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Assessment of Urban Neighbourhoods' Vulnerability through an Integrated Vulnerability Index (IVI): Evidence from Barcelona, Spain

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Abstract: Urban inequality, specifically in vulnerable areas, has been a study topic from the earliest days of sociology to the present. This study's objective is to discuss the scope and limitation of the concept of urban vulnerability, whilst generating an index that detects urban vulnerability in all its dimensions. A factor analysis of the main components was conducted resulting in the formation of four partial indices related to the social class, gentrification, social and employment, and physical & architectural dimensions of urban vulnerability, whilst their sums conform an integrated vulnerability index. This index is applied to the city of Barcelona, allowing its neighbourhoods to be positioned on a vulnerability continuum. Despite being applied in this city, the integrated vulnerability index emerges with the purpose of being replicated to other urban spaces. The mapping of these results using geographic information systems suggests a robust index that allows early identification of problematics, while also providing clues for policy intervention.

Keywords: inequality; vulnerability; neighbourhood; factor analysis

1. Introduction

Since the advent of cities, their organisation, particularly their inequal and heterogeneous structuring, has been a central study topic in social sciences, giving rise to a vast body of literature, with some studies focusing on 'the urban' expression of such inequalities. The key concepts of social studies, such as class struggle, polarisation, or inequality, are crystallised in the urban space, particularly on the neighbourhood scale (Zhang et al. 2018), as its most self-defining and sociological unit.

The study of urban inequality has a long and diverse tradition in sociology. It began with the Chicago School in the 1930s based on the idea that physical distances so frequently are—or seem to be—an indicator of social distances (Park 1926). Some of the most important topics of study since then have been the comparison of different urban structures, as well as the identification of causes and effects of urban inequalities and their spatialisation. The analysis of these inequalities was addressed by the neo-Marxist approaches of the new urban sociology, showing how the abandonment of the city to free market has generated speculation and surpluses in urban capital gains. Thus, land in cities has become a specific type of capital, and its value forges urban segregation and differentiates (and ranks) the different neighbourhoods (Urrutia Abaigar 1999) and their inhabitants. In this regard, class struggle, for authors such as Harvey (2013), is particularly manifested in the fight for the appropriation of space in cities. The intensification of the spatial divisions coincides very well with class divisions, resulting in a differential distribution among areas of the city (Harvey 2013).

However, the current global and urban scenario raises new challenges. Different authors have already mentioned the increase in spatial and social polarisation at the start of this century (Wacquant 2010; Secchi 2014; Seiz 2020). This increase was partly due

to the globalisation of migrations (Castles and Miller 1998) and to the expansion of the neoliberal city model. Financial globalisation has generated neoliberal city production models, which in turn has intensified social inequalities. These inequalities are likewise heightened in crisis contexts, whether the 2008 economic crisis, in which vulnerable areas and groups were most badly hit (Janoshcka and Hidalgo 2014; Echaves García and Echaves 2017; Fernández Aragón and Shershneva 2017), or the 2020 health crisis, which generated significant inequalities (Guterres 2020; Seiz 2020; Teixeira et al. 2022). The different crisis scenarios reveal the need to pinpoint the most vulnerable groups and areas in order to design public policies to offset the negative impacts of crises.

We are currently going through a scenario of fast and abrupt change. Thus, urban vulnerability is revealed as a highly relevant and complex issue, making it necessary to carry out an updated diagnosis tool that considers all of its dimensions. Even though it has been studied by different authors and from different perspectives, a comprehensive approach of urban vulnerability is sometimes missing, making it necessary to take previous discussions into account whilst taking a step forward on both a theoretical and a practical level. After addressing the main conceptual discussions related to urban vulnerability, as well as reconstructing the main efforts towards the construction of different vulnerability indices, a discussion on their limits and opportunities is presented. Thus, these discussions can help us better identify the dimensions of analysis of urban vulnerability, towards the construction of an integrated measure that can be applied in the city of Barcelona.

1.1. Conceptual Framework: Regarding the Concept of Urban Vulnerability

As a step prior to setting up an index that allows us to measure urban vulnerability, the concept of vulnerability and its application to the urban sphere should be examined. With regard to its most general perception, vulnerability emerged in the literature of the English-speaking world to move beyond the concept of poverty that proved insufficient (Rodríguez 2001). The vulnerability approach, when realising the defencelessness, insecurity, and exposure to risk, shocks, and stress (Chambers 1989; Ochoa-Ramírez and Guzmán-Ramírez 2020) caused by extreme socioeconomic events, provides a more comprehensive view of the living conditions of people in poverty or at risk. Thus, vulnerability would encompass those processes that often occur in parallel, such as the increased risks and threats that could affect an individual or group, the fracture and weakening of the protection instruments, or the difficulty to overcome structural poverty (Rodríguez 2001). The application of this concept to the urban analysis must consider the convergence of personal, social, and physical parameters occurring in the urban space.

There are multiple ways of defining urban vulnerability, some giving greater importance to one or another aspect. Thus, from the social perspective, urban vulnerability refers to the potentiality of a given population of a specific urban space of being affected by certain adverse circumstance(s) (Alguacil Gómez et al. 2014). In this regard, it is not only defined by the current critical disadvantage, but more specifically by the threat of exposure to certain exclusion risks (Callejo et al. 2005).

The United Nations defines vulnerability as a state of high exposure to risks and uncertainties, in combination with a reduced ability to protect or defend oneself against these and cope with their negative consequences (United Nations 2003). Therefore, this definition stands out on two basic points: on the one hand, the increased risks that may negatively affect individuals or social groups and, on the other hand, the weakening of the tools that enable protection against those risks (Moser 1998).

In this regard, the concept of urban vulnerability alludes to a dynamic and complex process, as it combines different residential economic and socially disadvantaged dimensions leading to exclusion (United Nations 2003). Thus, we can speak of at least three basic dimensions of vulnerability: the sociodemographic, the socioeconomic, and the spatial (Pizarro 2001; Rodríguez 2001). The first of them, sociodemographic vulnerability, is more linked with population ageing, migratory movements, and the appearance of household structures presenting great risks of vulnerability. The socioeconomic dimension, in turn,

refs to job instability and insecurity, exposing individuals to economic exclusion and poverty. Lastly, the residential dimension refers to poor conditions, both of housing and of the physical spaces in which daily social activities take place (Alguacil Gómez et al. 2014). On the other hand, authors (Hernández-Aja 2007; Zhang et al. 2021) have stressed the importance of considering the psychosocial dimension or the subjective perception of the environment in which they live.

