), public facilities (blue), and unoccupied premises (black). In addition to the aforementioned activities, other complementary uses were identified and classified as follows: open spaces (white), common spaces (light grey), housing (turquoise), and private storage/parking (mint green).

Subsequently, a graphic analysis was deployed through the examination of different uses and activities at the scales of urban fragments, blocks, streets, and plots, identifying the relationships between proximity and the quality and quantity of services across various scales and contrasting the urban analysis with the planning determinations of the same areas. Some preliminary partial results testing this methodology were published [44,45], ranging from metropolis-wide interpretations to block-by-block analyses.

Additionally, in order to achieve not only a graphic comparison but also to provide its parametric correlation, it was proposed to measure the mixticity through three indices: R-NR, LUM, and PNR-Mix.

The R-NR equilibria are based on diversity measurement [46,47] and considered in a plot-by-plot scale, using the following formula, where R refers to residential uses while NR refers to non-residential uses. This index used the data from the Land Registry, which were applied from a plot point of view and displayed in Table 1 (see Section 4.2.1).

$$\mathrm{R{-}NR}_i = 1 - \left| \frac{\mathrm{R} - \mathrm{NR}_i}{\mathrm{R} + \mathrm{NR}_i} \right|$$

The LUM Index is a parametric resource for calculating the proportion among different categories, based on the Entropy Index [48] that states that the more balanced the different categories are among them, the higher the index. The formula was as follows, where P_i refers in each fragment to the percentage of floor area for each of the six categories—excluding non-occupied premises—on the ground floor level. The final result was the sum of each percentage multiplied by its own natural logarithm, converted to positive numbers (see Table 2).

$$\mathrm{LUM}_i = \left| \frac{\sum_{i=1}^{n} P_i \ln(P_i)}{\ln(n)} \right|$$

Finally, the proximity Distance of NR Mix Balance (PNR-Mix) represented the average distance from every activity to its four closest activities and was divided by the diversity of

those activities found, with its LUM index, and, therefore, the PNR Mix Index expressed both the proximity and mixticity of the five activity clusters (see Table 3), according to the following formula:

$$\text{PNR Mix} = \frac{\frac{1}{n}\left(d_1 + \cdots + d_n\right)}{\frac{\sum_{i=1}^{n} P_i \ln\left(P_i\right)}{\ln(n)}}$$

4. Results

Following an examination of the evolution of land use regulations in the city from the mid-20th century to the present day (Section 2), this section compares the current planning regulations with the mixed-use reality in the 12 areas previously presented, where measures and expressions of the mix balances are tested and defined. Firstly, a comparison is made of the current planning parameters (public–private), measuring standards, and the degree of heterogeneity in urban codes (Section 4.1). Secondly, the balances between the different activities in each of the fragments are detailed, mapped, and quantified (Section 4.2).

The result is a graphic atlas of different situations regarding the balance of uses, illustrating and quantifying the variety of outcomes that planning has produced, some of the outputs of which are presented. Finally, the Section 4.3 presents the patterns of vitality and mixticity in the analyzed case studies and parametrizes some of the graphical results using numerical indices to enable objective quantitative comparisons.

4.1. Mixed-Use in Planning: Standards, Codes, and Building Eras

The first set of maps that compose the atlas comes from the extraction of open data, both from the current PGM [49] and the Spanish Land Registry [41]. The information was progressively broken down, looking at the following: zones–public land versus systems–private land; the diversity of planning codes; the diversity of building ages and their relationship to the different plans, as explained in the previous section; the balances between residential and non-residential uses; and the diversity of ground floor activities.

The comparison between planning and regulatory standards starts from three initial approaches: (1) a figure–ground map to differentiate the public space, as defined by streets and green areas, compared to the blocks that are used for buildings and open spaces (Figure 3); (2) an image of the mosaic of different urban codes that make up the land that can be built on (private land and plots for facilities), i.e., the resulting figure showing the background of streets and green areas (Figure 4); and (3) the observation of buildings in relation to the time of their construction, which links them to the succession of urban regulations (Figure 5).

