

## Article

# Discontinuities, Limits and Barriers: Quantifying the Intensity of Urban Spatial Ruptures

José Lasala  and Carme Bellet \* 

Department of Geography, History and Art History, Universitat de Lleida, 25003 Lleida, Spain; jose.lasala@udl.cat

\* Correspondence: carme.bellet@udl.cat

## Abstract

Urban fragmentation has emerged as a central issue in the study of socio-spatial dynamics in contemporary cities, reflecting processes of inequality, segregation, and spatial discontinuities. This article introduces a new methodological approach to measure fragmentation by focusing on discontinuities at limits rather than on the content of statistical units alone. The method applies robust standardization of selected socioeconomic variables—higher education, foreign-born population, and low-income population—at the census tract scale in the city of Lleida, Spain. Rupture intensity is measured through a Rupture Intensity Index, which integrates standardized differences across 217 limits. Principal component analysis identifies the most influential variables, while cluster analysis characterizes the multidimensional nature of limits. Results show that fragmentation in Lleida does not follow a simple center-periphery model but a tessellated pattern of fracture lines and gradient zones. Intense fractures emerge at borders between advantaged and disadvantaged neighborhoods, whereas gradients mark gradual transitions. The study demonstrates that limits are critical sites for observing and quantifying urban fragmentation and proposes a transferable methodology for comparative research and urban policy design in diverse urban contexts. This approach provides a replicable tool for urban analysis and the design of cohesion-oriented policies.

**Keywords:** urban fragmentation; socio-spatial discontinuities; limits; barriers; rupture intensity index (RII); medium-sized cities



Academic Editor: Dario Domingo

Received: 10 October 2025

Revised: 3 November 2025

Accepted: 10 November 2025

Published: 14 November 2025

**Citation:** Lasala, J.; Bellet, C. Discontinuities, Limits and Barriers: Quantifying the Intensity of Urban Spatial Ruptures. *Urban Sci.* **2025**, *9*, 475. <https://doi.org/10.3390/urbansci9110475>

**Copyright:** © 2025 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

## 1. Introduction

### 1.1. Anisotropy and Fragmentation of Space

One of the fundamental principles of geography—and of spatial organization more broadly—is the anisotropy of space, expressed through discontinuities. The space that surrounds us is inherently discontinuous [1] and does not manifest isotropically in any direction, plane, or variable. This condition poses a cognitive challenge for the human mind, which must compartmentalize and structure sensory stimuli—experienced through the body—into a set of cognitive categories [2]. The formation of a category necessarily involves the definition of boundaries that enable its identification and distinction from others. Thus, category and boundary form an inseparable pair: the existence of one inherently implies the presence of the other.

The apprehension of a category is therefore deeply conditioned by the boundaries that constitute it. Indeed, power lies in the capacity to delineate and legitimize such categories through the establishment of boundaries between them [3]. These boundaries become

institutionalized, on the one hand, through the repetition and stabilization of social relations via institutions such as family, education, or religion, which ensure their persistence and reproduction within the social sphere [4]. On the other hand, boundaries are reinforced by coercive mechanisms that safeguard orthodoxy in their definition [5]. Spatial discontinuities unfold continuously and display considerable complexity in terms of legibility, making it necessary to construct cognitive categories to classify them [6]. Consequently, space can be conceived as a mosaic of hierarchically ordered tiles, each representing a homogeneous category that differentiates itself from its surroundings [7].

Borders and boundaries that structure these categories have been widely examined in political and perceptual geography [2]. Nevertheless, it remains relevant to explore how these concepts are mobilized in other branches of the discipline, since the notion of boundary is inherent to geography and manifests itself in virtually every spatial inquiry. This is rooted in the very object of the discipline: understanding spatial phenomena through processes of categorization.

One of the earliest antecedents in the study of these cognitive categories can be traced back to the early twentieth century, with the work of Trowbridge [8]. However, the first consolidated reference is Tolman's Cognitive Maps in Rats and Men [9], in which the author links the experimental behavior of laboratory animals with the orientation and navigational abilities of humans. Piaget and Bärbel's The Child's Conception of Space [10] further explored spatial perception in childhood learning processes. Both studies followed distinct quantitative approaches, which limited the development of deeper ontological reflection. It was not until the crisis of positivism in the late 1950s that phenomenology and existentialism reemerged, bringing personal experience back to the center of analysis [11]. Within this renewed framework, behavioral geography gained prominence, notably through the work of Kevin Lynch [12], along with other contributions addressing environmental images [13] and decision-making processes [14].

From the 1970s onward, systematic efforts were consolidated to understand how spaces are mentally represented, focusing on the distortions that arise between reality and cognitive categorization, the modes of hierarchical ordering, and their relationships with spatial functions and boundaries [6]. The postmodern turn of the 1990s further intensified this interest. While traditional geographical scholarship on limits and barriers had primarily concerned itself with border demarcations and physical obstacles [15–17], postmodern approaches broadened the discussion toward more abstract dimensions such as identity, difference, and alterity [18,19].

### *1.2. Anisotropy in Urban Spaces*

In recent decades, inequality has risen on a global scale [20]. Urban areas and regions now exhibit pronounced forms of inequality, materialized in increasingly complex social divisions of space [21]. These dynamics have reshaped the spatial patterns of European cities [22], giving rise to new social divisions expressed through spatial discontinuities. Within the urban fabric, such discontinuities function as both mechanisms of connection and separation, which may be either material or immaterial [23]. Scholarly attention in this field has primarily focused on two key concepts: urban segregation and urban fragmentation.

Urban segregation refers to a multidimensional phenomenon, though it is often studied through its residential dimension [21]. It is a well-established concept, grounded in extensive research across diverse contexts [24]. Segregation can be understood as the process by which groups cluster in space according to demographic, socioeconomic, ethnic, or cultural characteristics [24,25]. This broad definition allows for considerable variation depending on the variables employed [25]. The multidimensionality of segregation across cities reflects the influence of structural factors such as wealth distribution, housing production and

governance, public policy, migration, and population mobility [26]. Traditionally, studies of segregation have been dominated by quantitative approaches, relying on indices and synthetic indicators that reduce the complexity of spatial relations to single measures [27]. Since the 1990s, however, scholars have begun incorporating perspectives centered on place attachment, non-representational theory, discourse, and everyday life [28,29]. These perspectives have deepened the understanding of how spatial inequality is experienced, moving beyond numerical abstraction toward the lived realities of segregation.

Urban fragmentation, by contrast, is a more diffuse concept, encompassing multiple interpretations and lacking a clearly defined theoretical framework [30–32]. In recent years, it has gained prominence within studies of segregation, largely due to the emergence of new urban patterns characterized by distinct enclaves with limited permeability [33]. This process has been associated with the post-industrial “kaleidoscope city” [34,35], marked by flexible and unstable urban processes and increasingly multipolar spatial structures. Like segregation, fragmentation is expressed across several dimensions and interpreted differently by various authors. Navez-Bouchanine distinguishes five: social, urban-form, socio-spatial, administrative, and lived-space dimensions [36]. Préteceille focuses on social class and its spatial manifestations [37]. Duroudier identifies political, symbolic, functional, socio-spatial, and physical dimensions, examining the variables that define each [23]. Overall, the theoretical corpus of fragmentation remains fluid, with diverse and sometimes competing approaches.

The diversity of these perspectives becomes even more pronounced when viewed across different geographical contexts. Latin American and Western countries have made major contributions to the study of fragmentation, but new centers of research have emerged, notably in China, where the topic has recently gained significant attention. Broadly, three academic traditions can be distinguished in this field: the Anglo-Saxon, the French, and the Ibero-American schools [30], each with its own particularities and conceptual adaptations.

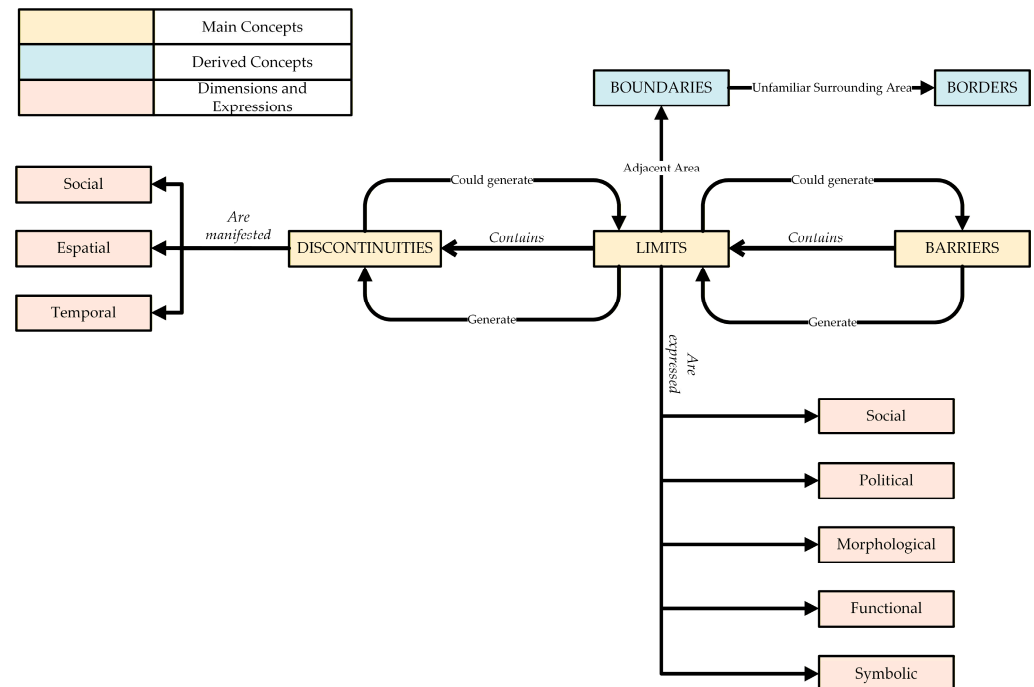
Despite their differences, most authors agree that discontinuity constitutes the fundamental unit of analysis for fragmentation—manifested through fractures or subtle shifts in the variables that shape urban space [23,38,39]. In this article, we build upon three core concepts for measuring urban fragmentation: discontinuities, defined as spatial or temporal changes in variables; limits, understood as the socially constructed dividing lines that articulate spatial units perceived as homogeneous; and barriers, conceived as the physical or symbolic materialization of fragmentation that impede the permeability between such units.