In relation to the characteristics of urban vulnerability, Castel's reflections (Castel 1991, 1995) on the dynamic nature of this phenomenon are of great interest. Castel argued that it is not an airtight condition, but rather that the conditions of the individuals change depending on the moment. Thus, the author differentiated three areas of vulnerability resulting from their social and employment conditions. These three areas constitute a continuum that ranges from the integration area, which includes individuals with stable employment and a strong network of social relations, to the marginalisation area at the other end of the scale, including people who lack work and social relations. The vulnerability area is between these two extremes and represents the combination of precarious employment with the fragility of relational support (Castel 1991). In this sense, the characteristics related to a higher risk of vulnerability have to do with the intersection of economic, social, cultural, and environmental factors such as job instability, low level of education, unemployment, chronic diseases, disability, domestic violence, residential segregation, and dependency (Ranci 2002).

In the urban space, vulnerability tends to be concentrated in certain areas of the city where there is a combination of unfavourable living, social, and job factors (Edwards 1975; Herbert 1975; Alguacil Gómez et al. 2014). Residential segregation, in turn, contributes to people with similar conditions coinciding in the same (under)privileged urban spaces (Egea Jiménez et al. 2008; Méndez 2013; Temes 2014). In the case of Spain, residential discrimination is a widely studied issue (Fernández Aragón et al. 2021a; Ministerio de Igualdad 2022; Checa Olmos et al. 2010), especially in the context of migration and ethnic minorities. Regarding the causes, one of the factors that influences urban spatial distribution is the price of housing (Martori and Hoberg 2004; Alguacil Gómez et al. 2014), with immigrants and young people on low incomes among the most vulnerable groups (Alguacil Gómez 2006). However, the residential discrimination is another relevant factor explaining residential segregation (Galster and Keeney 1988; Massey 2005). Galster and Keeney (1988) differentiated between public discrimination, which refers to local and state land and housing policies, and private discrimination generated by the real estate and private agents towards certain groups (Munnell et al. 1996). Among the consequences of residential segregation, previous research tended to focus mainly on its negative effects, specifically on socioeconomic integration and people's wellbeing (Kempen and Ozuekren 1998; Wacquant 2001; Musterd 2005).

Gentrification is another process related to urban vulnerability, as it may imply a potential threat to the locals living in a specific neighbourhood, in relation to their permanence or expulsion by the hike in housing and other prices (Hübscher 2018; Lin et al. 2021). Processes such as gentrification and touristification are generated when an urban area is appropriated by a population segment that did not previously live there, consequently expelling local inhabitants (Janoshcka and Hidalgo 2014; Hübscher 2018; Sorando and Ardura 2016). The expulsion is related, most directly, to the high price of rent resulting from the commodification and renewal of the neighbourhood (Callejo et al. 2005), as well as with the appearance of tourist or holiday rentals, which exerts great pressure on the rental market (Piñeira et al. 2021). Thus, gentrification and touristification, which particularly affect urban centres, may result in the modification of some cultural, economic, social and/or urban characteristics of the whole area under pressure. The discussion regarding these phenomena is divided between those who consider them a source of income and urban improvement, and those who view them as a factor for vulnerability and subjugation. Whichever the case, more and more definitions of urban vulnerability consider this dimension of analysis (Lin et al. 2021).

Therefore, focusing our research on urban vulnerability, trying to understand it in all of its dimensions is particularly important at this moment, as our results may lead to an early identification of urban areas with higher risks of social, economic, and/or residential exclusion. Furthermore, the interest in the Spanish context and the city of Barcelona is very well supported, given their specificities, as well as the possibility to extend our results to other similar contexts, mainly in the Spanish state but also in the Mediterranean.

The study of urban differentiation, specifically the use of indices, is well established in urban sociology. These kinds of studies received a significant methodological boost in 1955 with the dissimilarity index (Duncan and Duncan 1955), as the sole indicator to measure residential differential. Subsequently, other complementary measures were added to detect the multiple dimensions of the urban segregation phenomenon (Massey and Denton 1988). The methodological developments of this type and the generation of indices as summarised and simple values, but with great explanatory power, have since then multiplied. In this regard, Table 1 shows some relevant efforts to operationalise vulnerability, i.e., to provide an index capable of identifying its distribution in the urban space. Specifically, we differentiate between those studies that, from a more traditional vision, analysed vulnerability on the basis of social and economic indicators and those which, starting from a broader understanding of the concept, analysed it in terms of multiple aspects of the urban environment. All of these studies used available secondary data and operationalised urban vulnerability using a set of indicators, before following different methodologies for the calculation of a synthetic index (Fernández-García et al. 2017).

Table 1. Vulnerability and/or inequality indices.

Index	Author	Year	Area	Method	Indicators
Socioeconomic					
The social status index	Ley	1986	Canada	Correlation model	Socioeconomic; residential (gentrification)
Small-area index of socioeconomic deprivation	Havard	2008	France	Factorial analysis	Sociodemographic; socioeconomic
Deprivation index	Townsend	1988	UK	Logarithmic transformation	Socioeconomic; residential
Socioeconomic level index	Fernández-Garcia	2017	Spain	Factorial analysis	Sociodemographic; socioeconomic; residential
Vulnerability					
Urban vulnerability index	Egea Jiménez	2008	Spain	Factorial analysis	Sociodemographic; socioeconomic; residential; subjective
Comprehensive urban vulnerability synthetic index	Ministry of Development	2010	Spain	Multicriteria analysis	Sociodemographic; socioeconomic; residential; environmental
Indices of deprivation	Ministry of Housing	2011	UK	Factorial analysis	Sociodemographic; socioeconomic; residential; environmental
Synthetic index of comprehensive urban vulnerability	Fernández Aragón	2021b	Spain	Factorial analysis	Sociodemographic; socioeconomic; sociopolitical; residential
Comprehensive vulnerability	Hanoon	2022	Iraq	Fuzzy logic function	Environmental; residential; urban
Composite vulnerability index	Gerundo	2020	Italy	Aggregation method	Sociodemographic; urban; residential

Source: Prepared by the authors.