4.1.1. Zones vs. Systems

The private land in each group varied from one-third to three-fourths, the mass-housing areas being the ones with the highest public standards—between 60 and 70%—in comparison with the majority of other areas, with the percentages of private land being higher than 50% and reaching almost the 80% in the case of BSBI. In this framework, the case of BCSI was quite paradigmatic, as it had the highest ratio of open spaces, a condition that can be related with the ecosystemic services ratio, including the green percentage and air quality. Nonetheless, the very balanced relationship identified between public urban planning standards—in thirds: private land; green and facilities; and road—did not transfer an optimal balance to the activities, as will be seen later.

Figure 3. Green areas and public streets vs. plots for public facilities and private land. Source: Authors' elaboration, after PGM.

4.1.2. An Ad-Hoc Basis Zoning Classification

Beyond the streets, green areas, and facilities, there was a varying degree of homogeneity regarding the private land within the 500 by 500 m fragment. This aligned with the morphological traits of different urban sectors. Accepting that there is normally a correspondence between the degree of homogeneity in terms of urban morphology and in terms of planning, these images explored to what extent a higher or lower number of different zone codes would match with the parameters of mixticity within each sector. The comparison between the planning codes and the total surface when qualified differently offered an interesting array of situations. Some of them were mono-code or had only two codes, whereas others were more diverse and had five codes (B22@); four codes (BCER); or three codes (BPAC, BSBC, and, to a lesser extent, BBDN).

This illustrated the degree of fragmentation of land planning, which did not present large-zoned areas, but rather demonstrated block-by-block behavior.

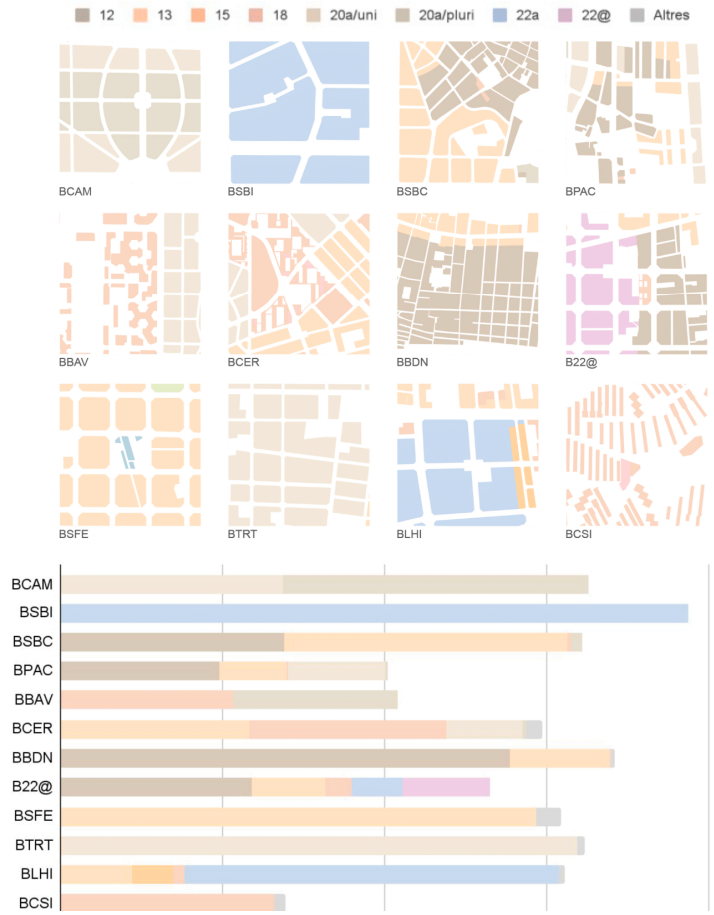

Figure 4. Urban planning codes. Source: Authors' elaboration, after PGM.

4.1.3. Building Eras

Jane Jacobs [1] stated that a mix of old and new buildings in neighborhoods contributed to a dynamic urban environment, creating a sense of place, supporting a variety of uses, and promoting social interaction.