Numerous indicators have been proposed to measure and quantify urban fragmentation. Most existing studies assess fragmentation by comparing the internal characteristics of a spatial unit to those of neighboring units—for example, through spatial autocorrelation measures [40], machine-learning classification of aerial imagery [41], or composite indicators that relate each unit to its surroundings [32,42]. However, relatively few studies have examined discontinuities and limits as primary analytical lenses for understanding spatial fragmentation. In this regard, the works of Duroudier [23] and Ariza & Sorando [43] stand out as pioneering efforts to observe urban segregation and fragmentation through the analysis of discontinuities and their boundaries.

### *1.3. Discontinuities, Limits, and Barriers in Urban Space*

The concepts of discontinuity, limit, and barrier are closely interrelated and develop in an accumulative sequence: barriers cannot exist without limits, and limits, in turn, presuppose a discontinuity that enables their delineation. This does not mean, however, that the creation of a barrier cannot itself produce new limits and discontinuities; rather,

its very existence already implies the presence of the previous ones. It is also important to note that a discontinuity does not necessarily manifest as a limit, nor does every limit entail the existence of a barrier. In some cases, limits—or edges, in Lynch’s terminology—may act as sutures between distinct urban sectors, whereas in others they may constitute actual, impassable walls [12]. To facilitate understanding of this section, see Figure 1.



**Figure 1.** Conceptual model of discontinuities, limits and barriers.

Discontinuities shape both everyday and specific spatial realities, while also acquiring a transcendental dimension, as they condition geographical knowledge a priori [44]. The main theoretical contributions stem from the French school, which posits that a discontinuity represents a locus of change in the value of a given variable [38]. In fragmented space, however, discontinuities cannot be observed in an orderly manner, since they generate heterogeneous spatial configurations that do not necessarily follow a structured logic. In other words, because their expression is continuous across space, their identification depends strongly on the scale of observation and measurement—an aspect that has direct implications for both the results obtained [26] and the sampling unit employed [45]. Depending on the selected scale, details that may appear homogeneous at one level of analysis become distinct at another, shaping our perception of spatial reality. Urban reality and its spatial processes are the result of the interaction between multiple scales, interconnected and dynamic over time [46]. The development of this premise leads us to consider that the categorization of space may behave as a fractal object [47]. This sensitivity to scale therefore emerges as a central methodological challenge for researchers. These discontinuities can be interpreted across three dimensions [23,38]:

- **Social Dimension.** Because the processes of spatial division cannot be reduced to a single criterion, this dimension encompasses social characteristics such as age, socio-professional categories, origin and income. Each of these variables, taken individually and collectively, manifests in distinct ways and can produce its own discontinuities in spatial patterns.
- **Spatial Dimension.** This dimension captures the visible manifestation of fragmentation, where the spatial position and distribution of social groups within the city reveal distinct processes and variations. It encompasses the material dimension of urban

form—expressed through the design, organization, and management of urban spaces—and may, in turn, influence the other dimensions [48].

- **Temporal Dimension.** In this dimension, discontinuities are no longer conceived as fixed snapshots but as evolving processes. They are closely tied to urban dynamics, with their expression changing through emergence, disappearance, or shifts in intensity over time. The persistence of discontinuities can therefore be seen as the result of significant transformations in their social or spatial dimensions.

On the other hand, the question of limits has been extensively examined within behavioural and perceptual geography. In his analysis of cognitive maps, Lynch [12] identified limits as a fundamental component of the cognitive structure through which urban space is perceived, alongside nodes, districts, paths, and landmarks. He defined limits as linear elements where two phases meet and continuity is disrupted.

Although the notions of limit and boundary are closely related, they may be understood differently: the limit can be conceived as the dividing line that separates distinct territories or spaces, whereas the boundary refers to the zone adjacent to the limit—an immediate area where social dynamics and the landscape are shaped by its presence [49]. The existence of the limit thus defines the different categories of a geographical object [50], marking their beginning and end and determining what does or does not belong to a given geographical entity.

From the perspective of perceptual geography, the border is understood as the surrounding area at the threshold of the unknown [13]. This notion resonates with certain processes of urban regeneration and gentrification [51], in which areas are valorized in the market precisely through their association with the unknown, the wild, or the exotic.

Unlike discontinuity, which exists in and of itself—though it may be interpreted differently depending on context [48]—limits are inherently social and political constructs. Power, exercised through various institutions, determines and legitimizes the line that defines different categories [3], both cognitively and spatially. As with discontinuities, scholars have emphasized the multidimensionality of limits. In this study, we understand the limit as the locus where discontinuity becomes manifest and can therefore be quantified in a structured way. Duroudier [23] classifies these manifestations into five categories:

- **Social.** Corresponding to patterns of residential segregation, this category relates directly to the logic of spatial differentiation along primarily social axes such as origin, education level, and income.
- **Morphological.** This category corresponds to the physical materialization of fragmentation. It includes spatial features such as topography, railways, highways, rivers, parks, and cemeteries, which often serve as the basis for residential separation strategies.
- **Political.** This category corresponds to the limits that define administrative units such as sectors, neighborhoods, and districts, within which specific territorial and political strategies are implemented.
- **Functional.** This category refers to limits that create gaps in mobility or reduce permeability between the different units that compose the urban fabric.
- **Symbolic.** This category encompasses the perceptions and representations that construct limits and shape residents' spatial practices.

Barriers are distinguished primarily by the obstacles they create to movement and interaction. These elements display varying degrees of permeability and serve multiple functions: restricting free passage, denying access to certain spaces, impeding the formation of networks, or obstructing the integration of different social groups [52]. They can be understood as the extreme materialization of spatial rupture, simultaneously categorizing and disconnecting urban spaces. This process is often accompanied by dynamics of threat and fear, which reinforce an “us–them” distinction essential to the persistence of such

barriers, whether spatial or symbolic [53]. Barriers constitute the principal fragmenting agents of urban space, and their effects often extend beyond the materiality of the built environment to encompass cognitive and symbolic dimensions, such as stigmatization and social labeling [54]. This materialization has been the most widely studied manifestation of spatial fragmentation, with extensive research on enclosures and gated communities across diverse geographical contexts [39,55–57].

Taken together, discontinuities, limits, and barriers interweave within a dynamic that can be interpreted through Deleuzian assemblage theory. Viewed as part of a processual framework, these concepts enable an analysis attuned to concrete materialities while simultaneously engaging with multiple temporalities, the agency of both objects and individuals, and the interaction between different spatial scales [58]. The study aims to develop and test a transferable index (RII) to quantify urban fragmentation through boundary discontinuities. Specifically, it seeks: (1) to identify the intensity of socio-spatial ruptures in the city of Lleida; (2) to classify the nature of limits through multivariate analysis; and (3) to evaluate the methodological potential of RII for comparative research. We hypothesize that urban fragmentation manifests through heterogeneous patterns of discontinuity not reducible to a simple center–periphery structure.

## 2. Materials and Methods

### 2.1. Research Objectives and Study Area

The aim of this article is to develop a new methodological framework for quantifying fragmentation processes and their associated ruptures. The objective is to design a methodology capable of identifying and measuring these ruptures in urban space through the integration and operationalization of multiple variables, without the need for prior assumptions about their scale of observation or unit of measurement. This approach rests on the premise that urban fragmentation is inherently multidimensional and therefore requires analytical tools capable of capturing this complexity.

With regard to socio-spatial fragmentation, the method spans different dimensions to account for both social and physical forms of separation, often driven by local transformations associated with broader processes of metropolization, globalization, and socio-technical and productive change [33]. In this paper, we adopt the conceptualization proposed by González, Parreño, and García [31], who link fragmentation to the rise of inequality and the decline of territorial permeability between differentiated social groups.