The socioeconomic dimension has been, traditionally, the most studied dimension in the field of urban sociology. In fact, it is notable how, from the most traditional to the most contemporary theories, the socioeconomic dimension has proven to be the determining factor to explain differences in urban spaces (Checa Olmos 2006). However, social indicators and dimensions, such as the access to services and environmental health (Navarro et al. 2016) and the living space,

have gained importance in recent years. This has likewise been the case in residential analysis (Garcia-Almirall et al. 2017), which most frequently ends up being linked to the gentrification process (Lin et al. 2021). Along with the socioeconomic, the sociodemographic dimension, with special focus on the presence of a foreign population given its greater vulnerability, is a constant in this type of analysis (Fernández Aragón et al. 2021b).

Table 1 shows the selection of a set of indices, focusing more on one or another dimension of vulnerability. In the case of the studies that focused more on socioeconomic aspects, a special mention should be made of the classic Townsend deprivation index in the United Kingdom (Townsend 1988) and updated by the government in 2011 (Ministry of Housing of the United Kingdom 2011). This list also includes the Havard small-area index of socioeconomic deprivation for the French case (Havard et al. 2018) and the socioeconomic level index created by Fernández-García and others in Spain (Fernández-García et al. 2017). They all share the priority use of social dimensions, including residential, socioeconomic, and sociodemographic indicators. The case of the social status index (SSI) developed by Ley (1986) for Canada is also very interesting. It clearly links urban poverty with gentrification processes, by taking some residential variables into account (Shevky and Bell 1955; Ley 1988).

The table also shows the selection of urban vulnerability indicators that, in addition to the abovementioned, consider dimensions related to the subjective level. This is the case of the urban vulnerability index (IVU) of Egea Jiménez et al. (2008), the urban synthetic vulnerability index included in the urban vulnerability atlas (Temes 2014) produced by the Spanish Ministry of Development, along with the English indices of deprivation (Ministry of Housing of the United Kingdom 2011). The consideration of new dimensions and indicators related to the residents' perception of their environment—which is known as 'subjective vulnerability' and involves the lack of green zones, pollution, antisocial behaviour, and transport—stands out in these proposals (Fernández-García et al. 2017). Although not included in the table, Ruá et al. (2019) proposed participatory techniques for the contrast of their selected indicators to elaborate an index for Castellon (Spain).

Furthermore, variables are incorporated related to the residential context, such as the price of the dwellings and other environmental attributes (Fernández Aragón et al. 2021b; Gerundo et al. 2020). A special mention should be made of the synthetic index of comprehensive urban vulnerability (ISVUI) (Fernández Aragón et al. 2021b), which is the direct predecessor of this paper. In addition to the more standard dimensions—sociodemographic, social and employment, and residential, this last index considers participation through formal (electoral) and informal (associative network) spaces. In addition to the dimensions listed in the table, some recent studies linked urban vulnerability to geographical and/or climatological factors, which is particularly relevant due to the consequences of climate change (Romero-Lankao and Qin 2011; Hanoon et al. 2022). This analysis, in the case of European cities, was carried out by considering these variables as future risks (Tapia et al. 2017).

Although there are different statistical tools used to integrate the different indicators, as shown in Table 1, the principal component factor analysis, whether exploratory or confirmatory, is the most common one. We can also find other techniques such as multicriteria analysis and correlation models. As we reveal in Section 2, this research is based on a factorial analysis.

1.2. Objectives

One of the first hypotheses of this work is that social differences have a spatial correlation. This was one of the starting points that motivated the research in terms of identifying the dimensions of vulnerability and the way in which they combine and result in the distribution of social groups in the territory. Secondly, the revision of literature as well as the study of other vulnerability indices resulted in a more or less conscious decision to include variables related not only to social, economic, and demographic aspects, but also to indicators of the urban and housing spheres, most related to the valorisation and commodification of urban areas (Serin et al. 2020). Thus, some of the questions addressed in this research are related to the weight of urban aspects in the conformation of a vulnerability index.

This research's objective is to discuss the scope and limitation of the concept of urban vulnerability, whilst generating an index that detects urban vulnerability in all its dimensions. This index is applied to the city of Barcelona, allowing its neighbourhoods to be positioned on a vulnerability continuum. Despite being applied in Barcelona, the integrated vulnerability index (hereinafter IVI) emerges with the purpose of being replicated in other urban spaces (with its appropriate adaptation to the different contexts).

This paper is structured in five parts. A brief review of the main theoretical perspectives on urban vulnerability and of some of the indices constructed in similar studies is provided in Section 1. Subsequently, the methodology used for this study, the secondary sources selected, and the data used for the construction of the IVI applied in the city of Barcelona are presented in Section 2. Then, Section 3 includes a description of the variables included in the model. This information was summarised by means of a principal component factor analysis (hereinafter FA) in order to establish the most important factors that influence urban vulnerability, as well as obtain an integrated measure. The main outcomes, together with validation and crosschecking, presented in Section 4, account for a highly consistent and robust index that is noted for measuring the vulnerability in a multidimensional way. Lastly, the main conclusions arising from this study are presented in Section 5.

2. Materials and Methods

In order to construct a synthetic index that detects vulnerability and that allows the different neighbourhoods of the city to be positioned on a vulnerability continuum, a quantitative analysis strategy was selected, starting from secondary data fonts in open access. This last point is of great importance, as this index seeks to be replicated; consequently, access to data must be streamlined. Specifically, this exercise was conducted for the city of Barcelona.

2.1. Measurement Unit: The Neighbourhood

With regard to the measurement unit for this analysis, the neighbourhood was selected as the reference space, even though it is more a sociological than an administrative category. Urban indices are divided between those using the census section or a micro-scale as unit and those that expand the scale to district or neighbourhood (Temes 2014). We found examples of this type of analysis, using the neighbourhood as unit, in Andalusia (Navarro et al. 2016), Madrid (Uceda Navas 2017), Bilbao (Fernández Aragón et al. 2021b), and the deprivation index applications (Townsend 1988). Access to data is one of the reasons for the decision to work at a neighbourhood level, as the data by census section are often not available, particularly those related to the 2011 Census (de Cos Guerra and Ferrer 2019). In any event, some of that data would be out of date. Consequently, prioritising the applicability of the IVI to other municipalities, the selected measurement unit is the neighbourhood. The choice of this scale is justified by the intention to crosscheck this methodology with other previous work, such as the index constructed by Fernández Aragón et al. (2021b) which is the basis of this research. At the same time, the neighbourhood scale has been the planning scale of different public policy initiatives in the city of Barcelona and in Catalonia, particularly after the 2004 Neighbourhood Act, which is very relevant to the local reality. At the same time, this scale is of particular importance, related to the presence of public service and social welfare at a neighbourhood scale, as well as its recognition as a value of proximity by local residents (Piasek et al. 2021).