To consider the impact of this factor on the fragments under consideration, this research observed which regulations have guided the construction of the urban fabric in each of the fragments. In some cases, the current buildings were constructed prior to the so-called County Plan (in lilac); a portion were precisely built during the two decades of validity (1953–1976); and finally, the most recent group was constructed following the regulations of the PGM (since 1976). On average, around 50% of the edification was built in the latest stage, and less than 15% of the buildings were built before the first Metropolitan Plan. It is worth noting two aspects here: The first is that in the differently analyzed fragments, very different proportions among the three periods were observed. B22@, BBDN, and BSBC were the fragments that had the highest density of buildings that were built before 1953, and to a lesser extent, BSFE and BTRT. Conversely, BCAM, BBAV, and BPAC were the places with the youngest buildings, which corresponded to the growth of the areas or the metropolis that hosted the migrant population at the time of their creation.

Although there was no direct relationship between the age of buildings and the uses that they facilitate (the varying adaptive reuses of old buildings being an example), the temporal diversity within the same neighborhood was considered as a quality of a building's age.

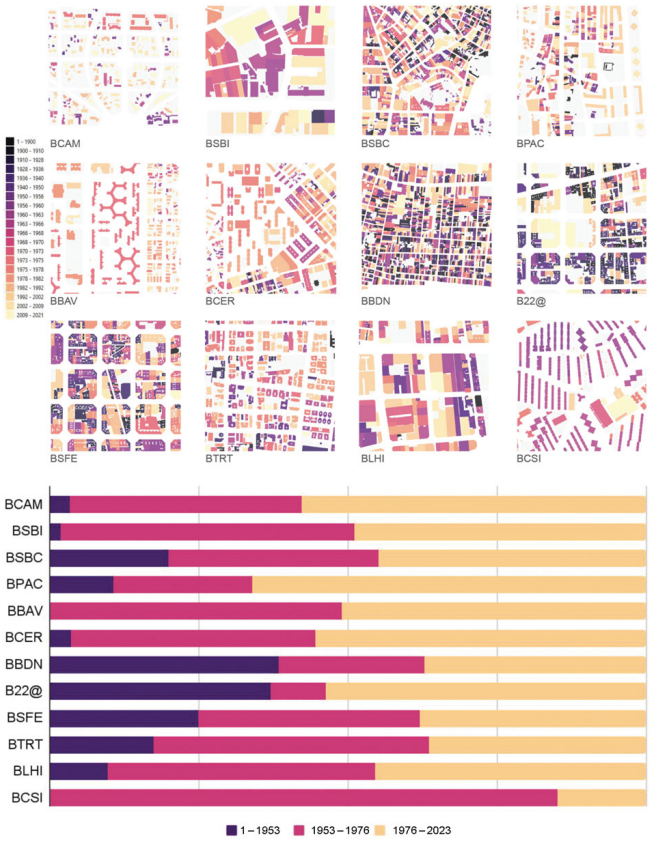

Figure 5. Years of construction of the built layout. In blue, those existing previously to County Plan 1953; in lilac, between 1953 and 1976; in orange, post-1976. Source: Authors' elaboration.

4.2. Mixed Conditions in the Urban Fabric

Contrasting with the schematic vision of urban planning, there are several characteristics of the urban fabric that explain its mixed and diverse condition. Two different and complementary components were analyzed in this regard: the proportion between residential and non-residential uses, as calculated plot by plot (Figure 6), and the ground floors in relation to the various uses they accommodate (Figure 7). While the previous drawings were automations of the information available in the open databases, the following maps presented in this section are a novel contribution to the research.

4.2.1. Residential vs. Non-Residential Balance

Although analyzing the balance between residential and non-residential uses can be seen as a reductive and not very complex measure, it is a good sign that proves that mixticity refers not only to the amount of NR (mapped in red) or R (mapped in blue), but also to the proportion between the two, and that the most balanced mix can be found in both high and low densities, as well as in central and peripheral areas [40].

From reading Figure 6 and the resulting indexes displayed in Table 1, it can be seen that the NR status is highly represented in BSBI—foreseeable, as it is regulated under code 22a—and is accompanied by BCER, BTRT, and BPAC, with an index of less than 0.25. What is interesting in this case is the diversity of codes that have promoted this almost-residential exclusivity: a majority of 15 and 18, with a pinch of 20, in the first case; almost exclusively 20 in the second; and 12 and 20, with some 15, in the third. Conversely, as the most balanced cases, with indexes between 0.7 and more than 1, BLHI, B22@, and BBDN corresponded to very diverse planning codes: 22a with a bit of 13 and 15 the first; 12, with some 13 and 22@ and a little 22a in the second; and almost all 12, with some 13, in the third. But in this case, while the first two were made up of pieces with 5 or 3 different codes, respectively, in

equivalent proportions, the third case was composed mostly of pieces in code 12, which makes this unexpected mixture of uses outstanding.

