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Urban and social vulnerability assessment in the built environment: An interdisciplinary index-methodology towards feasible planning and policy-making under a crisis context

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ABSTRACT

The current global crisis on Covid-19 has an adverse impact on urban regeneration of the built environment in emerging countries, with a recent world GDP drop of around 4.9 % and around 20–30 % decrease in economic funds intended for renovation policies, being required new decision support mechanisms to diagnose and quantify the vulnerability of existing neighbourhoods, aiming to conduct feasible and adjusted regeneration strategies. This research contributes with a novel interdisciplinary index-methodology for assessing the adequacy of housing environments with social backwardness, based on a dual weighting procedure of four main dimensions: Building, Urban, Environmental and Social (BUES), calculated through technical inspections, from technicians, together with social questionnaires, from users, with respect to 32 variables related to housing environments, urban services, and environmental issues. The operation and replicability of the system are tested in two representative neighbourhoods from Mexico and Spain, identifying most important weaknesses and needs according to each variable and displayed results, discussing a 0.7 points of deviation average from technicians and users in a 1–5 Likert scale. Conclusions incorporate important outcomes for urban policy-makers and technicians, providing methodological implications for adjusting public aids to promote effective regeneration guidelines based on a proper decision-making under an austere economic context.

1. Introduction

Global reports (United Nations, 2021; WHO, 2015) have established in recent years the urgency of adjusting urban and social decision-support tools to effectively adapt and renovate the built environment, in their most vulnerable areas, in order to comply main current regulatory requirements, in terms of habitability, mobility or comfort, following the established targets of the Sustainable Development Agenda or the European Agenda for Sustainable Buildings (GBCe, 2020). There is a growing difficulty with respect to obsolescence and deterioration in existing neighbourhoods, due to the expansion of cities carried out in the second half of the 20th century, which increasingly affects the well-being and quality of life of citizens, especially the vulnerable population (Carpino, Bruno, & Arcuri, 2020; United Nations, 2018). European reports state that more than 40 % of neighbourhoods were built over 50 years ago and around 85 % of residential buildings are over 25 years old (European Commission, 2017; Eurostats, 2019), demonstrating the need to design appropriate assessment models and decision support systems that incorporate technical, social and economic disciplines to promote towards an effective and sustainable integrated urban regeneration in the coming years (Gandini, Quesada, Prieto, & Garmendia, 2021; Serrano-Jiménez, Barrios-Padura, & Molina-Huelva, 2018).

The global health crisis due to COVID-19 will have an impact on economic, social and urban policies in the near future, with a world GDP drop of around 4.9 % in 2020 and an expected decrease in urban funds and priorities towards urban regeneration of cities, thereby making a higher challenge to adjust urban guidelines and optimise public resources in the urban, social and housing fields (OECD, 2021; WHO, 2020). This situation highlights the need to help governments with indicators that allow objectively to detect certain parameters and urgencies that must be addressed with public investments, considering the real needs from users and also addressing sustainable development goals (United Nations, 2021), as an economic promotion for recovering the
decline GDP in the post-Covid-19 crisis from the sector of construction, being this impact more pronounced in vulnerable countries where extreme poverty is estimated to return to percentages of 20 years ago (CONEVAL, 2020; European Commission, 2020b; The World Bank, 2020).

Under these circumstances, there is an increasing line of research which is related to deal with the complexity for policy-makers to incorporate successful and feasible renovation guidelines in the built environment, as Diaz-Lozano and Siegel (2018) and Stanganelli, Torrieri, Gerundo, and Rossitti (2020) focus in their studies. The alarming context raises the demand of incorporating new mechanisms that assess the vulnerability of urban spaces and buildings, involving important regulatory non-compliances and daily inconveniences for users, that must be quantified from multiple approaches to identify action strategies and determine priorities in the built environment (European Commission, 2018). The literature review developed for this research in Section 2 highlights, as concluded Ibarloza, Malles, Ibarloza, and Heras-Saizarbitoria (2018) for this research topic, that there is lack of decision support procedures that sensitively analysed the situation of vulnerable and deteriorated neighbourhoods from a technical, urban, social and environmental perspective, being useful for promoters, administrative entities and policy-makers for obtaining an integral assessment, discussing results and identifying priorities for renovation strategies according to each urban and socioeconomic context.