2.2. Selection of Variables

In order to answer to our objectives, a database at neighbourhood scale was first prepared on the basis of 21 indicators of different types (social, demographic, economic, urban, etc.) as a first step towards the construction of an urban vulnerability index. These indicators were selected following the same model proposed by the synthetic index of comprehensive urban vulnerability (ISVUI) applied to the city of Bilbao (Fernández Aragón

et al. 2021b). Specifically, its indicators are related to the sociodemographic, social and employment, residential, and participation dimensions. As for our case, the sociodemographic dimension includes the key variables for understanding the composition of the neighbourhood, which are very common in this type of study (Alguacil Gómez et al. 2014). Variables such as age or foreigners would be located in this dimension. Regarding the employment dimension, it is a classic dimension in the elaboration of urban factor analysis, commonly called 'social rank' (Shevky and Bell 1955). This includes variables related to employment and income. The residential dimension refers to the characteristics and conditions of housing. International studies show the relationship of housing equipment with the 'social rank' category (Shevky and Bell 1955; Hamilton and French 1979) or as an isolated factor, as in the case of Gittus (1965) for Liverpool. Variables such as the price of rent or heating in the dwelling are also included. Lastly, many studies linked poverty and vulnerability with social participation, either through electoral or associative participation (Gómez Fortes and Trujillo Carmona 2011). Thus, variables such as electoral abstention or participation in associations are also included.

Some limitations were found regarding the characteristics of the city of Barcelona that were not all represented in previous indices, making it necessary to take previous efforts into account, while proposing an updated tool of analysis. Consequently, urbanistic indicators are added for this research with the intention of shedding some light on a dimension that a priori seemed representative of Barcelona, and which has to do with the urban scale, with the inherent characteristics of the city, its tourist profile, etc. The dimensions used in the Bilbao case were repeated, whilst adding some other points linked to economic trends related to touristification, and the urban dimension (all measurements based on specific indicators such as buildings owned by foreigners, the proportion of youths out of the total population, the percentage of tourist accommodation out of the total building stock, the percentage of land dedicated to urban park, the population density, etc.). Lastly, regarding the selection of variables, in the case of Spain, at the institutional and academic level, it is common to use the synthetic indices of urban vulnerability included in the atlas of urban vulnerability (Ministry of Public Works 2011). These indices are created on the basis of three indicators: percentage of unemployed people, percentage of people with no education, and percentage of dwellings in buildings in poor condition. The authors of this paper consider that, although this basic index allows comparison, this selection of variables is insufficient to explain urban vulnerability as a whole, as it leaves out basic aspects such as the quality of housing, urban dimensions, and social class attributes. Moreover, this approach does not allow vulnerability to be measured as a scale, as it only detects extreme situations. In order to overcome these limitations, the IVI expands the selection of variables as can be seen in Table 2.

Nevertheless, this selection does not include variables related to the geographical/climatological dimension. While we consider this to be an interesting dimension, the lack of standardised data at a state level would prevent the index from being replicable in other cities. Likewise, the participation dimension is limited only to electoral participation and presence of local entities or associations, also due to the difficulty of obtaining data.

2.3. Index Creation Process

Specifically, the following steps were followed for the elaboration of the index: first, the most relevant variables related to the object of study were selected on the basis of the literature review and the identification of core dimensions. Second, the selected variables were recoded to convert them into numerical variables, an essential condition for carrying out a factor analysis. Third, an exploratory principal component factor analysis was carried out. In this phase, variables with little or no explanatory capacity were eliminated. Specifically, the variables 'population density' and 'urban green areas' were eliminated. Fourth, a factor analysis was carried out with the explanatory variables resulting in four factors obtained with Varimax rotation. With this second factor analysis, we were able

to rank and weight the impact of each dimension on the overall urban vulnerability of each neighbourhood. This is what is mapped in the next section. The weight assigned to each dimension by the second-order factor analysis was as follows: social class, with 23.7% explanatory capacity; gentrification, with an explanatory capacity of 23.1%; social and employment, 22.7%; physical and architectural, 11.4%. The calculation of the global index was then carried out considering the relative weight of each of these dimensions.

Table 2. Variables selected for the model.

Indicator	Source
House prices per m^2 (EUR)	Sect. of the Urban Agenda for Catalonia—GenCat (2021)
People with a university education (%)	Municipal Register of Inhabitants (2020)
People without basic education (%)	Municipal Register of Inhabitants (2020)
Available family income (EUR)	Open Data Barcelona (2018)
Age of the dwellings (years)	Cadastral General Directorate (2020)
Tourist accommodation (%)	Bcn Statistics Department (2020)
Entities per neighbourhood (N)	Open Data Barcelona (2020)
Foreign population (%)	Municipal Register of Inhabitants (2020)
Youth population (%)	Municipal Register of Inhabitants (2020)
Premises property of private foreign owners (%)	Cadastral General Directorate (2020)
People with vocational training (%)	Municipal Register of Inhabitants (2020)
No. of people unemployed (%)	Department of Work—GenCat (2021)
Abstention in last elections (%)	Ministry of the Interior (2019)
Over 65 years old (%)	Municipal Register of Inhabitants (2020)
Non-contributory pensions (%)	Department of Work—GenCat (2021)
Sex ratio (%)	Municipal Register of Inhabitants (2020)
Flats with lift (%)	Population and Housing Census (2011)
Average surface area of the housing (m^2)	Cadastral General Directorate (2020)
Housing with heating (%)	Population and Housing Census (2011)

Source: Prepared by the authors.