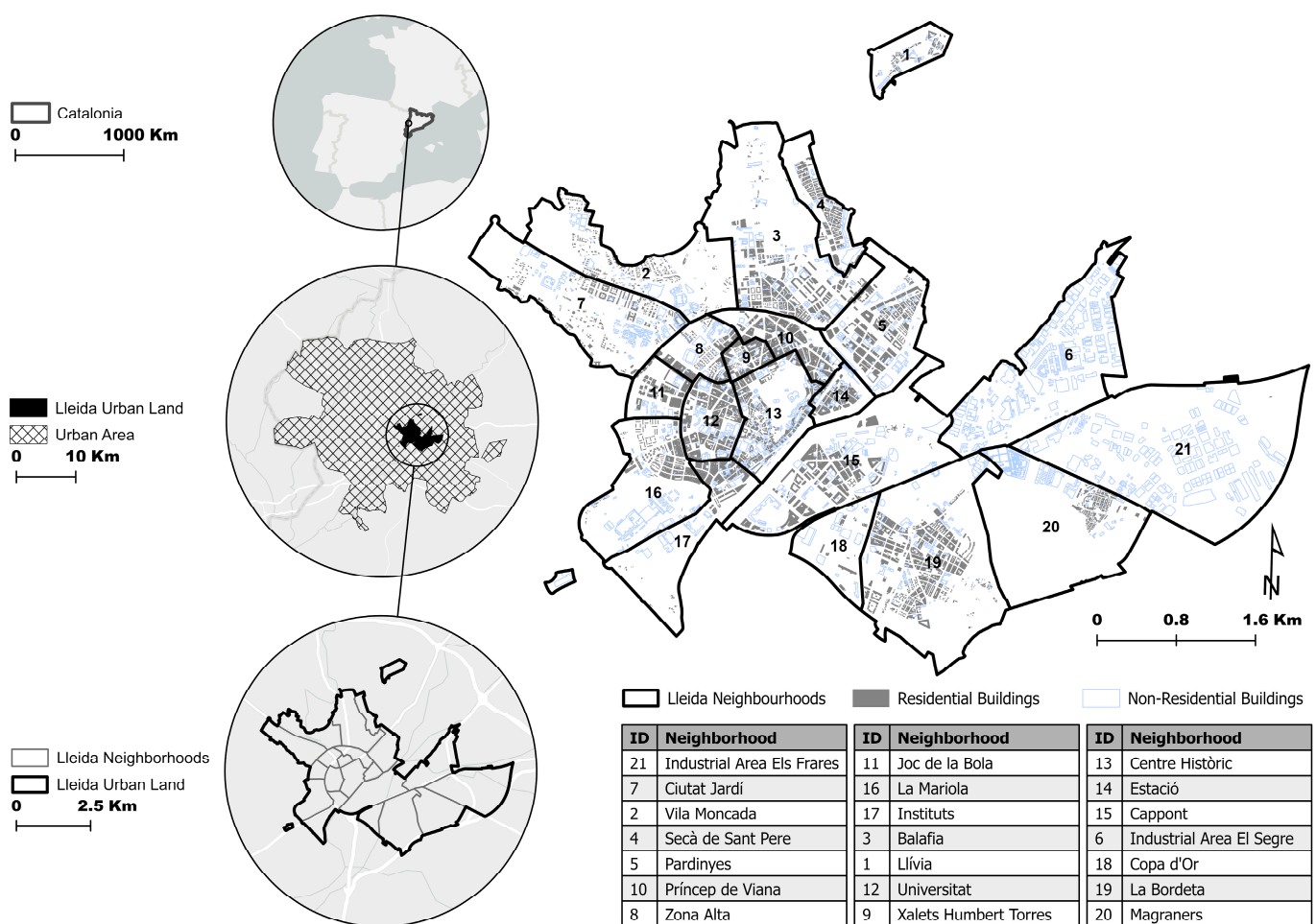
The proposed methodology is based on the intensity of rupture produced by variations in variable values along the adjoining limits of census tracts. The magnitude and accumulation of these ruptures provide an initial indication of fragmentation, which can later be explored at broader scales. We assume that when differences between contiguous sectors are substantial—whether due to discontinuities in a single variable or the combined effect of several—these may give rise to barriers of varying permeability [57], generating structural ruptures in the urban fabric [36]. The calculations were performed through the construction of models using ModelBuilder in ArcGIS Pro (version 10.8.2).

The methodological basis draws on the approach developed in *Cauces socioespaciales: la segregación y el arraigo en Madrid* [43], which introduced a procedure to measure income inequality between neighbouring districts in Madrid. For the present study, that formulation has been adapted to address several limitations.

First, the revised version establishes a methodology that reflects the multidimensional nature of limits. In the original index, raw values were used without standardization, preventing the inclusion of other variables. Second, the method aims to enable quantitative comparisons between urban spaces while accounting for their specific characteristics. Third, it addresses the underrepresentation of large adjacent income differences in the

indicator proposed by Sorando and Ariza, which tended to underestimate cases of sharp spatial disparity.

The study area is the city of Lleida (Figure 2), a medium-sized inland city in Spain with 144,878 inhabitants (2024) [59]. It covers an area of 212.3 km<sup>2</sup> and comprises three population settlements: the city of Lleida and the two decentralized municipal entities of Raïmat and Sucs. For the application of the proposed methodology, only the urban and developable land of the city's core area was selected, covering 21.64 km<sup>2</sup>. The selection of this case study is particularly relevant due to its condition as a compact, medium-sized city [60]—a type of urban context in which social distance cannot easily be expressed through spatial distance, and where segregation patterns tend to be shaped by highly local explanatory factors [61]. For the calculation of two variables related to average income, we used the urban area delineation proposed by Andrés, Bellet, and Cebrián [62], based on variables such as urban mobility and peripheral construction cycles associated with the metropolitan core.



**Figure 2.** Location and spatial structure of the study area.

In cities of this kind—characterized by a compact and continuous urban fabric combined with a relatively limited spatial extent—there is a greater likelihood that different socioeconomic groups coexist in close proximity [23,57]. In such contexts, social distance, when present, is not primarily expressed through physical separation. Instead, other spatial mechanisms emerge to articulate social distance, both through processes of segregation—resulting from the concentration of specific social strata—and through the creation of barriers that seek to contain them [57].

## 2.2. Selection of Variables

A set of six variables has been selected:

- % of population born abroad
- % of population without compulsory education
- % of population with higher education
- % of high-income population, with incomes above 160% of the average income of the urban area
- % of low-income population, with incomes below 60% of the average income of the urban area
- Mean income per consumption unit

All variables correspond to the year 2021, with data drawn from the Population and Housing Census and the Income Distribution Atlas of the Spanish National Statistics Institute (INE). Their inclusion follows the recommendations of several scholars who highlight the importance of these indicators for analyzing and understanding residential segregation processes [24,40].

## 2.3. Calculation of the Rupture Intensity Index (RII)

First, for each variable, the difference between contiguous census tracts (SSCC) was calculated, and the resulting value was assigned to the boundary separating the corresponding sections. In total, 217 limits were identified within the study area. Subsequently, the results for all variables were standardized using a robust standardization procedure to obtain Z-scores. The expression is as follows:

$$x_i = x_1 - x_2$$

$$x_1 - x_2 \in \Omega$$

where  $x_i$  is the difference between census tracts at limit  $i$ ,  $x_1$  is the value of the variable in census tract A (maximum) and  $x_2$  is the value of the variable in census tract B (minimum), within the overall sample universe ( $\Omega$ ).

Then:

$$Z_i = x_i - \bar{x} / \text{IQR}(x)$$

where  $\bar{x}$  is the arithmetic median of the variables in the study area,  $\text{IQR}(x)$  is the interquartile range of the variable, and  $Z_i$  is the Z-score of the variable at limit  $i$ .

The advantage of the robust standardization procedure—which uses the interquartile range and the median instead of the standard deviation and the mean—lies in its ability to minimize the influence of outliers in the data distribution [63]. Standardization ensures the comparability of variables that differ in range and scale.

Subsequently, a principal component analysis (PCA) was performed using the six standardized variables to retain only those with a significant contribution to the overall structure of the dataset. The PCA was conducted using eigenvalues greater than 0.4 and applying a Varimax rotation. The results are shown in Table 1. The 0.4 threshold ensures the retention of variables with substantial communality following standard PCA criteria [64]. The K-medoids algorithm was chosen for its robustness to outliers and its suitability for non-Euclidean socio-spatial data.

**Table 1.** Results of the rotated component matrix.

| Variable                                     | PC1   | PC2   | PC3   | Uniqueness |
|----------------------------------------------|-------|-------|-------|------------|
| % of population with higher education        | 0.936 |       |       | 0.058      |
| % of high-income population                  | 0.903 |       |       | 0.094      |
| % of population without compulsory education | 0.893 |       |       | 0.171      |
| Mean Income per Consumption Unit             | 0.834 |       |       | 0.153      |
| % of foreign-born population                 |       | 0.956 |       | 0.031      |
| % of low-income population                   |       |       | 0.896 | 0.000      |

Source: authors' elaboration.

As indicated in Table 1, three principal components were extracted, providing overall coherence to the model. Among them, two components account for three main groups of explanatory variables: (i) the percentage of foreign-born population, (ii) the percentage of low-income population, and (iii) a third group comprising variables related to income and educational attainment.

Based on the results obtained from the principal component analysis, the following variables were retained for further analysis:

- Percentage of population with higher education, as it is the variable with the highest extraction value for Component 1.
- Percentage of foreign-born population, as it alone structures Component 2.
- Percentage of low-income population, as it alone structures Component 3.

The selection of these variables aligns with recent research on urban segregation in the city of Lleida. It is consistent with the findings of Bellet et al. [61], who identified housing tenure, place of origin, life course, and social status as key structuring factors of urban segregation processes in Lleida.