This paper designs and develops a novel index-methodology for obtaining a multidisciplinary assessment of multiple technical priorities and social needs that exist in the built environment, especially in vulnerable regions with limited resources, offering a weighting procedure that allows to see through results indices the main shortcomings and weaknesses to solve in buildings, housing spaces or urban areas, towards a more efficient and sustainable management of cities. The final aim is to establish an indicator guide that serve as a basis for achieving support based on renovation policies, adjusting new indicators from a technical and social perspective and displaying them on various action scales. The novelty of this approach fulfils the existing research gap by combining priority values from technical inspection sheets, filled by technicians, along with survey results related to demands and needs from users, in order to quantify and check independently the deviation results of 32 quantitative and qualitative multidisciplinary variables, which are organised in 4 main dimensions (BUES): 1. Building, 2. Urban, 3. Environmental and 4. Social. The usefulness of the model will serve to optimise public and private funds in urban regeneration and visualise overall results for decision-making by gathering a dual diagnosis and interrelating indexes from technicians and users, to finally identify the main action priorities and urgencies for each dimension and determine feasible and satisfactory action proposals.

As its main contribution, this BUES index-methodology incorporates a new mechanism for diagnosis and a weighting procedure based on multiple factors and disciplines related to housing environments, indoor/outdoor environmental quality, urban services and other multidisciplinary issues, linked to technical requirements and social demands in vulnerable areas, aiming to provide policy-makers, municipalities and promoters with particular and global results as a decision support system for the built environment. The following sections present a literature review of the related research topics and their main research gaps, subsequently defining and justifying the proposed BUES index-methodology; and its application and testing in two reference neighbourhoods from Mexico and Spain. The key results and the main conclusions will be finally discussed regarding its replicability and insights.

2. Literature review

Table 1 highlights the main reference studies from the literature review, defining for each work their main contributions, novelties and detailing certain gaps according to different research topics. These reference papers represent important outcomes for each research field and have incorporated relevant approaches for the aims and the design stage of the proposed BUES decision support system. Carrying out an analysis of the references in their different topics, there is a current demand in recent studies to incorporate multidisciplinary approaches for promoting effective actions in the built environment.

Table 1
Main contribution, findings or gaps of related research on their subsequent topics.

| Topic | Research paper | Contributions / Gaps |
|-------|----------------|----------------------|
| Multidisciplinary assessment of the built environment | da Cruz et al. (2021) | • A multi-indicator model for identifying urban areas of higher need of funding. |
|        | Kumar, Ramkumar, and Samanta (2018) | • Pending gap on how to analyse various criteria in urban planning decisions. |
|        | Moghadernegad et al. (2018) | • Enhance urban renewal as a major challenge in improperly planned cities. |
|        | Garrido-pierro and Mercader-moyano (2017) | • Incorporate 27 socio-technical variables into policy-making in South India. |
|        | Serrano-Jimeinez et al. (2020) | • Propose a multi-criteria tool to assist designers for the best façade solution. |
|        | Aigwi et al. (2019) | • Particular study only focused on façades but interesting to extrapolate. |
| Combination of Technical and social variables | Kamaruzzaman et al. (2018) | • Multidisciplinary rating of eco-efficient actions for implementing in housing. |
|        | Li et al. (2018) | • Difficulties of including users’ demands in the action proposal model. |
|        | Santangelo and Tondelli (2017) | • Combine technical diagnosis and residents’ perceptions for decision-making. |
|        | Stanganelli et al. (2020) | • Reduced approach on social indexes for the complex building renovation. |
|        | Monzín and López-Mesa (2018) | • Guidelines to balance interests from all stakeholders on building renovation. |
| Index-Methodology as Decision support systems | Riera Pérez et al. (2018) | • Highlight the absence of ranking model for choosing action proposals. |
|        | Liang et al. (2016) | • Incorporate weighting system for decision-making applied on many themes. |
|        | Olsson et al. (2016) | • Exploratory study that gathers certain survey responses with reduced sample. |

Table 1 highlights the main reference studies from the literature review, defining for each work their main contributions, novelties and detailing certain gaps according to different research topics. These reference papers represent important outcomes for each research field and have incorporated relevant approaches for the aims and the design stage of the proposed BUES decision support system. Carrying out an analysis of the references in their different topics, there is a current demand in recent studies to incorporate multidisciplinary approaches for promoting effective actions in the built environment.
environment, even higher due to the current crisis on Covid-19 (WHO, 2020). The work published by da Cruz, Marins, and Kurokawa (2021) demonstrate the usefulness of facing the urban regeneration challenge by assessing the technical, economic and social fields, among other environmental parameters that ensure sustainable interventions. In fact, the methodology proposed by Garrido-piñero and Mercader-moyano (2017) already gave different scores, from different disciplines, to know the validity of eco-efficient actions in housing renovation.