The secondary data used, which are detailed in Table 2, were obtained from statistical information sources available in open format, including the Statistics Department of Barcelona City Council, the Observatory of Districts and Neighbourhoods, the Sociodemographic Survey, the Housing Census, and the city's Survey Register. Most of the indices used to measure urban poverty or vulnerability use census data, which can only be updated every 10 years, when the census is carried out. Therefore, for the elaboration of the IVI, we opted for other types of sources that allow vulnerability to be monitored in shorter periods of time.

The factorial analysis is a data reduction technique, whose ultimate aim consists of searching for the minimum number of dimensions capable of explaining the vast amount of information contained in the data (De la Fuente Fernández 2011). The method seeks to simplify the available information in order to make it easier to handle and interpret. In this regard, it offers huge benefits when working with a large number of variables and cases, which is the reason for selecting it as the most appropriate method to reduce the number of indicators to a series of interlinked dimensions, without losing valuable information. At the same time, some limitations of this methodology can also be indicated, particularly those linked to the use of statistical techniques where the researcher does not handle the information directly. Even though this could be seen as a guarantee of relative objectivity in the method, the 'capacity of agency' is an integral part of any research task; both the selection of the indicators and the interpretation of the data are eminently qualitative activities according to earlier studies and readings that set the course, along with the result of certain '*habitus*' of the researcher (Bourdieu 1978). According to these comments, the FA is, therefore, the most appropriate technique given the research goals of this paper.

After having obtained the most appropriate model to explain the dimensions of urban vulnerability, the factors obtained were reduced in an integrated vulnerability index

consisting of the sum of the relative weights of each of the dimensions arising from the FA. Having checked the contribution of the variables—above 0.5—and the KMO and Bartlett indicators—above 0.6 in the first case and significant in the second—four factors were selected according to the eigenvalue method which altogether explain more than 81% of the variance.

2.4. Presentation of Results

Lastly, the results were mapped (the maps in the next section represent the distribution of each of the factors, as well as of the IVI), using geographic information systems (GIS) (Qgis 3.10-A Coruña, Free Software Foundation Inc., Boston, MA, USA), a powerful technology used by different disciplines when the subject matter has a territorial component (geographic, environment, landscape, etc.) (Garcia-Almirall et al. 2017). They can, thus, be used to identify different dimensions in the territory being studied, with huge implications both for the research and for the planning of cities and neighbourhoods.

3. Results

This section portrays the main results obtained following the methodological strategy with the intention to answer our research objectives related to the discussion of the concept of vulnerability and the validation of an integrated vulnerability index. After the selection and inclusion of 19 indicators in our model, we conducted a factorial analysis that resulted in the formation of four subindexes and an integrated comprehensive measure of vulnerability, which we named IVI. The implications of these measurements are presented in this section. Secondly, the application of the IVI to the city of Barcelona resulted in the construction of four partial maps—related to the four dimensions of vulnerability previously identified—as well as final map portraying the different neighbourhoods of the city in a vulnerability continuum. These maps are analysed, according to recent data, as well as following recent findings from academic work. Subsequently, an analysis of the implications of our results in terms of research and public policy is presented.

3.1. The IVI Factors

After normalising and standardising the values for each of the 21 indicators introduced into the model, two variables were excluded, resulting in aa total of 19 indicators which were introduced into the factorial analysis, obtaining robust results: four subfactors and statistical confidence. To account for the suitability of the FA's results, two of the most commonly used alternatives are the Kaiser–Meyer–Olkin (KMO) test and the Bartlett test of sphericity. In our case, as can be seen in Table 3, the KMO was greater than 0.7, and we were statistically able to accept the proposed model. At the same time, the significance tended to 0, showing that the model is statistically reliable.

Table 3. KMO and Bartlett test.

Kaiser–Meyer–Olkin Measure of Sampling Adequacy		0.776
Bartlett's test of sphericity	Approximately chi-square	1716.212
	df	171
	Sig.	<0.001

Source: Prepared by the authors.

The factorial analysis resulted in the formation of four factors differentiated from each other, but whose components were related, altogether explaining 81.03% of the total variance of data. As Table 4 shows, the first three factors explained between 22.8% and 23.7% of the total variance, while the last one explained 11.4%.

Table 4. Total of the explained variance.

Factor	% Variance	% Accumulated Variance
1	23.722	23.722
2	23.095	46.817
3	22.783	69.601
4	11.432	81.032

Source: Prepared by the authors.

The composition of each of the factors obtained, i.e., the indicators included in each of them, is presented below.

Factor 1: Social class

- Price of the square meter of the dwellings
- Percentage of people with a university education
- Percentage of people with basic education
- Available family income

Factor 2: Gentrification

- Age of the dwellings
- Percentage of tourist accommodation
- Number of entities per neighbourhood
- Percentage of foreigners
- Percentage of young population
- Premises property of private foreign owners

Factor 3: Social and employment

- Percentage of people with vocational training
- Percentage unemployed
- Percentage of people who abstained in the last elections
- Percentage of people over 65
- Percentage of people with non-contributory pensions
- Sex ratio

Factor 4: Physical and architectural

- Percentage of flats with lifts
- Average surface area of the housing (m^2)
- Percentage of housing with heating

Each of the four factors obtained by the FA accounted for a specific dimension of vulnerability, while their sum conformed the integrated vulnerability index. The names of the subfactors were given, following the literature on the subject, as well as by conducting some analysis of the variables' relations. In the next subsection, the results of applying this index to the city of Barcelona—by using geographic information systems—provide us a reading of the spatialisation and distribution of each of these factors, as well as the IVI, for the different neighbourhoods of the city.

3.2. The IVI and Its Implications for Barcelona

The maps for each of the four factors, along with the synthetic index, are summarised here, and show the distribution of the vulnerability dimensions, along with the IVI for all the neighbourhoods of Barcelona. The areas of the *Collserola* mountains and the city port were eliminated from the map. Thus, the results are displayed more clearly, given that only the mostly urbanised areas are depicted, which are, in short, artificial land, with the presence of commercial premises, amenities, and/or housing, among others.