To calculate rupture intensity, the mean Z-score of the selected variables was computed, assigning equal weight to each. Depending on the research objective, different weighting schemes could be applied to emphasize specific variables. In this study, the resulting indicator is the Rupture Intensity Index (RII), calculated as the mean of the standardized values of the selected variables.

$$RII = \sum Z_i / n$$

where RII is the Rupture Intensity Index,  $\sum Z_i$  is defined as the sum of Z-scores across the selected variables and  $n$  is the count of selected variables. Thus, the general expression of the procedure is described as the average of the robust Z-scores calculated at the limits, based on the differences between census tracts across the entire sample universe for the set of variables. It is expressed as follows:

$$RII = \sum (((x_1 - x_2) - \bar{x}) / IQR(x)) / n$$

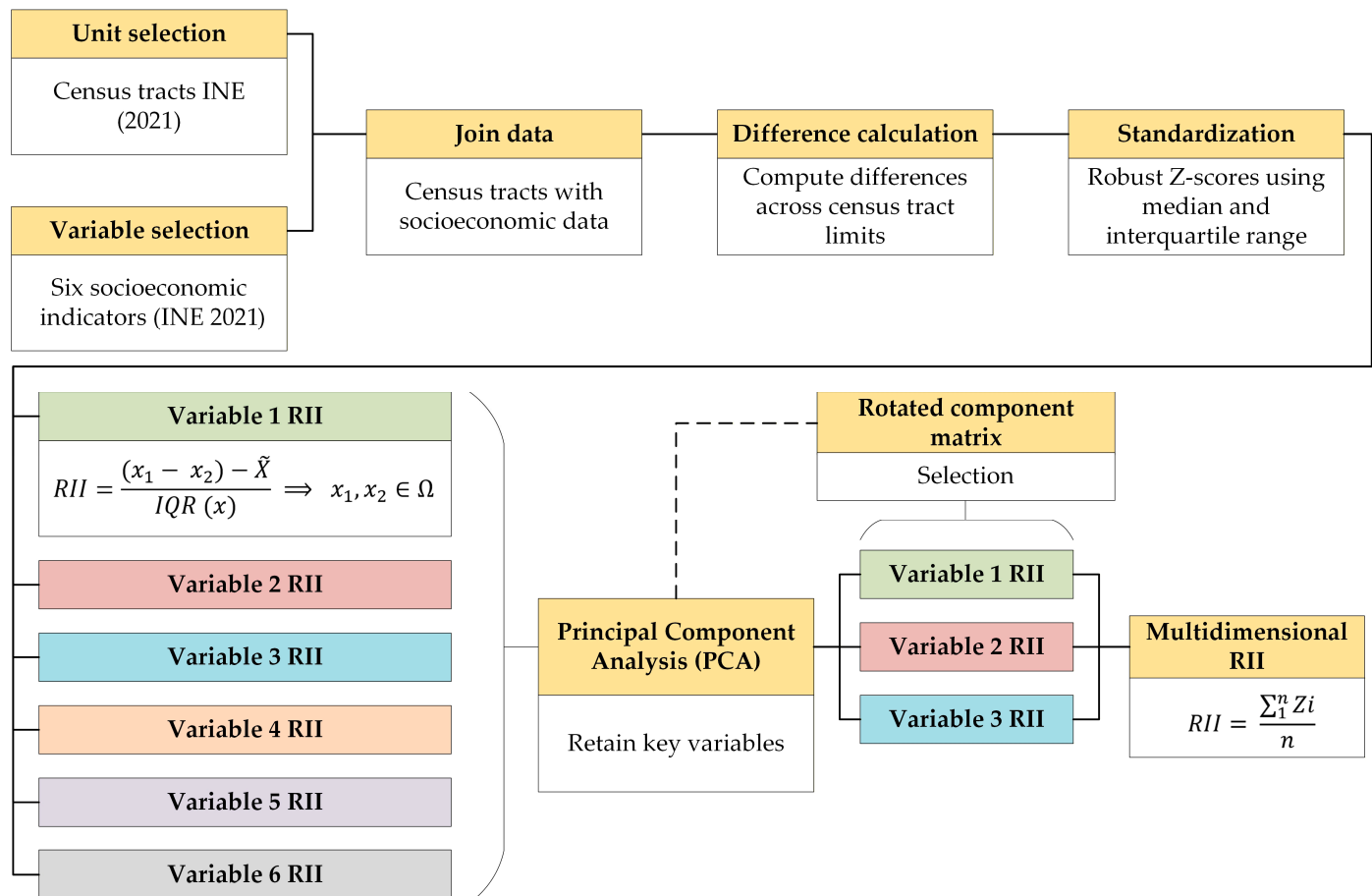
$$x_1 - x_2 \in \Omega$$

To enhance the readability of the cartographic outputs, the robust standardization method was also applied to the selected census tract variables. This approach facilitates clearer interpretation and visual comparison across the maps. In this case, however, the variables are not absolute—as they are for the limits—and their sign in the composite mean must be adjusted depending on whether they indicate an advantaged or a disadvantaged sector (Table 2). To facilitate understanding of the methodological workflow, see Figure 3.

**Table 2.** Determination of the average Z-score sign for census tracts.

| Trend in Z-Score Values    | % of Population with Higher Education | % of Foreign-Born Population | % of Low-Income Population |
|----------------------------|---------------------------------------|------------------------------|----------------------------|
| Increase in the Z-score    | Advantaged sector                     | Disadvantaged sector         | Disadvantaged sector       |
| Decrease in Z-score values | Disadvantaged sector                  | Advantaged sector            | Advantaged sector          |

Source: author's elaboration. Used only for the calculation of the census tract averages.

**Figure 3.** Methodological workflow for calculating and applying the Rupture Intensity Index (RII).

#### 2.4. Characterization of Limits

Finally, because the global RII is calculated as the mean of the Z-scores of the selected variables, it is possible to conduct a cluster analysis of the limits that display similar Z-score patterns. A multivariate clustering technique was applied using the K-medoids algorithm. This approach groups limits exhibiting comparable discontinuities into the same cluster, enabling the characterization of the nature and multidimensionality of urban fragmentation processes.

The choice of five clusters was determined by the configuration that best corresponded to the Calinski–Harabasz pseudo-F score (Figure 4), which represents the ratio of between-cluster variance to within-cluster variance and thus reflects both the similarity within groups and the differences between them [65]. This approach preserves the intrinsic structure of the data while demonstrating the stability of the clustering solution in the application of the RII.



**Figure 4.** Calinski-Harabasz pseudo-F statistic results for different cluster aggregations.

### 2.5. Comparative Methodological Positioning of RII

A variety of quantitative approaches have been developed to examine urban fragmentation and segregation. Much of the existing literature relies on spatial autocorrelation indices, which measure proximity under the assumption that spatially closer units tend to exhibit greater similarity. Yet these tools have well-known limitations: they depend on the size and shape of spatial units, lack a displacement parameter, and assume a single, typical spatial scale—an approach that proves inadequate for analyzing multiscalar or fractal urban phenomena [66].

Traditional segregation and dissimilarity indices, though widely used, are also constrained by their non-spatial nature, which limits their relevance in fragmented urban contexts. Without incorporating spatial relationships, they suffer from analytical issues such as the checkerboard problem and the modifiable areal unit problem (MAUP) [67].

Composite indicators—such as the Residential Vulnerability Index [68] or the Urban Vulnerability Index [69]—allow multiple variables to be integrated into the analysis, but they raise methodological challenges regarding variable definition and selection. Weak conceptual framing can distort the entire process, while statistical bias or imputation errors may introduce hidden uncertainty [70].

In this sense, the RII represents a significant departure from conventional approaches. Although it remains sensitive to the MAUP and to variable selection, focusing on limits as the unit of observation helps to overcome several methodological drawbacks of areal analyses, including the checkerboard problem. The use of robust standardization further reduces the influence of extreme values and enhances the detection of both gradual and abrupt spatial transitions. By incorporating adjacency and directionality, the RII enables discontinuities to be measured precisely where they occur—at the limits—providing a more nuanced understanding of socio-spatial fragmentation. Table 3 illustrates the main contributions of this section.

**Table 3.** Synthesis between theoretical concepts and limit topology obtained from cluster analysis.

| Approach                                          | Focus Analysis                          | What It Measures                                  | Main Limitation                                                       | How RII Differs/Improves                                                                             |
|---------------------------------------------------|-----------------------------------------|---------------------------------------------------|-----------------------------------------------------------------------|------------------------------------------------------------------------------------------------------|
| Spatial autocorrelation indices (e.g., Moran's I) | Statistical units (e.g., census tracts) | Degree of dissimilarity between neighboring areas | Emphasizes spatial clustering/Ignores internal or limit heterogeneity | RII measures discontinuity along limits, capturing local rupture lines instead of spatial similarity |
| Segregation indices (e.g., Dissimilarity Index)   | Population groups within units          | Separation of social groups across space          | Aggregates populations within fixed zones/Weak spatial context        | RII incorporates adjacency and directionality of contrasts between neighboring tracts                |

Table 3. Cont.

| Approach                                          | Focus Analysis                  | What It Measures                         | Main Limitation                                                                     | How RII Differs/Improves                                                                         |
|---------------------------------------------------|---------------------------------|------------------------------------------|-------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------|
| Composite indicator (e.g., vulnerability indices) | Aggregated unit-level data      | Multidimensional conditions within areas | Average internal values that can mask transitions                                   | RII uses robust standardized differences between tracts, revealing abrupt or gradual transitions |
| Rupture Intensity Index (RII)                     | Limits between contiguous areas | Intensity of socio-spatial discontinuity | Requires detailed data and variable selection/It's highly sensitive to scale factor | Provides a boundary-based, comparable, multidimensional measure of fragmentation                 |

Source: author’s elaboration.

3. Results

3.1. The Nature of Urban Fragmentation in the City of Lleida

The analytical process developed through the proposed methodology allows the identification of limits that reveal the presence of discontinuities—an initial indication of socio-spatial fragmentation—applied here to the city of Lleida. The cartographic results are presented in Figure 5. The distribution of Z-score intervals is organized into quintiles for rupture intensity and into deciles for the distribution of variables across census tracts.