Another important premise in recent years is to combine technical perceptions, through inspections carried out by architects, builders and other construction firms in relation to the thermal deficiencies and conservation status, together with the perceptions, demands and preferences of the resident population, as published Kamaruzzaman, Lou, Wong, Wood, and Che-Anti (2018) and Li, Zhang, Ng, and Skitmore (2018) in their recent works. Serrano-Jiménez, Lima, Barrios-Padura, and Molina-Huelva (2020) and Santangelo and Tondelli (2017) already introduced the use and integration of questionnaires to determine action proposals in housing renovation, although both studies do not incorporate an integral assessment that considers the influence of the occupant’s preferences of works.

The design and development of decision support systems have emerged in recent studies, in their multiple applications, as an effective mechanism to be applied in different built environments in order to analyse and decide most suitable interventions (Liang, Peng, & Shen, 2016; Riera Pérez, Laprise, & Rey, 2018). The works developed by Monzón and López-Mesa (2018) and Stanganelli et al. (2020) incorporate decision support models as a successful procedure to guarantee feasible and sustainable actions, although both models have been specifically designed just for energy retrofitting in existing buildings, without taking into account participatory questionnaires from users. Lastly, Olsson, Malmqist, and Glaumann (2016) already concluded in a theoretical reflection that the ideal model for deciding effective actions in housing renovation should be based on decision support protocols by analysing multiple factors under different action scenarios.

However, this literature review demonstrates the lack of integral and multidisciplinary assessment systems that can be focused on vulnerable neighbourhoods of the built environment, from both technical and social perspectives, missing assessment procedures that can allow the quantification of multiple variables and dimensions for decision-making, in order to distribute public funds and adjust resources for a proper city management, as promoted by United Nations (2021) and GBce (2020).

3. Methodology

Following the main aim of establishing an integral assessment model through multidisciplinary indicators for policy-making in vulnerable environments, Fig. 1 represents a graphic outline of the proposed BUES index-methodology, which is based on two main methodological principles to conduct a proper assessment of the built environment (Cinelli, Coles, & Kirwan, 2014): 1. Analytical Hierarchy Process (AHP), that compares alternatives and ranks different criteria according quantitative and qualitative parameters; and 2. Multi-attribute utility theory (MAUT), which quantifies different measurements and units on a standardised comparison scale (1–5 or 0–1), according to the stakeholder preferences. The combination of both principles seeks to gather the objective technical situation of the built environment and the social backwardness that exist in certain vulnerable neighbourhoods, as an appropriate decision support system for urban environments, being structured in 4 main dimensions and comprising a total of 32 qualitative and quantitative variables, whose technical urgencies and social demands are respectively obtained through technical inspection grids and survey responses.

The proposed methodology follows standardised stages defined within the selected methodological principles of decision-making: 1. Identify problems and constraints; 2. Determine requirements; 3. Establish goals; 4. Define criteria; 5. Outline methodological principles for the decision-making tool; 6. Design a weighting procedure for the graphical output of results and 7. Develop a sensitivity analysis for the validation of solutions and alternatives for each socioeconomic context.

The following subsections define the utility of this BUES index-methodology for decision-making and urban planning, defining the 4 dimensions (Building; Urban; Environmental; and Social) and the 32 variables along with their weighting procedures, in order to graphically represent the multidisciplinary results as a decision support system. This methodology is going to be tested and validate through the graphical output of results and its usefulness for deciding action strategies for policy-makers and local governments, thereby highlighting the main contributions and insights for the built environment.

3.1. BUES Index-Methodology for urban vulnerability assessment

The proposed decision support system for the built environment incorporates a novel approach to obtain an urban vulnerability assessment by combining the results from technical inspection documents and participatory social questionnaires of neighbourhoods, through 32 representative variables related to urban spaces and housing environments, in their different scales, which have been classified in 4 main dimensions. The selected 32 variables belong to technical, urban and social standards, which involve the assessment of buildings, public spaces, housing environments, indoor and outdoor environmental conditions, basic services as well as the social relationships and users’ needs in their housing and urban environments, having incorporated certain variables that were used in the design of previous assessment models and weighted indices from referenced works, such as the one developed by Riera Pérez et al. (2018); Kamaruzzaman et al. (2018) and Delmastro, Mutani, and Corgnati (2016).