The first dimension, which we called 'social class', groups different variables related to education, income, and dwelling prices. Given its composition, and following recent studies, it is clear that the variables selected by the model account for a sort of measurement

of the difference in status between an individual and others in social life ([Kraus et al. 2009](#)). Of course, many efforts have been made to define and operationalise the concept of social class. This is not the place to give such a discussion, which we do believe of importance to the sociological field. The distribution of this factor is portrayed in the first of the maps obtained in Figure [1](#), showing a certain concentration of problems, particularly inside the *Nou Barris* district, and some neighbourhoods of the *Sant Andreu* and *Horta* districts. At the same time, some particularly dark red areas can be seen in the neighbourhoods near to the course of the River *Besòs*, and then some areas in the central *Ciutat Vella* district. Those results are coherent and complementary to recent studies considering the territorialisation dynamics of inequalities in the city ([Nello 2018](#); [Borrell et al. 2020](#); [Checa et al. 2020](#); [Checa and Nello 2021](#)). They also coincide with and endorse the prioritisation of areas of action of some local policies, such as the *Pla de Barris*, which seeks to equate the baseline conditions between different areas of the city, based on investments in education, social rights, economy, housing, public space, and energy.
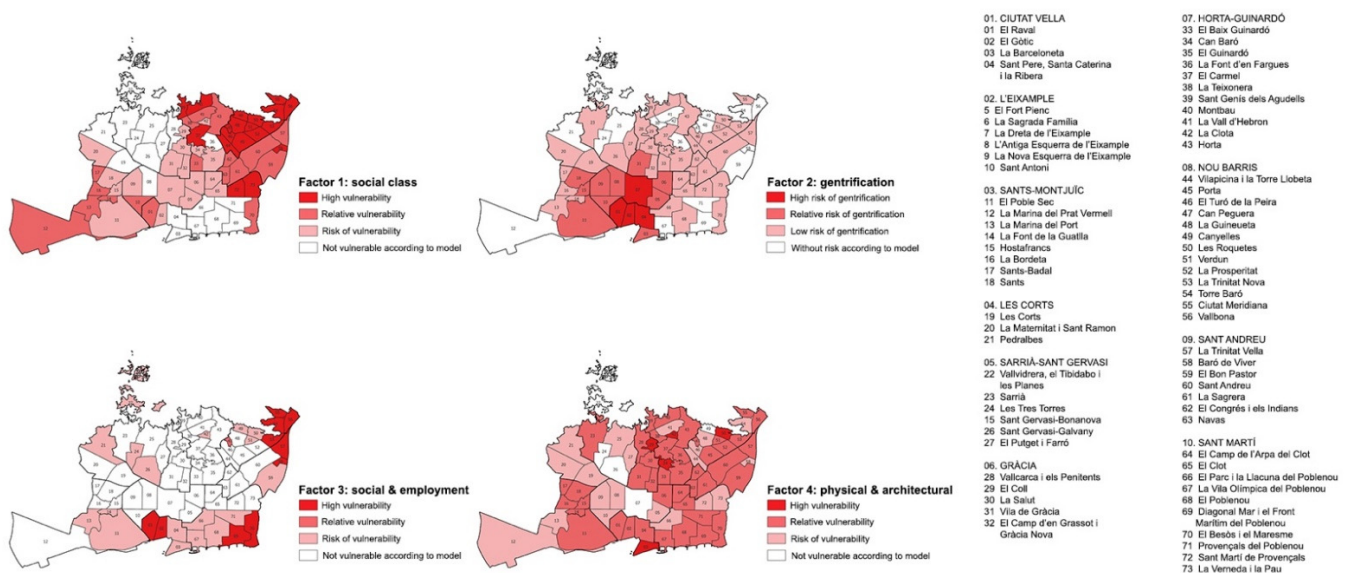
Figure 1. Maps identifying the dimensions of the vulnerability obtained from the factor analysis, linked to social class, gentrification, social and employment, and physical and architectural dimensions, showing the 73 neighbourhoods of Barcelona. Prepared by the authors.

In turn, the second map of Figure [1](#)—linked to the areas identified as the most vulnerable in relation to the 'gentrification' dimension—show that the most affected areas are those around the *Ciutat Vella* district and part of the *Eixample*. This potential threat of gentrification is related to some social and economic trends that are subject to change, something that has been gaining more and more attention in recent research. Although its study necessarily implies a deep analysis of the behaviour of both socioeconomic and urbanistic trends throughout time, some current empirical data can still give us a partial, yet general idea of what is going on in some neighbourhoods that might be undergoing certain rapid changes that may or may not pose a threat. Recent research shows that gentrification usually causes supply, facilities, and services to shift away from the resident population's needs to those of new inhabitants and also tourists ([Gonzalez-Morales et al. 2021](#)); this is the general representation of what is going on in the Ciutat Vella district, witnessing resistance from its residents to problems such as excessive noise, modification of commercial profile, loss of social bonding, and expulsion of population due to price appreciation. Of course, a priori having many restaurants or hotels cannot be displayed as good or bad, since attraction of tourists results in economic gain, but recent research has been putting into question the sustainability of a too-touristic-wise model, forcing the local government to come up with specific legislation for these areas in order to partially

control some of these trends (rent price control, maximum number of hotels, formalisation of Airbnb contracts, etc.).

Using open-source statistical databases, some indicators have been tracked in time in order to account for this factor related to rapid change or transition of the neighbourhood's profile. When comparing data from 2015 and 2021 for the neighbourhoods that have been identified as vulnerable by this specific factor, variables such as 'housing for touristic use', 'available family income', or 'percentage of young people' all show increasing values. The fact that the population's composition is rapidly changing in areas such as the *Ciutat Vella* district (showing an increase of 15% in family income, an increase of around 5% in the percentage of young residents among the total population, and a rise in the number of housings for touristic use of around 2%) may imply economic change and touristification. In fact, older residents in these neighbourhoods are leaving more and more often towards less central areas of the city, implying some degree of expulsion.

When analysing the gentrification dimension, the most affected neighbourhoods seem to be *Raval*, *Gòtic* and *Born*, along with the central part of the *Eixample*. It is no coincidence since those are the locations where there is greater concentration of tourist flats and a very widespread and diversified commercial activity. In turn, they are areas where there is great coexistence of problems in the public space, higher noise levels, etc. At the same time, the living conditions in many of those buildings are poor, an issue that is particularly aggravated in the *Ciutat Vella* district. This is down to the age of the building stock and to the lack of building maintenance, partly due to improvement being impossible given the material living conditions of most of their residents, along with the fact that the building stock is usually protected due to its historical value. Once again, these results are in line with recent studies that report on the consequences of gentrification in the city, particularly in the aforementioned neighbourhoods (López-Gay 2018; López-Gay et al. 2019), along with other research focusing on the difficulties of part of the population to access urban renewal programmes and subsidies (Piasek et al. 2021) given their economic and social conditions, as well as a result of the inherent dynamics and conditionalities of some of those same policies.