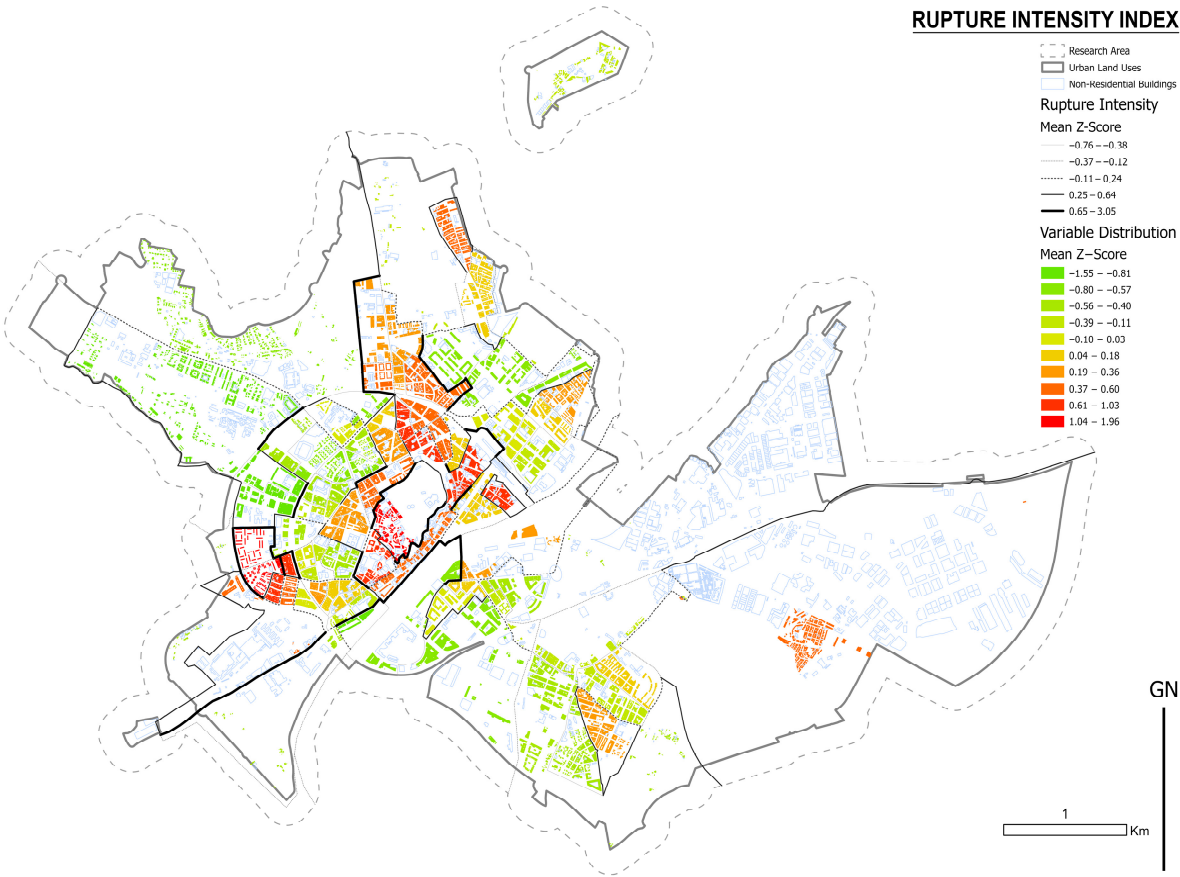


Figure 5. Spatial distribution of RII in Lleida.

In the case of Lleida (Figure 5), the intensity of limits is greatest where the extremes of socioeconomic variables—income, educational attainment, and foreign-born population—come into contact. Rather than a clearly dualized structure restricted to a few points of direct contact between advantaged and disadvantaged sectors, the results suggest that when social space is translated into physical space, the classic center–periphery model loses

explanatory strength. Instead, a more tessellated pattern emerges, composed of irregularly interlocking urban pieces. This finding indicates that the fragmented city model more accurately reflects Lleida's socio-residential structure—a pattern also observed in larger cities, as noted by Van Kempen and Porcel [22,40].

The analysis also shows that sectors which might initially appear relatively homogeneous (La Mariola, Centre Històric, Ciutat Jardí) exhibit pronounced internal limits. This may be related to the scale of observation and the sampling unit employed, as the RII is particularly sensitive to these parameters. In any case, the results reveal that discontinuities and rupture processes extend beyond the predefined categories established by the researcher, and that spatial units which seem homogeneous at first may, in fact, contain significant internal discontinuities.

Urban fragmentation processes thus extend across the entire urban fabric, producing the kaleidoscopic pattern visible in Figure 5. However, their manifestation is not limited to abrupt fractures: in some areas, they unfold more gradually and progressively. Overall, a clear tendency is observed whereby intense rupture processes concentrate in the urban core and expand outward along different axes, while peripheral sectors tend to display greater homogeneity. Factors such as the coexistence of distinct urban fabrics, recent urban growth, and morphological differentiation may explain these varied fragmentation dynamics.

In summary, the map not only reveals the spatial location of major discontinuities but also provides a structured understanding of the spatial logic of urban fragmentation, highlighting the role of limits as privileged sites for its observation.

### 3.2. *Fractures and Gradients in the Expression of Fragmentation in a Medium-Sized City*

In the case of Lleida, two main expressions of discontinuities can be observed, following the approach proposed by François [38]:

- Fracture lines, characterized by limits of deep intensity.
- Gradient areas, where discontinuities are expressed more gradually, as subtle permutations [39] that serve as transitions between two socioeconomic extremes.

Fracture lines are primarily articulated at points of contact between the most advantaged and disadvantaged sectors, or, where the rupture is less pronounced, through a sequence of transitional steps marking the gradient between them. The highest RII values correspond to the first case, notably around the neighborhood of La Mariola, located in the southwest of the city. The urban fabric of this neighborhood consists mainly of housing estates promoted by the *Obra Sindical del Hogar* and built between 1941 and 1974 [57]. Its social composition is characterized by a high concentration of low-income residents and the lowest levels of higher educational attainment in the city. In some census tracts, there is also a significant proportion of foreign-born residents. The most pronounced fracture line occurs along the limit separating this neighborhood from Joc de la Bola, one of the city's most advantaged areas, which exhibits socioeconomic characteristics diametrically opposed to those of La Mariola. Here, the most extreme RII values are recorded, reaching 3.05 Z.

Strong limits are also observed in the Centre Històric, another area with a high concentration of residents showing unfavorable socioeconomic indicators. These fracture lines are particularly intense where the Centre Històric tracts border Zona Alta, an advantaged neighborhood that forms part of the city's high-income axis extending along the Huesca road. Another favored area is found in the Copa d'Or sector, linked to the broader urban fabric through new housing developments. Located between the historic neighborhoods of Cappont and La Bordeta, it also exhibits discontinuities with its surroundings, though less intense than those observed in the Centre Històric or La Mariola.

In the second case, *gradient areas* are defined by a more gradual weakening of limits, expressed as a stepwise progression of discontinuities generated by the analyzed variables. This pattern can be observed along the axis extending from the Centre Històric toward Joc de la Bola and Ciutat Jardí, showing a gradual decline in indicators associated with disadvantaged sectors as one moves toward advantaged ones. Similar diffusion processes occur along the Vielha road axis but in the opposite direction—from advantaged to disadvantaged sectors. This axis is flanked by recently developed neighborhoods characterized by middle- to upper-income residents, relatively high educational levels, and a low percentage of foreign-born population. Another example of such gradient areas extends southeast from La Mariola. As shown in Figure 5, unlike the sharp fracture at its northern limit with Joc de la Bola, the discontinuity here unfolds more progressively, resembling the pattern along the Centre Històric–Joc de la Bola axis. In Lleida, these gradual transitions appear to be associated with the age and morphological quality of housing, as more recent urban growth correlates with higher income and educational levels.

Finally, the lowest RII values correspond to urban sectors exhibiting relative homogeneity and continuity in their variable patterns. The minimum value ( $-0.76 Z$ ) occurs in the Capped neighborhood, specifically in the Zafer blocks, where the limit lies between two public housing estates that effectively form a single unit. Similarly, the limits between Ciutat Jardí, Zona Alta, and Joc de la Bola, as well as those in Copa d'Or, display these characteristics. These tracts share a comparable construction morphology, as they are expansion areas developed during similar periods. This relatively homogeneous urban fabric likely explains why the socioeconomic discontinuities analyzed are not strongly expressed along these limits.

### 3.3. Characterization of Limits and Their Expression in the City of Lleida

The selection and characterization of variables through PCA enables the identification of those that exert the greatest influence on the manifestation of discontinuities along the limits. This, in turn, allows each limit to be characterized according to the dimension exhibiting the highest intensity. These results indicate that processes of urban fragmentation do not depend on a single variable, nor can they be explained by one alone. Rather, they are articulated through a constellation of discontinuities of various kinds, which manifest at specific limits according to their contextual conditions.

When applying multivariate clustering using the K-medoids method, the following clusters were obtained (Figure 6).

First, we identify a group of limits characterized by below-average rupture intensity. These correspond to boundaries separating urban units with relatively homogeneous features and similar socioeconomic profiles.