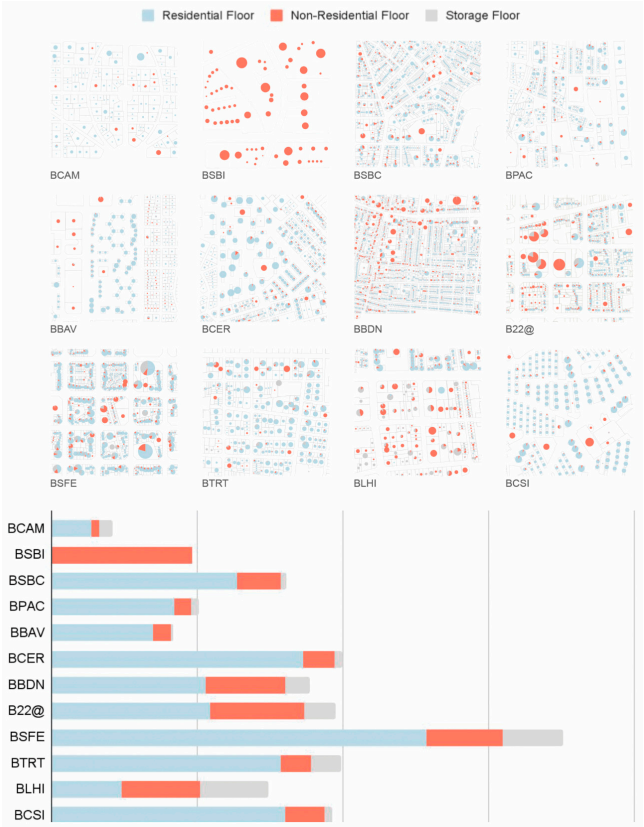

Figure 6. Mixed-use balance in terms of surfaces on a plot-by-plot basis. Source: Authors' elaboration.

Table 1. Comparison between fragments, R-NR balance. Source: Authors' elaboration.

BCAM	**BSBI**	**BSBC**	**BPAC**
0.35	...	0.28	0.25
BBAV	BCER	BBDN	B22@
0.31	0.23	0.69	0.75
BSFE	BTRT	BLHI	BCSI
0.34	0.23	1.06	0.28

4.2.2. Ground Floor Activity

The result of our observation of the ground floors is a vindication of the socializing potential of the street. When presented in a continuous and dense manner, the diversity of activities at the pavement level provokes chance encounters with the unfamiliar. Following the few years in which lockdowns were in place (which, on the one hand, led to the discovery of convenience technology that allowed working, eating, shopping, and entertaining from home and, on the other hand, caused an economic crisis from which ground floor activities suffered) new urban planning discussions are being raised in relation to the reconfiguration of the premises and to the balance between uses [45–50].

A precise drawing of the plot layout representing the uses at the ground floor level was developed to represent the richness of the diversity of their plot occupations and the street perceptions that they evoke. The resulting output represents the morphology of the activities on the ground floor, considering seven categories related to economic activities. This means that the coexistence of more than one activity on the same plot is visible, as

well as the collective domestic spaces of the staircases that connect the residential uses of the upper floors within the street.

The resulting image shows the vibrancy of the mixture both in relation to the variety of uses—colors—and in relation to the extension that they occupy—the variety of colors in consecutive fragments. Thus, at one extreme of the minimum mixed-use conditions, the BSBI—large plot—and BCAM—small grain—stand out. For fragments with the maximum apparent vibrancy, B22@ and BSFE show mixes that seem to be spread homogeneously, while BBDN shows the mix as concentrated in two axes, and BCSI shows vibrancy as concentrated on the walls of buildings. On the other hand, in the rest of the areas in which housing accounts for 50% or more of the activity on the ground floor, the mixticity that may exist between the rest of the activities is apparently camouflaged by the resulting equilibrium.