The dimension is a key concept, already used in recent works such as Ali and Hashlamun (2019) or Mercader-Moyano, Flores-García, and Serrano-Jímenez (2020), which is useful to classify the set of quantitative and qualitative variables regarding the different technical, social, economic or environmental fields, thus facilitating decision-making towards a sustainable regeneration of the built environment in vulnerable neighbourhoods under precarious socioeconomic conditions. The four dimensions are 1. Building, 2. Urban, 3. Environmental and 4. Social, in order to organise the results of diagnosis, through technical priority levels and needs from users, as well as provide action proposals in each scale according to multiple disciplines. The 4 dimensions are further defined as follows:

- **Building** ($D_1$) gathers architectural, design and technical attributes related to the building assessment, its composition and its elementary supplies. Each typology will be assessed by diverse patterns related to materials, aesthetics and thermal performance and also the conservation status of the envelope, all of them related to provide comfort conditions for users in vulnerable environments.

- **Urban** ($D_2$) integrates eight variables linked to assess mobility, safety and comfort conditions in the existing urban environment, aiming to introduce useful improvements towards a more efficient operation of the built environment. Aspects such as the presence of physical barriers, the composition of streets and open spaces, as well as the suitability of paths are going to be assessed and weighted with respect to urban regulations, regarding the compliance of regulations and conservation status.

- **Environmental** ($D_3$) focuses on quantitative and qualitative parameters related to the indoor/outdoor environmental quality in which the building and urban space are located, in order to measure and quantify the suitability of basic parameters for ensuring comfort and air quality of users, such as lighting, ventilation, acoustics, indoor air quality, among others.

- **Social** ($D_4$) incorporates variables to assess well-being, uses and feelings of residents regarding their built environment, measuring and quantifying parameters such as habitability, access to basic
services, use and maintenance, and other aspects related to improving the city management. The obtained values are measured with respect to technical regulations and local guides for sustainable management of cities along with their preferences. As an original contribution, the obtained values in these variables complement the priority and determination of the action proposals to be carried out together with the results obtained in the other three dimensions.

The criteria to identify and select 32 variables, organised in 4 dimensions, follows basic urban principles established in world cities reports on comfort, safety and security in vulnerable areas of the built environment, specially published in United Nations - Habitat (2007) and United Nations (2020). These established principles have been combined with technical regulations, representative patterns of social housing and demands from users and policy-makers, aiming to improve the management of urban environments (European Commission, 2020a; IEA, 2017; Trotta, 2018). The selection of these 32 variables aims to gather representative and standardised aspects to be quantified for providing urban vulnerability indices, all of them regarding technical urgencies and social demands, being a flexible sample that could be extended for particular urban and socioeconomic contexts and specific approaches.

Tables 2a and 2b gathers and defines the 32 variables considered for each dimension, and subsequently presents the valuation scale for quantifying the Technical level of urgency ("T"), from mild to immediate, and the Need responses ("N") obtained from users, from unnecessary to highly necessary. In order to obtain independent and standardised values for each variable, a weighting system is used that is based on normalised means, as followed Vafaei, Ribeiro, and Camarinha-Matos (2018), that allows regulating the scores of all the variables on the same scale to be discussed and compared. The valuation procedure is carried out in a dual way from technicians and users, obtaining average scores between 1–5 for each one, weighted on the same rating score by using the Likert scale, referring to the level of technical urgency to carry out retrofitting actions in each area, and on the other hand, the level of demands and needs expressed through questionnaires. Both the proposed technical inspection sheet and the social questionnaire for users are included as supplementary material in Annex I.

The calculations are obtained by weighting through normalised means all the technical and social scores assigned for each variable ($v_T; v_S$), depending on the number of the sample in the technical field ($x$).
or the number of participants (p), which quantifies the sample of users who provide demands and needs. The sum of each variable will be weighted in a range of values between 1 and 5, according to expression [1] and [2]. Then, following expressions [3] and [4], each of the determined 8 variables that correspond to each dimension will be determined. Then, following expressions [3] and [4], each of the variables will be weighted in a range of values between 1 and 5, according to expression [1] and [2]. Then, following expressions [3] and [4], each of the determined 8 variables that correspond to each dimension will be weighted with respect to Technical priority and Social needs with respect to the maximum value established (\(v_{\text{T-S max}}\)), in order to obtain both final values (\(T/S_{D_{n}}\)) for each dimension in a final scale between 0 and 1. Expressions [1] to [4] are detailed below with a brief legend of their symbols:

\[
\begin{align*}
[1] & \quad V_{1.2...8} = \left(\sum_{i=1}^{8} v_{i}\right)/8 \\
[2] & \quad V_{1.2...8} = \left(\sum_{i=1}^{8} v_{i}\right)/p \\
[3] & \quad T_{D_{n}} = \frac{\sum_{i=1}^{8} v_{i} - n_{i}}{(n_{i} + v_{\text{max}}) - n_{i}} \times 10 \\
[4] & \quad S_{D_{n}} = \frac{\sum_{i=1}^{8} v_{i} - n_{i}}{(n_{i} + v_{\text{max}}) - n_{i}} \times 10
\end{align*}
\]