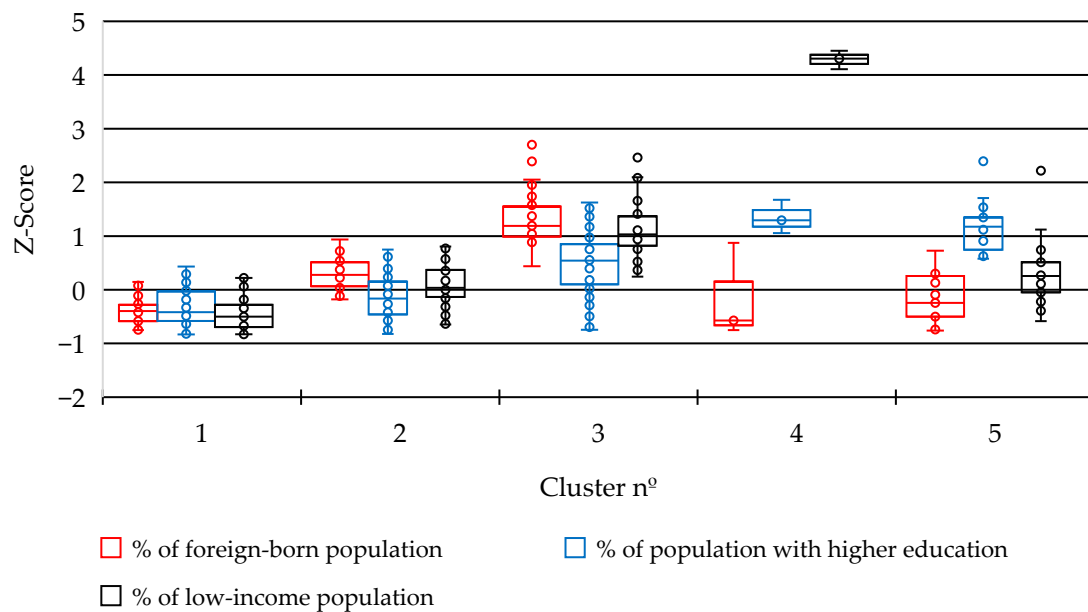
Second, there is a group of limits situated around the average, with a slight influence from population origin. As shown in Figures 5 and 7, these limits tend to articulate the gradual transitions observed in gradient areas.

Third, we identify limits with high rupture values, mainly associated with differences in origin and income. These are located along the fracture lines that structure urban fragmentation.

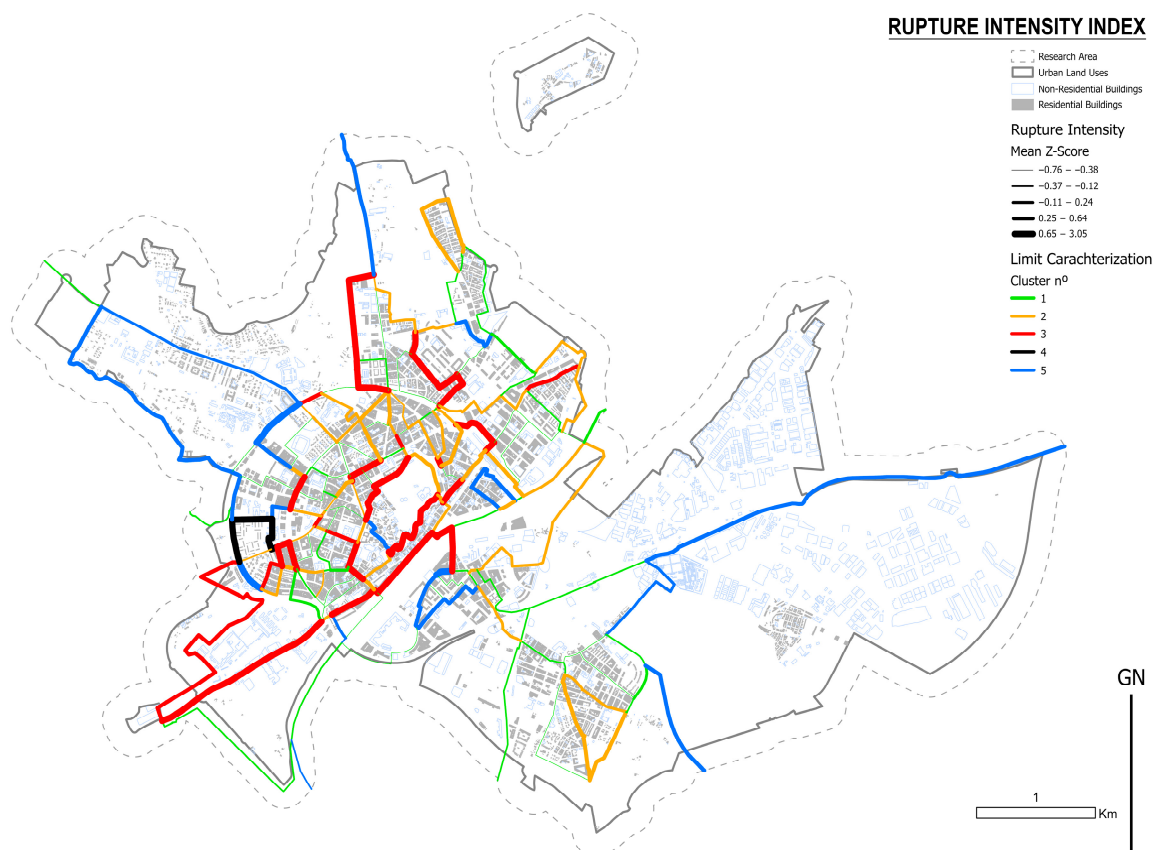
The fourth group includes the most intense fracture lines, explained by large disparities in income and higher educational attainment, though not in population origin. These limits are concentrated in the northern sector of La Mariola, constituting the most significant socio-residential rupture in the city.

Finally, a fifth group is characterized by differences in higher education levels. These limits are primarily located within advantaged areas, revealing processes of horizontal segmentation among social strata in spaces that might otherwise appear relatively homoge-

neous. As illustrated in Figure 7, they are found between Ciutat Jardí, Joc de la Bola, and Zona Alta.



**Figure 6.** Z-score of characterization of limits through multivariate clustering.



**Figure 7.** Characterization of limits through multivariate clustering.

## 4. Discussion

### 4.1. The Study of Urban Fragmentation Through Limits

As discussed in Section 2, most studies that have sought to measure and quantify urban fragmentation have done so by focusing on the content of spatial units rather than on

the discontinuities expressed at their limits. Yet, urban fragmentation cannot be properly understood without considering the role of limits. Delimitation is a fundamental act in the categorization of space, as it enables the identification of homogeneous units in contrast to others. Limits are therefore not merely lines drawn on the territory but social and political constructions that reveal the capacity and agency of both agents and objects.

Limits also possess an epistemological dimension, conditioning the very possibility of cognitively apprehending spatial categories. The perception of a neighbourhood, a centrality, or a periphery is mediated by the presence of a limit—whether social, morphological, functional, political, or symbolic. At the same time, limits have a methodological dimension, as they represent the observable points where fragmentation becomes measurable. Discontinuities, which are continuous and multiscalar phenomena, gain intelligibility when they manifest at a specific limit. It is at these points that the researcher can detect ruptures in the variables that shape urban space.

Moreover, limits perform a dynamic function in fragmentation processes. They are not static entities but mobile constructions that may act either as sutures or as urban scars. This duality is crucial to understanding the heterogeneity of fragmentation: where one limit organizes the coexistence of differences, another may reinforce exclusion and segregation. Approaching urban fragmentation through the lens of limits therefore opens new avenues for understanding this complex phenomenon that characterizes twenty-first-century cities.

#### *4.2. Potentialities and Limitations of the Proposed Method*

The methodology proposed for calculating the Rupture Intensity Index (RII) presents several advantages over existing approaches. The index provides a quantitative perspective on urban fragmentation processes while preserving their multidimensional character. Because it is based on variables standardized through a robust procedure, it enables comparison across different spaces and contexts, minimizing potential biases that may arise when contrasting structurally diverse urban areas. This is achieved by performing the standardization with reference to the selected urban area, thereby avoiding distortions that might occur, for example, when comparing an industrial city with one oriented toward tourism or services. The indicator thus allows for meaningful comparison across different urban contexts.

Another key strength of the method lies in its use of principal component analysis (PCA), which facilitates the classification and examination of the nature of limits. While limits are often treated as uniform categories, the multidimensionality highlighted in the theoretical framework is captured by the indicator, allowing limits to be classified or typified according to the dominant dimensions that manifest with greater intensity. In other words, the RII enables the systematic classification of discontinuities and their expression in limits based on the variables that define them.

However, the indicator is highly sensitive to both the variables analyzed and the scale of study. In this article, census tracts were chosen as the basic unit of analysis, as they represent the smallest statistical unit for which the Spanish National Statistics Institute provides data for the selected variables. Nonetheless, the method can be applied to other spatial scales or boundary designs (e.g., municipalities, districts, grid or hexagonal meshes). The indicator therefore allows for cross-scale comparison, although its sensitivity to the chosen scale of observation must be taken into account. In addition, since the analysis was conducted at the census tract level to capture fine-scale spatial discontinuities, it is important to acknowledge the potential influence of the modifiable areal unit problem (MAUP) and the inherent limitations in the accuracy and consistency of census data at this micro-spatial scale.

Finally, an important limitation lies in the variables used in the analysis. The indicator is particularly sensitive to the selection of variables, as it is designed to detect and express the discontinuities of those variables at limits. Consequently, the results may vary substantially depending on the dataset employed. In our case, we selected variables commonly associated in the literature with processes of residential segregation. Further research and theoretical refinement are needed to identify and validate additional variables that influence urban fragmentation processes beyond the strictly residential dimension. Beyond its social dimension, urban fragmentation also manifests in the ecological sphere through the loss of territorial cohesion and environmental resilience. Recent methodological approaches, such as Córdoba and Camerin [71], propose the assessment of ecological capacity based on the European MAES framework, linking ecosystem services and spatial planning. Integrating the detection of socio-spatial ruptures with the evaluation of ecological discontinuities would allow a more comprehensive understanding of urban fragmentation as a combined social–ecological process.