B22@, BSFE, and BCSI—three of those that stood out in Figure 7, which shows the perception of intensity on the street—had LUM indices above 1.25 (Table 2). BTRT, BBAV, BPAC, BSBC, BSBI, and also BCAM had indices below 1.

Table 2. Comparison between fragments, LUM index. Source: Authors' elaboration.

BCAM	**BSBI**	**BSBC**	**BPAC**
0.35	0.64	0.89	0.98
BBAV	BCER	BBDN	B22@
0.95	1.01	1.08	1.44
BSFE	BTRT	BLHI	BCSI
1.42	0.8	1.01	1.25

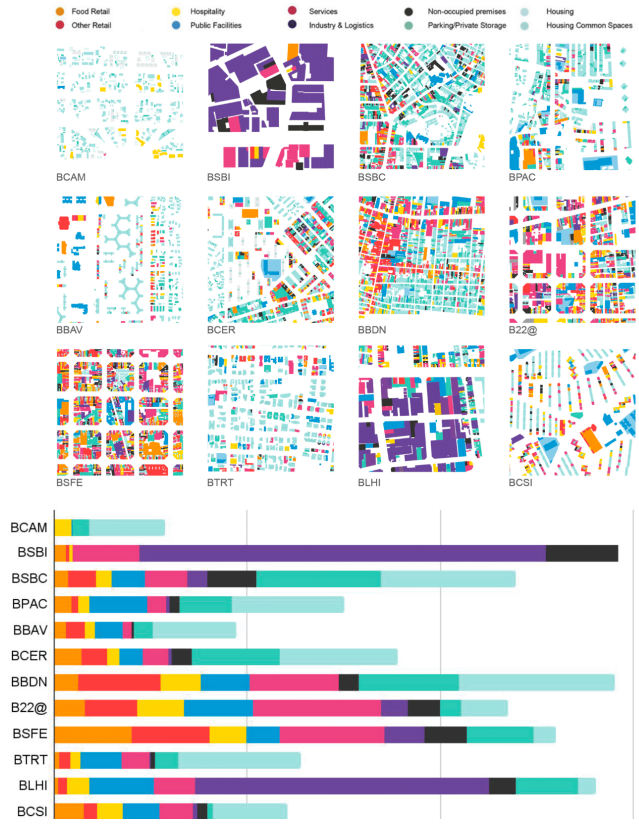

Figure 7. Variety of uses at the ground floor level. Source: Authors' elaboration.

4.3. Patterns of Vitality and Mixticity in Barcelona Metropolitan Fabrics

The information gathered in the previous maps allowed a final series of cartographies and index calculations that aimed to depict and measure the differences and similarities in the conditions of mixticity and proximity reflected on the street. Two different approaches offered a mixed-use overview of the twelve selected samples, illustrating this through graphic images which approached the plot-by-plot reading through two lenses: (1) street vitality and (2) the activities' proximity and mixed-use index (PNR-Mix).

4.3.1. Street Vitality on the Ground Floor

In an attempt to represent the impact that the uses have on the urban structure and adding the incidence of the activities on higher floors, Figure 8 explores a phenomenological representation, in which the perception of activities is depicted through the interaction between premises and dwellings.

On the one hand, Figure 8 represents the residential units on the ground floor and the residential buildings' entrances, and, considering the associated daily flow of people, every node is represented with a diameter, depending on the number of residential units it serves. On the other hand, six of the seven categories of activities—excluding non-occupied premises—are grouped in two colors and represented in a 25 m radius circle around their entrance: food retail, other retail, and hospitality premises are in red; services, industry, logistics, and public facilities whose entrances are normally less visually connected with the street and referred to non-daily services are in purple. As a result, the map shows not only the concentration of flows in the selected fragments but also the blind facades and the lack of vivid commerce doors and dwelling entrances, which generate spaces where the feeling of security experienced by the pedestrian might be critical.

BSFE and BCSI show an image of a higher concentration of activity towards the street layout. Also, B22@ and BCER show a similar finding, although these two do so in an asymmetric way. In the cases of BBDN, BPAC, and BSBC, some axes stand out that fade in the area, something that happens more forcefully with the areas of intensity that stand out in BTRT and BBAV. In these last two, and even more so in BCAM or BSBI, it is possible to speak of an urban fragment made of corners rather than streets.