\(T_{D_{n}}\): Final Technical/Social index weighted for each Dimension (D) according to the variables; \(V_{T-S}\): Technical/Social score for each variable; \(\times\): Num. of collected technical inspection sheets; \(p\): Num. of participants in social questionnaires; \(n_{i}\): Num. of weighted variables for each Dimension; \(v_{\text{T-S max}}\): Max. technical or social valuation for each variable.

Therefore, the results obtained are dual with respect to the technical and social disciplines to identify best opportunities for improvement, allowing this system to compare the partial and overall performance and determine the importance of each dimension through a sensitivity analysis. The proposed technical priority level (TJ) together with the level of needs (NJ) have enriched the integral diagnosis and multidisciplinary assessment for designing efficient proposals with respect to current regulations and social standards, incorporating a flexible and adaptable notion that ensures the validity of the BUES index-methodology, being able to extend with new dimensions or variables to different urban or socioeconomic scenarios, in order to replicate it to different case studies in any city and country.

### 3.2. Case studies of application

This paper aims to test and check the operation of the designed BUES index-methodology assessment for decision-making in urban planning, so this subsection defines two representative case studies that have been selected in Mexico and Spain, as countries that have suffered great financial damage from the pandemic, especially in Mexico, where the poverty rate is expected to affect 2/3 of the population, and whose consequences will be suffered by vulnerable neighbourhoods in their cities [CEPAL, 2021; Government of Spain, 2020].

Both selected neighbourhoods incorporate representative patterns of social housing in the built environment of many countries [United Nations, 2018], which were built at least 40 years ago and involve obsolete environments with difficulties to afford renovation actions in

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**Table 2a**

Dimensions, variables, valuation and weighting expressions of the BUES index-methodology system.

| DIMENSION (D) | VARIABLES (v) | WEIGHING EXPRESSION |
|---------------|---------------|----------------------|
| 1. Building   | 1) Façade     | P_{1.2...8} = \left(\sum_{i=1}^{8} v_{i}\right)/8 |
|               | 2) Windows    | TJ 1: Mild           |
|               | 3) Roof       | 2: Normal            |
|               | 4) Materials and finishes | 3: Moderate          |
|               | 5) Drainage   | 4: Urgent            |
|               | 6) Water supply | 2: Mildly necessary |
|               | 7) Gas supply | 3: Middle necessary  |
|               | 8) Electricity supply | 4: Necessary       |
| 2. Urban      | 9) Accessess  | 5: Highly necessary  |
|               | 10) Topography | TJ 1: Mild           |
|               | 11) Mobility and transport | 2: Normal          |
|               | 12) Security  | 3: Moderate           |
|               | 13) Pathways and routes | 4: Urgent          |
|               | 14) Equipment | 5: Immediate         |
|               | 15) Lighting  | TJ 1: Unnecessary    |
|               | 16) Open spaces | 2: Mildly necessary |
| 3. Environmental | 17) Ventilation | 3: Middle necessary |
|                | 18) Natural lighting | 4: Necessary         |
|                | 19) Thermal conditions | 5: Highly necessary |
|                | 20) Energy performance | TJ 1: Mild          |
|                | 21) Indoor air quality | 2: Normal           |
|                | 22) Indoor mobility | 3: Moderate          |
|                | 23) Acoustics  | 4: Urgent            |
|                | 24) Textures and colours | 5: Highly necessary |
| 4. Social     | 25) Wellbeing | TJ 1: Mild           |
|                | 26) Habitability | 2: Normal            |
|                | 27) Population Density | 3: Moderate         |
|                | 28) Place attachment | 4: Urgent          |
|                | 29) Use and maintenance | 5: Immediate       |
|                | 30) Access to basic services | TJ 1: Unnecessary |
|                | 31) Economic accessibility | 2: Mildly necessary |
|                | 32) Community feeling | 3: Middle necessary |

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multi-family buildings and public spaces to adapt to current regulatory requirements. The application in two neighbourhoods has allowed to justify the determination of the 32 variables, and their organisation in 4 dimensions, since both are located in vulnerable environments that require a detailed comfort, well-being and safety assessment with respect to the building, urban, environmental and social approach. Both neighbourhoods demonstrate the relevance of studying each variable, from multiple criteria to promote a proper urban planning and policy-making, even more after the huge impact of the global health crisis.