The third factor addressing the 'social and employment' dimension of vulnerability includes both sociodemographic and work-related variables. Sex, age, participation and work-related variables are all partially represented in this factor. This subindex speaks of the degree in which the residents are more or less integrated in work and civic life, accounting for some sorts of social capital. The concept of disaffiliation has been widely studied in relation to vulnerability (Castel 1991). The third map in Figure 1—linked to the social and employment-related vulnerability—depicts certain areas which appear as the most vulnerable ones. On the one hand, there are certain neighbourhoods of the *Nou Barris* district, some neighbourhoods of the *Sant Martí* district, particularly those close to the River *Besòs*, and the *Gòtic* and *Raval* neighbourhoods, in the *Ciutat Vella* district. As can be seen, most of the 'central' city apparently does not show any risk of vulnerability. We can again associate these results with recent studies explaining the differences between neighbourhoods as a function of training and socio-professional integration (López-Gay 2016), the degree of centrality and localisation (Pareja-Eastway and Simó-Solsona 2014), and the role of immigration (Hernández-Aja et al. 2018), among others.

Lastly, as far as the physical and architectural vulnerability is concerned, an initial reading of the fourth map (Figure 1) shows that most of the city has at least some degree of vulnerability, which would indicate an imperative need for the building stock to be retrofitted in terms of energy, accessibility, and/or safety. Areas with situations of extreme fragility, particularly in the *Barceloneta* neighbourhood and some areas of *Nou Barris* and of the *Horta* district, can also be observed. The fact that some areas of the *Sarrià* district appear as problematic could be indicating a lack of lifts, even though that is not accidental, as there are some areas with nonvulnerable single-family houses.

Then, the synthetic index obtained starting from the four factors arising from the FA indicates certain areas of the city of Barcelona with greater or lesser concentration of

vulnerability. As we can see, this is linked to social class, gentrification, physical and architectural, and social and employment dimensions, as components of the IVI. The final calculation of this index was made by adding each of its components, obtaining a final measurement of integrated vulnerability.

As an initial observation, we can identify some areas with higher levels of vulnerability as shown in Figure 2, particularly in the *Ciutat Vella* district, followed by some areas of the *Sants-Montjuic*, *Besòs-Maresme*, and the *Nou Barris* districts, along with some neighbourhoods in *El Carmel* area. These results are relevant since they allow us to concentrate our attention on areas that may require some sort of assistance, while making us ask ourselves about the origin of these inequalities and whether these unequal situations are new or are actually long-standing. Some of these questions are addressed in Section 4. However, we may now say that the highlighted areas of the maps and most of our results are similar to those obtained in earlier studies (Garcia-Almirall et al. 2017; Hernández-Aja et al. 2018) that either worked on smaller scales (census section or plot), or only took a few indicators into consideration (illiterate population, unemployment, and constructive quality of the housing; the migrant population percentage was added later), respectively, which speaks to a certain validity of our study. In any event, the results obtained using an FA with 19 multidimensional indicators at a neighbourhood scale are worthy of consideration.
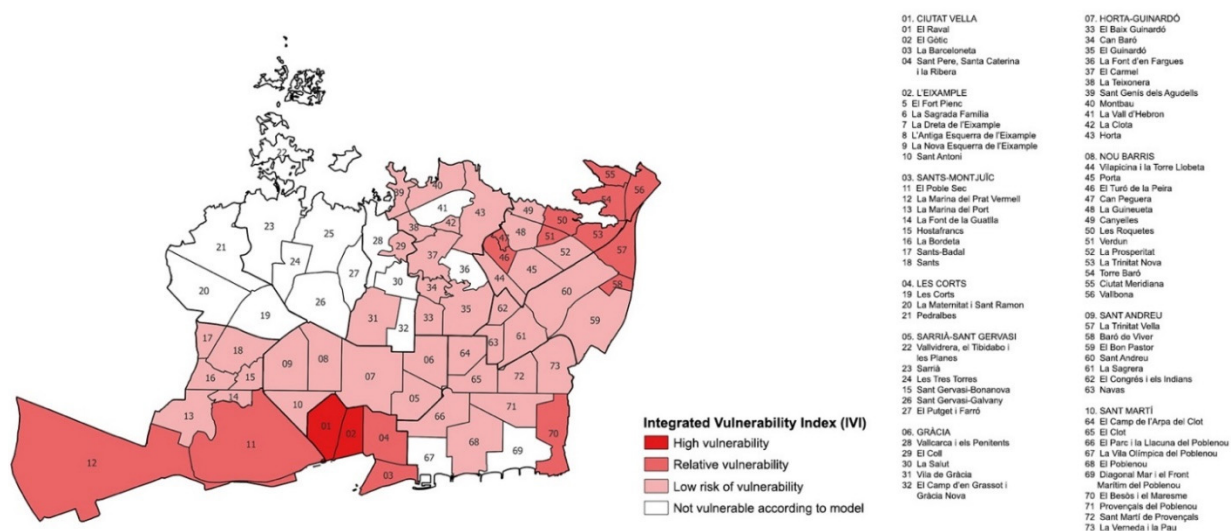
Figure 2. Result of applying the integrated vulnerability index (IVI) to 73 neighbourhoods of the city of Barcelona. Prepared by the authors.

4. Discussion

The objective of this research was to discuss the scope and limitation of the concept of urban vulnerability, whilst generating an index that detects its multidimensionality. This index was applied in the city of Barcelona, allowing its neighbourhoods to be positioned on a vulnerability continuum. In this section, the results obtained by the application of our index in the city of Barcelona are compared with other recent studies, in order to assess whether the territories identified as vulnerable coincide with each other, and to discover whether certain neighbourhoods have modified their profiles over time, asking ourselves how we could explain this behaviour. Coincidence as a vulnerable territory over time may be an indicator of structural poverty, while the noncongruence of neighbourhoods may point to situations of improvement or deterioration in some of the dimensions of vulnerability, changes to the living standards of the resident population, the retrofitting of property, more or less successful urban renewal processes, etc. The analysis of this or such cases would require much deeper analysis that this work does not contemplate at this point; however, although it is outside the purposes of this paper, we try to present some general ideas intended to orientate future research and/or policy.