## 5. Conclusions

This article has presented a quantitative methodological contribution for identifying ruptures and measuring the intensity of different variables, aimed at operationalizing the study of intra-urban socio-spatial fragmentation. Although further work is needed to consolidate a robust theoretical and methodological field of its own, this research seeks to advance the identification and measurement of ruptures as a means of detecting potential fragmentation processes. To this end, we have introduced an index that calculates the rupture intensity of variable values along the limits of adjacent areas—represented here by census tracts. The intensity and accumulation of ruptures along these limits provide an initial indication of spatial fragmentation. When ruptures between contiguous sectors are significant or cumulative, they may give rise to more or less permeable barriers, generating new structural discontinuities in the urban fabric. These structural limits and discontinuities—defined by intense and cumulative ruptures—allow the identification of distinct “fragments” and, together with other approaches, contribute to advancing a comprehensive characterization of the fragmentation process.

Methodologically, the proposal addresses several limitations identified in previous indicators of rupture intensity, particularly through the incorporation of multiple variables that capture the multidimensionality of socio-spatial fragmentation. Its standardized procedure also resolves the challenge of integrating variables measured on different scales and units.

Furthermore, because the calculation is standardized within a defined spatial unit (whether a city, urban area, or region), the index enables comparison across different contexts, reducing potential biases. This not only allows for typological comparison but also facilitates multiscale analysis. As such, the index represents a potentially valuable tool for comparative urban policy design, applicable to both medium-sized cities and metropolitan areas, as well as across different national contexts.

Finally, the method allows for a more detailed examination of the composition and nature of limits using additional statistical classification techniques. These help to better observe and interpret spatial rupture processes, contributing to a richer understanding of the multidimensionality through which fragmentation manifests.

The methodology proposed here constitutes a further contribution to the study of urban fragmentation through the lens of limits. Two objectives remain essential for consolidating this line of research: first, to expand the methodology by incorporating additional variables (dimensions) and scales, and second, to develop a shared and stable theoretical framework around key concepts, enabling the construction of suitable instruments for its

study and measurement. Our findings reveal that the most intense socio-spatial fractures concentrate at the interfaces between high- and low-income sectors, particularly around La Mariola and Joc de la Bola. From an urban policy perspective, the RII can support planners in prioritizing interventions along these rupture corridors, promoting mixed-housing strategies, improved accessibility, and increased spatial permeability as key drivers of territorial cohesion. Moreover, the international transferability of this approach—based on statistical data available in many countries—opens the possibility of conducting transnational and longitudinal comparisons, thereby enriching both academic debate and practical applications in spatial and urban planning.

**Author Contributions:** Conceptualization, J.L. and C.B.; methodology, J.L.; software, J.L.; validation, J.L. and C.B.; formal analysis, J.L. and C.B.; investigation, J.L. and C.B.; resources, C.B. and J.L.; data curation, J.L.; writing—original draft preparation, J.L. and C.B.; review & editing, J.L. and C.B.; visualization, J.L. and C.B.; supervision, C.B.; project administration, C.B.; Funding acquisition, C.B. All authors have read and agreed to the published version of the manuscript.

**Funding:** The results of this research are part of the project funded through the public call of the Spanish Ministry of Science and Innovation (MCIN): Socio-spatial Segregation and Geographies of Everyday Life in Medium-Sized Spanish Cities and Their Urban Areas (PID2021-124511NB-C21).

**Data Availability Statement:** All primary data used in this study can be found in the Population and Housing Census of the Spanish National Statistics Institute (INE) and in the Atlas of Household Income Distribution of the Spanish National Statistics Institute. Links: Population and Housing Census: <https://www.ine.es/Censo2021/Inicio.do?L=0> (accessed on 24 September 2025). Atlas of Household Income Distribution: [https://www.ine.es/dyngs/INEbase/es/operacion.htm?c=Estadistica\\_C&cid=1254736177088&menu=resultados&secc=1254736195774&idp=1254735976608](https://www.ine.es/dyngs/INEbase/es/operacion.htm?c=Estadistica_C&cid=1254736177088&menu=resultados&secc=1254736195774&idp=1254735976608) (accessed on 24 September 2025).

**Conflicts of Interest:** The authors declare no conflicts of interest.

## Abbreviations

The following abbreviations are used in this manuscript:

|      |                              |
|------|------------------------------|
| RII  | Rupture Intensity Index      |
| MAUP | Modifiable Area Unit Problem |

## References

1. Di Méo, G.; Veyret, Y. Problématiques, enjeux théoriques et épistémologiques pour la géographie. In *Limites et Discontinuités en Géographie*; CDU SEDES: Paris, France, 2002; pp. 5–26.
2. Jones, R. Categories, borders and boundaries. *Prog. Hum. Geogr.* **2009**, *33*, 174–189. [\[CrossRef\]](#)
3. Bourdieu, P. *Language and Symbolic Power*; Thompson, J.B., Ed.; Polity Press: Cambridge, UK, 1991.
4. Berger, P.L.; Luckmann, T. *The Social Construction of Reality*; Penguin Books: London, UK, 1966.
5. Foucault, M. *Discipline and Punish: The Birth of the Prison*; Vintage Books: New York, NY, USA, 1995.
6. Mark, D.M.; Freksa, C.; Hirtle, S.C.; Lloyd, R.; Tversky, B. Cognitive models of geographical space. *Int. J. Geogr. Inf. Sci.* **1999**, *13*, 747–774. [\[CrossRef\]](#)
7. Tversky, B. Cognitive Maps, Cognitive Collages, and Spatial Mental Models. In *Spatial Information Theory*; Springer: Berlin/Heidelberg, Germany, 1993. [\[CrossRef\]](#)
8. Trowbridge, C.C. On Fundamental Methods of Orientation and “Imaginary Maps”. *Science* **1913**, *38*, 888–897. [\[CrossRef\]](#)
9. Tolman, E.C. Cognitive maps in rats and men. *Psychol. Rev.* **1948**, *55*, 189–208. [\[CrossRef\]](#)
10. Piaget, J.; Inhelder, B. *The Child’s Conception of Space*; Routledge and Kegan Paul: London, UK, 1956.
11. Capel, H. *Filosofía y Ciencia en la Geografía Contemporánea*, 2nd ed.; Ediciones El Serbal: Barcelona, Spain, 2012.
12. Lynch, K. *The Image of the City*; MIT Press: Cambridge, MA, USA, 2008.
13. Lowenthal, D. Geography, Experience, and Imagination: Towards a Geographical Epistemology. *Ann. Assoc. Am. Geogr.* **1961**, *51*, 241–260. [\[CrossRef\]](#)
14. Wolpert, J. The Decision Process in Spatial Context. *Ann. Assoc. Am. Geogr.* **1964**, *54*, 537–558. [\[CrossRef\]](#)