The utility of checking the assessment procedure and displaying the weighted results, in diverse urban typologies with different socio-economic contexts from different countries, is based on demonstrate the usefulness of this model to public and private entities, promoters and politics, in order to adjust feasible and more sustainable renovation proposals in the built environment, also allowing for a comparison and possibility problems in buildings without elevator are frequent. The state of conservation is generally deteriorated and the measures required (Norma UNE 41805:2015, 2015Norma UNE 4: 2015, Building Diagnosis, 2015).

A) “Cruz del Cerro” in Pachuca (Mexico). Vulnerable and deteriorated urban district from Pachuca de Soto in Mexico, located on the outskirts of the city, being a dispersed settlement mainly built during the 70 s. The urban morphology is irregular, with narrow streets, being the predominant building typology single-family homes, although they are commonly combined with multi-family apartments of two or three storeys. Most of existing buildings have not received adjustment and repair works in recent years and the overall state of conservation is alarming (Norma UNE 41805:2015, 2015Norma UNE 4; 2015Norma UNE 41805:2015, 2015). This is a case study with a high level of social backwardness in its population, which mean that most residents cannot afford repair works and adaptation interventions in their buildings or in their urban environments without public funding (CONEVAL, 2020).

B) “Zaidín” in Granada (Spain). Case study predominantly composed of social housing in the city of Granada, in southern Spain, located in the surroundings of the city centre and being a neighbourhood mainly composed of multi-family buildings, whose construction period was in the 70 s and 80 s. The urban morphology is more orderly, with wider streets and public neighbourhood mainly composed of multi-family buildings, or in their urban environments without public funding (CONEVAL, 2020).

### Table 2b
Main results of each case study using the BUES index methodology system.

| DIMENSION | VARIABLES | PACHUCA (Mexico) | GRANADA (Spain) |
|-----------|-----------|------------------|------------------|
|           | DIMENSION | TECHNICAL Prior. Level | NEEDS Survey dem. | TECHNICAL Prior. Level | NEEDS Survey dem. |
| 1.Building| 1) Façade | 4.30 | 3.41 | 3.62 | 2.93 |
| 1.Building| 2) Windows | 4.42 | 3.90 | 4.18 | 3.87 |
| 1.Building| 3) Roof | 4.12 | 4.67 | 4.10 | 3.60 |
| 1.Building| 4) Materials and finishes | 4.25 | 3.63 | 3.49 | 4.11 |
| 1.Building| 5) Drainage | 3.74 | 3.94 | 2.46 | 2.18 |
| 1.Building| 6) Water supply | 3.76 | 4.19 | 1.73 | 1.47 |
| 1.Building| 7) Gas supply | 4.08 | 2.90 | 2.94 | 2.23 |
| 1.Building| 8) Electricity supply | 3.72 | 3.46 | 2.66 | 3.16 |
| 1.Building| Average Index | 4.01 | 3.64 | 3.10 | 2.90 |
| 1.Building| Average Index (0/1) | 0.74 | 0.68 | 0.53 | 0.48 |
| 1.Building| 9) Accesses | 2.42 | 1.66 | 3.83 | 2.92 |
| 1.Building| 10) Topography | 2.93 | 2.24 | 3.25 | 4.10 |
| 1.Building| 11) Mobility and transport | 2.45 | 2.17 | 2.22 | 2.70 |
| 1.Building| 12) Security | 3.62 | 4.43 | 2.98 | 3.79 |
| 1.Building| 13) Pathways and routes | 3.79 | 4.27 | 4.10 | 3.66 |
| 2.Urban| 14) Equipment | 3.12 | 4.32 | 3.29 | 4.22 |
| 2.Urban| 15) Lighting | 3.45 | 4.42 | 2.92 | 3.58 |
| 2.Urban| 16) Open spaces | 2.22 | 3.10 | 4.11 | 4.56 |
| 2.Urban| Average Index | 2.96 | 3.29 | 3.30 | 3.65 |
| 2.Urban| Average Index (0/1) | 0.49 | 0.56 | 0.58 | 0.66 |
| 3.Environmental| 17) Ventilation | 2.41 | 2.91 | 2.92 | 2.66 |
| 3.Environmental| 18) Natural lighting | 1.80 | 1.58 | 2.63 | 2.45 |
| 3.Environmental| 19) Thermal conditions | 3.62 | 2.92 | 3.01 | 3.70 |
| 3.Environmental| 20) Energy performance | 4.30 | 3.40 | 4.12 | 3.81 |
| 3.Environmental| 21) Indoor air quality | 4.58 | 3.25 | 3.80 | 4.05 |
| 3.Environmental| 22) Indoor mobility | 4.16 | 3.44 | 4.68 | 4.68 |
| 3.Environmental| 23) Acoustics | 3.40 | 1.97 | 3.15 | 2.54 |
| 3.Environmental| 24) Textures and colours | 2.34 | 3.24 | 2.98 | 2.23 |
| 3.Environmental| Average Index | 3.30 | 2.80 | 3.29 | 3.23 |
| 3.Environmental| Average Index (0/1) | 0.58 | 0.45 | 0.57 | 0.56 |
| 4.Social| 25) Wellbeing | 4.13 | 3.42 | 2.82 | 4.38 |
| 4.Social| 26) Habitability | 4.42 | 3.58 | 3.16 | 4.23 |
| 4.Social| 27) Population density | 3.78 | 2.85 | 2.65 | 3.60 |
| 4.Social| 28) Place attachment | 2.14 | 2.44 | 2.49 | 3.65 |
| 4.Social| 29) Use and maintenance | 3.13 | 3.74 | 2.53 | 4.00 |
| 4.Social| 30) Access to basic services | 4.28 | 3.69 | 2.34 | 4.43 |
| 4.Social| 31) Economic accessibility | 4.73 | 4.20 | 3.32 | 4.12 |
| 4.Social| 32) Community feeling | 2.26 | 2.67 | 3.60 | 3.21 |
| 4.Social| Average Index | 3.53 | 3.28 | 2.83 | 3.93 |
| 4.Social| Average Index (0/1) | 0.64 | 0.57 | 0.46 | 0.73 |
3.3. Data collection: Technical inspection grid and participatory survey