Nearly all the neighbourhoods identified as vulnerable by the IVI (except for *Baró de Viver*) coincide with the neighbourhoods defined as vulnerable by either of the two earlier models presented in Table 5. It should be noted that the proposal of Hernández-Aja et al. (2018) identified a total of 47 (out of a total of 73) vulnerable neighbourhoods of the city (to different degrees), while that of Garcia-Almirall et al. (2017) worked on a microscale, before transferring the results to a neighbourhood level. At this point, this first comparison speaks of a certain degree of validation of the IVI; nevertheless, this index's main contributions remain to be revealed.

Table 5. Cross-checking results obtained from the IVI with earlier indices.

Neighbourhood	Hernández-Aja et al. (2018)	Garcia-Almirall et al. (2017)	IVI (2022)
La Barceloneta	X		X
El Born	X		X
El Gòtic	X		X
El Raval	X	X	X
Poblesec	X		X
Hostafrancs	X		
Sants	X	X	
Vila de Gràcia	X		
Sant Antoni	X		
El Fort Pienc	X		
El Coll	X		
El Carmel	X		
El Turó de la Peira	X		X
Porta	X		
Verdum	X		X
Roquetes	X		X
Trinitat Nova	X		X
Torre Baró	X	X	X
Ciutat Meridiana	X	X	X
Trinitat Vella	X	X	X
El Bon Pastor	X	X	
Sant Martí	X		
La Pau	X		
Besòs-Maresme	X	X	X
Prov. del Poblenou	X		
Poblenou	X		
Valbona		X	X
Can Peguera		X	X
La Clota		X	
Marina		X	X
Baró de Viver			X

Source: Prepared by the authors.

At the same time, the proposed IVI validates the conclusions of contemporary studies regarding certain areas that have been transformed in the city in recent years, confirming that central neighbourhoods such as *Sant Antoni* and *Gràcia* probably no longer correspond to vulnerable areas. This is related to the fact that they have experienced economic, physical, and social improvement in terms of its indicators, which also point to (very) probable gentrification processes. Issues of this type are also appreciable when comparing the results from 2011 with the current ones for certain neighbourhoods of the *Sant Martí* district, which give evidence of the major upgrading processes of recent years with the development of *22@* and *Diagonal Mar* districts. The question raised here is whether those processes of improvement are due to real cases of upward mobility of the resident population, or if they have actually more to do with expulsion and, therefore, a certain transformation of the typical residential profile in those areas. Cross-referencing indicators of remaining or

mobility within the neighbourhood, along with a qualitative approach could help shed light on this matter, orientating possible future research.

On the other hand, another thing worth mentioning is that, despite the effort of local policies and programmes, the results of this paper show the persistence of areas of high vulnerability over time, as we could refer to possible spaces of structural poverty in the city, particularly in the *Besòs-Maresme* area, in some sectors of the oldest district of the city, and in some neighbourhoods of the *Nou Barris* district. Consequently, innovative methodologies, both for the study and identification and for the intervention of vulnerable urban areas, which seek to level the starting baseline of all citizens, should focus firstly on the specific areas identified by the IVI, while keeping a close eye on new or potential vulnerability spaces identified in the city as a result of applying our index. Another positive aspect is the fact that this research also accounts for vulnerability measures on each of the four factors or dimensions. This can help us better focus the efforts of intervention in one or another direction. Lastly, this index should be repeated on a regular basis, allowing a follow-up and cross-reference of some variables that may require an analysis throughout shorter or longer periods of time, such as those related to gentrification.

5. Conclusions

We are now in a position to pinpoint some questions arising directly from our research, which have implications both for the study and for the intervention of urban vulnerability. The ideas here presented are in the form of key findings, recommendations, and/or practical implications derived from our results.

First, this article allows us to argue for the need to study vulnerability as a multidimensional phenomenon. The 19 indicators finally included in the model resulted in—following the use of statistical techniques—four dimensions linked to social class, social and employment, physical and architectural, and gentrification. Vulnerability is, thus, complex and multicausal. In this regard, any initiative that seeks to study and/or act on the offsetting of the harmful effects of vulnerability should also be as comprehensive.

This research sheds some light on the main dimensions that are key to the study of urban vulnerability. The IVI provides a simple and unique image of reality, while the partial indices show the origin of the vulnerability in a more complex and specific way. In contrast to other indices, the IVI includes variables of different spheres in order to provide a multidimensional and more accurate image of the reality, not only from a socioeconomic or demographic aspect.

Very often, research and policy decisions have relied on indices to quickly and unanimously label Spanish neighbourhoods according to their vulnerability. Specifically, the indices used have been those promoted by the ministry (Hernández-Aja et al. 2018), which show some limitations. The first is that they only use census information. This means that they can only be updated every 10 years resulting in 2011 as the latest photograph available. The second limitation is related to the three indicators on which the index is constructed: percentage of unemployed people, percentage of people with no education, and percentage of dwellings in buildings in poor conditions. These indicators show only extreme vulnerability, leaving out other previous stages or relevant dimensions. In an attempt to overcome these limitations, the proposed IVI provides, on the one hand, a greater capacity to update by not using only census information, providing a much richer photo. On the other hand, by including other variables and dimensions, it confers greater multidimensionality and explanatory capacity. In this sense, and considering that vulnerability is a multidimensional phenomenon, the partial indices show the dimension in which an urban area shows greater risk in one or more aspects. This constitutes a fundamental contribution to the diagnosis and design of public policies adapted to each territory.

The application of this tool to the case of Barcelona revealed some areas of the city with a concentration of one vulnerability subtype or another. Some neighbourhoods of *Ciutat Vella*, *Sant Martí*, and *Nou Barris* seem to be particularly relevant, in keeping with findings of the recent literature. The follow-up of some neighbourhoods' behaviour could

be crucial in terms of preventing potential physical deterioration, gentrification, or silent expulsion tendencies.

Lastly, it should be stressed that the application of the IVI to Barcelona proves that it is important to constantly obtain an updated and 'early' identification of complex situations of inequality and vulnerability. Moreover, this should trigger a proactive response by stakeholders involved in the planning and production of the city, from a perspective of human rights and social justice.

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