Figure 8. Interpretation of street perception of intensity. Source: Authors' elaboration.

4.3.2. Activities Proximity

Finally, the last map of the series depicts the proximity and mixticity of activities both from the street and the urban fabric. In this case, the research has layered the drawing with

a heatmap that counts the number of activities of each category at any given point within the 500 by 500 m crop in a 20 m radius (Figure 9).

Figure 9. Patterns of proximity of urban mix. Source: Authors' elaboration.

The graphical result obtained was quantified by calculating the average distance from each activity to four other activities (other than residential), following the criteria established in the heatmaps.

The PNR-Mix index (Table 3) makes it possible to measure the visual impression derived from the heatmaps, in which the greater the number of plots hosting the same use, the greater the intensity associated with the place; the greater the variety, the more extended the vibrancy. This index shows how the fragments with the lowest diversity of planning codes (BSBI and BCAM) are also the only ones with a PNR-Mix above 20 and how the lowest values—maximum distances—correspond to fragments that have both residential and productive regulations codes as their majority (BSFE, BCER, BBDN, BSBC, and BCSI, vs. B22@).

Table 3. Comparison parameters between fragments, PNR-Mix distance. Source: Authors' elaboration.

BCAM	**BSBI**	**BSBC**	**BPAC**
265.02	62.06	14.56	17.35
BBAV	BCER	BBDN	B22@
20.54	14.64	9.82	10.53
BSFE	BTRT	BLHI	BCSI
9.6	19.98	18.69	14.35

5. Discussion

There are some patterns in the relationship between the resulting fabric and the activities that are housed in it, as well as in the balance relations between the different uses that the combination of various planning codes has resulted in. Given the level of detail in the planning maps in Barcelona, the availability of open resources, and the specific fieldwork conducted in certain areas, it was possible for this research to provide well-contrasted information at diverse scales, something quite exceptional compared to the majority of analogous GIS studies [29,30,32–36].

The collective of planning decisions and regulations, operating at various scales and timeframes, represents a primary regulatory mechanism for the diverse sectors of the city. However, the actual mixture of uses in the city is far more intricate and challenging to plan,

design, and describe with precision. The methodology explored develops a specific set of tools to compare and graphically and parametrically represent the varying degrees of diversity and complexity in the urban mix in metropolitan Barcelona.

In the introductory section, the article began by reviewing the planning that has shaped the distribution of uses in Barcelona up to the present day, with an emphasis on two crucial moments. On the one hand, looking at the first Metropolitan Plan of Barcelona in 1953, which was established with the aim of improving the pre-existing urban disorder. Like many others, it introduced very rigid zoning guidelines that created segregation among different areas, emphasizing strict regulations to avoid unwanted mixes of uses and users. At that time, the city planning image was binary: residential areas for living and industrial areas for working.

On the other hand, the new Metropolitan Plan of 1976 scaled down to more detailed urban regulations, transitioning from the sector unit to the block unit. This shift facilitated, on the one hand, the coexistence of different types of activities in closer proximity and, on the other hand, a more inclusive and complex regulation for each urban planning code.

This research makes a contribution to the field by providing comprehensive and detailed mapping and a quantitative dataset for the purpose of comparing the consequences of such plans in different parts of the metropolis. By analyzing urban fragments of 25 ha, the diversity of metropolitan situations was characterized, and some key aspects of the mixed-use phenomenon were revealed through three consecutive and complementary approaches, which became increasingly complex. The initial stage of the analysis involved the comparison of the current planning standards between public and private domains, as well as the degree of homogeneity and the predominance of specific urban codes. In a second, more complex reading, the mixed conditions in the urban fabric were evaluated through two complementary results. The first of these was an evaluation of the proportion of the built floors between residential and non-residential areas, which is related to the whole of the urban fabric. The second was a more qualitative approach to the diversity of ground floors (street level), which follows a categorization that was based on the previous two series of maps and measures. In conclusion, the patterns of mixticity were illustrated through the graphic representation of street vitality on the ground floor and activities' proximity, measuring distances and concentrations. The graphic results corresponded to measurements that blended units (the number of premises and number of dwellings) with distances (meters) and with surfaces (square meters), which allowed, in its complex processing, the development of some indicators.