Following the technical and social documents to be completed included as supplementary file in Annex I, the application in the two case studies has required numerous visits and inspection from technicians and the participation from users in participatory questionnaires, having been carried out both phases between June and December 2021, immersed in a context of global crisis due to the pandemic. Architects have carried out diverse technical inspections for each case study, which has led to assigning a degree of priority to act on each of the 32 defined variables, assigning the priority rating from mild to immediate. Furthermore, the participation of residents in each neighbourhood has also been required through social surveys to show the level of need in each of the 32 defined variables, giving a degree of needs from unnecessary to highly necessary.

Regarding case study A) in Mexico, technicians have visited and

![Fig. 2. Location in the city, representative view and urban planimetry of both case studies in Mexico A) and Spain B).](image)
inspected a building sample of \( (x) = 23 \) and their corresponding immediate urban environment, representing around 55 % of the building typology of the neighbourhood, assigning a technical valuation to variable and obtaining a final weighted value. In addition, the number of participants in the questionnaire included in Annex I has been \((p) = 56\), around 22 % of the total population of the selected buildings; gathering the number of responses for each variable and thus obtain their average indexes of the social results.

Regarding case study B) in Spain, technicians have visited and inspected a sample of \( (x) = 45 \) buildings and their corresponding immediate urban environment, representing 70 % of the building typology of the neighbourhood, assigning a technical valuation to each one of them and obtaining a final weighted value for each variable. Additionally, the number of participants in the survey has been \((p) = 94\), between 15–20 % of the total population of the selected buildings, which has made it possible to gather the number of responses for each variable and thus obtain their average indexes of the social results.

4. Results and discussion

This section presents the results obtained after applying and testing the urban vulnerability assessment model in two case studies from Mexico and Spain. Following the operation of the BUES index-methodology expressed in Section 3, Tables 2a and 2b presents the weighted indices obtained for each case study, in Pachuca and Granada, based on the technical evaluation of the priorities or the level of social needs expressed in participatory questionnaires. The results show a weighted mean value obtained for each of the 32 defined variables, on a weighting scale between 1 and 5 due to the Likert work scale according to the technical and social response forms expressed in Annex 1, being highly demanded and urgent those values above 3.

The technical and social weighted values for each case study show the performance of each variable for each selected case study, with respect to different disciplines, which gives a complete and global vision of the suitability of the built environment for current requirements and demands. The results obtained vary from 1.47 to 4.73 between the different assessment values of the variables, allowing to identify the weak and strong points of each neighbourhood with a global vision of the table, having designed the methodological process a graphical output of results that leads to an effective process of sensitivity analysis for the consequent decision-making.

The multi-variable indicators are displayed in the following Figs. 3 and 4, which have been carefully designed for their efficient sensitivity analysis by comparing the social and participatory diagnosis with respect to the technical dimension, aiming to identify coincidences and deviations between both evaluations, and recognise those actions with the highest priority and most needed in the different areas.