15. Jones, S.B. The Description of International Boundaries. *Ann. Assoc. Am. Geogr.* **1943**, *33*, 99–117. [\[CrossRef\]](#)
16. Hartshorne, R. Geographic and Political Boundaries in Upper Silesia. *Ann. Assoc. Am. Geogr.* **1933**, *23*, 195–228. [\[CrossRef\]](#)
17. Kristof, L.K.D. The nature of frontiers and boundaries. *Ann. Assoc. Am. Geogr.* **1959**, *49*, 269–282. [\[CrossRef\]](#)
18. Newman, D. The lines that continue to separate us: Borders in our ‘borderless’ world. *Prog. Hum. Geogr.* **2006**, *30*, 143–161. [\[CrossRef\]](#)
19. Newman, D.; Paasi, A. Fences and neighbors in the postmodern world: Boundary narratives in political geography. *Prog. Hum. Geogr.* **1998**, *22*, 186–207. [\[CrossRef\]](#)
20. Piketty, T. *Capital and Ideology*; Harvard University Press: Cambridge, MA, USA, 2020.
21. Musterd, S. Advanced introduction to urban segregation. In *Elgar Advanced Introductions*; Edward Elgar Publishing: Cheltenham, UK; Northampton, MA, USA, 2023.
22. Van Kempen, R.; Murie, A. The new divided city: Changing patterns in European cities. *Tijdschr. Voor Econ. En Soc. Geogr.* **2009**, *100*, 377–398. [\[CrossRef\]](#)
23. Duroudier, S. The Social and Spatial Divisions of Intermediate Cities in the United States. *Espace Géographique* **2014**, *43*, 134–147. [\[CrossRef\]](#)
24. Musterd, S. Urban segregation: Contexts, domains, dimensions and approaches. In *Handbook of Urban Segregation*; Edward Elgar Publishing: Cheltenham, UK, 2020; pp. 2–17. [\[CrossRef\]](#)
25. Dadashpoor, H.; Keshavarzi, S. Defining urban segregation: A qualitative meta-synthesis. *Cities* **2024**, *149*, 104947. [\[CrossRef\]](#)
26. Haandrikman, K.; Costa, R.; Malmberg, B.; Rogne, A.F.; Sleutjes, B. Socio-economic segregation in European cities. A comparative study of Brussels, Copenhagen, Amsterdam, Oslo and Stockholm. *Urban Geogr.* **2023**, *44*, 1–36. [\[CrossRef\]](#)
27. Yao, J.; Wong, D.W.S.; Bailey, N.; Minton, J. Spatial Segregation Measures: A Methodological Review. *Tijdschr. Voor Econ. En Soc. Geogr.* **2019**, *110*, 235–250. [\[CrossRef\]](#)
28. Jacobs, J.M. The City Unbound: Qualitative Approaches to the City. *Urban Stud.* **1993**, *30*, 827–848. [\[CrossRef\]](#)
29. Lindon, A. Geografías de la vida cotidiana. In *Tratado de Geografía Humana*; Anthropos: Mexico City, Mexico, 2006; pp. 356–400.
30. Picó-Gutiérrez, V.; González-Ramírez, F.E.; Escudero-Gómez, L.A. From Segregation to Fragmentation: Mapping the Recent Global Literature. *Urban Sci.* **2025**, *9*, 98. [\[CrossRef\]](#)
31. González Pérez, J.M.; Parreño Castellano, J.M.; Sánchez Aguilera, D. Fragmentación urbana. Macro conceptual para el análisis de la desigualdad en España. In *XXVIII Congreso de la Asociación Española de Geografía*; 2023; pp. 811–820. [\[CrossRef\]](#)
32. Yu, P.; Yung, E.H.K.; Chan, E.H.W.; Wong, M.S.; Wang, S.; Chen, Y. An integrated approach for examining urban fragmentation in metropolitan areas: Implications for sustainable urban planning. *J. Clean. Prod.* **2023**, *419*, 138151. [\[CrossRef\]](#)
33. Burgess, R. Segregación y fragmentación urbana: Algunos comentarios. *Rev. Iberoam. De Urban.* **2018**, *14*, 79–86.
34. Helbrecht, I. The Creative Metropolis: Services, Symbols and Spaces. *Int. J. Archit. Theory* **1998**, *3*.
35. Hendriks, F.; Hendriks, F. The Post-Industrialising City: Political Perspectives and Cultural Biases. *Geojournal* **1999**, *47*, 425–432. [\[CrossRef\]](#)
36. Navez-Bouchanine, F. *La Fragmentation en Question: Des Villes Entre Fragmentation Spatiale et Fragmentation Sociale?*; L'Harmattan: Paris, France, 2002.
37. Préteceille, E. La ségrégation sociale a-t-elle augmenté? *Sociétés Contemp.* **2006**, *62*, 69–93. [\[CrossRef\]](#)
38. François, J.C. Ressemblances et proximités: Un point de vue sur le contexte théorique de la notion de discontinuité géographique. *Cybergeo Rev. Eur. Géographie* **2002**, *241*, 1–16.
39. Le Goix, R. *Sur le Front de la Métropole: Une Géographie Suburbaine de Los Angeles*; Éditions de la Sorbonne: Paris, France, 2022. [\[CrossRef\]](#)
40. Porcel López, S. *Desigualdad Social Y Segregación Residencial, Una Relación Compleja*; Cáritas Española Editores: Madrid, Spain, 2020.
41. Fan, C.; Myint, S. A comparison of spatial autocorrelation indices and landscape metrics in measuring urban landscape fragmentation. *Landsc. Urban Plan.* **2014**, *121*, 117–128. [\[CrossRef\]](#)
42. Wei, Y.; Zhang, Z. Assessing the fragmentation of construction land in urban areas: An index method and case study in Shunde, China. *Land Use Policy* **2012**, *29*, 417–428. [\[CrossRef\]](#)
43. Sorando, D.; Ariza de la Cruz, J. Cauces socioespaciales: La segregación y el arraigo en Madrid. *Rev. Española Sociol. (RES)/Span. J. Sociol.* **2018**, *32*, 190. [\[CrossRef\]](#)
44. Hubert, J.-P. *La Discontinuité Critique*; Publications de la Sorbonne: Paris, France, 1993. [\[CrossRef\]](#)
45. Roberto, E. The Spatial Proximity and Connectivity Method for Measuring and Analyzing Residential Segregation. *Sociol. Methodol.* **2018**, *48*, 182–224. [\[CrossRef\]](#)
46. Brenner, N. *New Urban Spaces: Urban Theory and the Scale Question*; Oxford University Press: Oxford, UK, 2019.
47. Mandelbrot, B.B. *The Fractal Geometry of Nature*; W. H. Freeman and Company: San Francisco, CA, USA, 1983.
48. Pullan, W. Spatial Discontinuities: Conflict Infrastructures in Contested Cities. In *Locating Urban Conflicts*; Palgrave Macmillan: London, UK, 2013; pp. 17–36. [\[CrossRef\]](#)

49. Ayala, L.S. De territorios, límites, bordes y fronteras: Una conceptualización para abordar conflictos sociales. *Rev. De Estud. Soc.* **2015**, *53*, 14–27. [\[CrossRef\]](#)
50. Smith, B.; Mark, D.M. Ontology and Geographic Kinds. In Proceedings of the 8th International Symposium on Spatial Data, Vancouver, Canada, 12–15 July 1998.
51. Smith, N. *La Nueva Frontera Urbana. Gentrificación y Ciudad Revanchista*, 1st ed.; Traficantes de Sueños: Madrid, Spain, 1996.
52. Low, S.M. The Edge and the Center: Gated Communities and the Discourse of Urban Fear. *Am. Anthropol.* **2001**, *103*, 45–58. [\[CrossRef\]](#)
53. Van Houtum, H.; Strüver, A. Borders, Strangers, Doors and Bridges. *Space Polity* **2002**, *6*, 141–146. [\[CrossRef\]](#)
54. Wacquant, L. *Las dos Caras de Un Gueto*, 1st ed.; Siglo XXI: Buenos Aires, Argentina, 2015.
55. Morales, E.R. Planned Socio-Spatial Fragmentation: The Normalisation of Gated Communities in Two Mexican Metropolises. *Urban Plan.* **2024**, *9*, 1–20. [\[CrossRef\]](#)
56. Bandauko, E.; Arku, G.; Nyantakyi-Frimpong, H. A systematic review of gated communities and the challenge of urban transformation in African cities. *J. Hous. Built Environ.* **2022**, *37*, 339–368. [\[CrossRef\]](#)
57. Bellet Sanfeliu, C. La producción de un barrio desfavorecido en los márgenes de una ciudad media: La Mariola (Lleida). *Scr. Nova. Rev. Electrónica Geogr. Y Cienc. Soc.* **2021**, *25*, 75–103. [\[CrossRef\]](#)
58. McFarlane, C. One assemblage and critical urbanism. *City* **2011**, *15*, 204–224. [\[CrossRef\]](#)
59. Institut d’Estadística de Catalunya (IDESCAT). Idescat. El municipi en xifres. Lleida (Segrià). Available online: <https://www.idescat.cat/emex/?id=251207> (accessed on 24 September 2025).
60. Bellet Sanfeliu, C.; Andrés López, G. Urbanización, crecimiento y expectativas del planeamiento urbanístico en las áreas urbanas intermedias españolas (1981–2018). *Investig. Geográficas* **2021**, *76*, 31–52. [\[CrossRef\]](#)
61. Bellet Sanfeliu, C.; Lasala Fortea, J.; Andrés López, G.; Cebrián Abellán, F. Juntos pero separados: La segregación residencial en las ciudades medias españolas. *Ciudades* **2025**, *28*, 73–91. [\[CrossRef\]](#)
62. Andrés López, G.; Bellet Sanfeliu, C.; Cebrián Abellán, F. Buscando límites a la urbanización dispersa: Metodología para la delimitación de áreas urbanas en las ciudades medias españolas. *Ciudades* **2023**, *26*, 143–166. [\[CrossRef\]](#)
63. Chanal, D.; Steiner, N.Y.; Chamagne, D.; Pera, M.C. Impact of standardization applied to the diagnosis of LT-PEMFC by Fuzzy C-Means clustering. In *2021 IEEE Vehicle Power and Propulsion Conference (VPPC 2021)*; IEEE: New York, NY, USA, 2021. [\[CrossRef\]](#)
64. Hair, J.F., Jr.; Black, W.C.; Babin, B.J.; Anderson, R.E. *Multivariate Data Analysis*, 8th ed.; Cengage Learning EMEA: Andover, UK, 2019.
65. Hasan, F.M.; Hussein, T.F.; Saleem, H.D.; Qasim, O.S. Enhanced unsupervised feature selection method using crow search algorithm and Calinski–Harabasz. *Int. J. Comput. Methods Exp. Meas.* **2024**, *12*, 185–190. [\[CrossRef\]](#)
66. Chen, Y. An analytical process of spatial autocorrelation functions based on Moran’s index. *PLoS ONE* **2021**, *16*, e0249589. [\[CrossRef\]](#) [\[PubMed\]](#)
67. White, M.J. The measurement of spatial segregation. *Am. J. Sociol.* **1983**, *88*, 1008–1018. [\[CrossRef\]](#)
68. Rodríguez-Suárez, I.; Viedma Guiard, A.; Hernández Aja, A. Renta y calidad de la vivienda: Un análisis de la fragmentación urbana. *Ciudades* **2025**, *28*, 23–46. [\[CrossRef\]](#)
69. Antón-Alonso, F.; Porcel, S.; Cruz, I.; Pujol, F.C. La vulnerabilitat urbana a Barcelona: Persistència, concentració i complexitat. *Pap. Regió Metrop. Barc. Territ. Estratègies Planejament* **2020**, *63*, 50–67.
70. Dialga, I.; Giang, L.T.H. Highlighting methodological limitations in the steps of composite indicators construction. *Soc. Indic. Res.* **2017**, *131*, 441–465. [\[CrossRef\]](#)
71. Córdoba Hernández, R.; Camerin, F. Assessment of ecological capacity for urban planning and improving resilience in the European framework: An approach based on the Spanish case. *Cuad. Investig. Geográfica* **2023**, *49*, 119–142. [\[CrossRef\]](#)

**Disclaimer/Publisher’s Note:** The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.