The R-NR index provided a fundamental and basic dimension of the mix, closely aligned with the approach of the 1950's planning regulations. From this standpoint, it is likely not coincidental that the highest R-NR index corresponded precisely to the two oldest urban fabric fragments, whereas the lowest corresponded to the most monofunctional fragments, either with residential or productive predominance.

Beyond the binary R-NR and the codes in planning as primary expressions of the urban mix, this article validated the effectiveness of a more complex graphic representation and parametrization for a more accurate description of the qualities of blocks, streets, plots, and buildings. In this way, the LUM index measured the proportions among different categories on the ground floor: the more diverse and present the different uses, the higher the index. The phenomenological representation of the street was depicted through streets and corners, highlighted by the footprint of premises and dwellings and the number of potential users. Finally, the most abstract PNR-Mix distance quantified the perceptions of proximity and diversity between uses at the pavement level. This showed how the highest values corresponded to fragments with more diverse planning codes, establishing specific measures and correspondences among many of the graphics and parameters illustrated in this research.

Accepting the limitations inherent to urban indices (e.g., different spatial configurations might have similar indices, and vice versa), the results of this work (Table 4) propose not to reduce the mixticity to a single index (such as residential density, for example),

but to understand it as a combination of the three, something that seeks its coherence with the series of plans. In the same way that the planning code maps are essential for understanding the phenomenon, together with the cartographies on the diversity of ground floor uses and urban vitality and the sense of proximity, it is also necessary to mix a basic ratio such as R-NR with a more complex index such as LUM and the average distance PNR-Mix. Without considering that a mathematical formula that mixes the three results could be significant, the comparative view of the three parameters is considered useful to empirically decipher the mixed value of each of the fragments analyzed.

Table 4. Overall index comparison: a balance (R-NR), an index (LUM), and a distance (PNR-Mix). Source: Authors' elaboration.

Fragment		R-NR	LUM	PNR-Mix
BCAM	Castelldefels Mar	0.35	0.35	265.02
BSBI	Sant Boi Industrial	...	0.64	62.06
BSBC	Sant Boi Centre	0.28	0.89	14.56
BPAC	Pallejà Centre	0.25	0.98	17.35
BBAV	Badia del Vallès	0.31	0.95	20.54
BCER	Cerdanyola	0.23	1.01	14.64
BBDN	Badalona Centre	0.69	1.08	9.82
B22@	Barcelona—Poblenou	0.75	1.44	10.53
BSFE	Barcelona-Sagrada Família Eixample	0.34	1.42	9.60
BTRT	Barcelona Tres Torres	0.23	0.80	19.98
BLHI	L'Hospitalet—Industrial	1.06	1.01	18.69
BCSI	Cornellà-Sant Ildefons	0.28	1.25	14.35

6. Conclusions

In addition to offering a detailed analysis of the mixed-use aspects of several representative urban areas within the Barcelona metropolitan area, this research has also provided insights into the evaluation of mixed-use developments. These insights are intended to enhance our understanding of cities shaped by this approach and, subsequently, to facilitate the creation of tools for the promotion and planning of more sustainable and efficient urban areas.

Despite the solid methodology that was developed and tested, some shortcomings in this research were anticipated. On the one hand, the selected fragment samples are all set in relatively dense and compact places, where formal and regulated activities were taking place. Low-density sites, or sites on the edge of the metropolis, or sites with informal activities, were left out of the discussion. Hence, it could be said that this research has been verified to diagnose the missing mixticity only in those places that meet the minimal conditions of compactness and density.

Also, as remarked in previous reports [32], there was difficulty in ensuring the consistency of the categorization, since there were some overlaps and absolute continuities between the different categories, which were as numerous as the activities identified in the city. The shape of the selected samples can also be discussed in this context. In windows that do not respond to the urban form, an analysis may be conducted outside of the possible distortions that may be present on the edges that were left out.

On the other hand, some other important factors in the measurement of urban mixticity, such as the social, economic, or environmental features, were overlooked in this study, despite their strong influence. These aspects might be considered on the agenda for further study from complementary perspectives.

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