As a mechanism for a better understanding of the results, Fig. 3 represents the valuation of each variable in a Likert range between 1 and 5, according to the technical inspection (circle) and the social responses (square) in order to see the coincidence or deviation between both valuations and what value is higher depending on which discipline. Graphs 3 and 4, in which all the variables are gathered in a star-shaped graph, allow to understand the performance and suitability of a neighbourhood as a whole, as well as to identify abnormalities, strengths and weaknesses that determine the renovation strategies and distribute the economic funds.

Following the results obtained in Figs. 3 and 4 for the case study in Pachuca (Mexico), there is a certain proximity between the obtained technical priority and survey needs indicators. The disparity of results is summarised in a total average of 0.7 points, although this mean value does not represent the higher disparity that exists between technical perception and social questionnaires in certain variables such as 1) Façade, 14) Equipment, 15) Lighting or 21) Indoor air quality, with a difference of about 1.5 points between the weighted average values.

Focusing on particular results, these figures remark for Pachuca the urgent perception of technicians in the buildings inspected to repair and adjust problems in the building envelope, regarding variables 1) to 4), with technical values obtained over 4.0, being lower the needs of the residents in this dimension. Technical values are higher from technicians in variables related to dimensions 3) Environmental and 4) Social with respect to survey responses from residents, especially in variables such as 19) Thermal conditions (3.62 < 2.92), 20) Energy performance (4.30 < 3.40), 25) Wellbeing (4.13 < 3.42) or 26) Habitability (4.42 < 3.58). However, in variables related to dimension 2, the need values obtained in the residents’ questionnaires are higher than the technical priorities in variables such as 12) Security (3.62 < 4.43), 13) Pathways and routes (3.79 < 4.27), 14) Equipment (3.12 < 4.32) or 16) Open spaces (2.22 < 3.10).

Regarding obtained results from case study in Granada (Spain), Figs. 3 and 4 show greater overall disparity between the results obtained by technicians and demanded by residents, with a total average gap over 1.1 points. In any case, there are coincident values in certain variables (5) Drainage, 17) Ventilation, or 18) Natural lighting), the disparity is higher than in case study from Mexico, being the level of need demanded by users being predominantly higher than the technical priority detected according to regulations by the technicians, and the value of need being higher in 19 of 32 variables.

Discussing the particular results obtained for the case of Granada, an alternation of dominant technical or need parameters depending on each variable is observed in dimensions 1) Building, 2) Urban and 3) Environmental, however, regarding dimension 4) Social, the need results from surveys show significantly higher mean values from residents in variables 25) Wellbeing (2.82 < 4.38), 26) Habitability (3.16 < 4.23), 27) Population density (2.65 < 3.60), 28) Place attachment (2.49 < 3.65), 29) Use and maintenance (2.53 < 4.00) and 30) Access to basic services (2.98 < 4.43), evidencing a higher perception of social need in these parameters when designing urban regeneration policies with respect to the technical priority required according to mandatory regulations. Additionally, results obtained in variables related to the thermal envelope 1) Façade (3.62 > 2.93), 2) Windows (4.18 > 3.87) and 3) Roof (4.10 > 3.60), as well as variable 20) Energy performance (4.30 > 3.40), show a higher priority of action from technical requirements than the need perception from users, which shows that they are not as important factors for residents compared to other variables to be solved in the action proposals.

Furthermore, in order to obtain the final results for each of the four dimensions in the two case studies, a weighting mechanism is established for total values in the range between 0 and 1 in order to facilitate decision-making. Following this prescription, Fig. 5 represents a box-and-whisker diagram that allows representing the majority perception, through the quartile, and the maximum and minimum values obtained according to the technical and social diagnosis for each dimension and in each case study. This graph contributes to immediately visualise what prevalence exists in each dimension, and what degree of urgency when establishing the preferences to be treated in the design and management of the built environment.

The usefulness of representing the results according to Figs. 3–5 is demonstrated by viewing the trend for each variable and dimension according to the technical priorities and the demands made by residents, according to their predominant maximum and minimum values. This graph allows directing political action strategies by establishing a decision support system with a relevant impact on the improvement of the built environment, after a complete diagnosis and a sensitivity analysis that leads to adjust efficient and satisfactory action proposals, considering the graphical output of results in itself as an important outcome for this research topic. In the case of Pachuca, a higher technical priority of action is observed than in the case of Granada, especially in dimension 1 Building (0.74 > 0.53) and 4) Social (0.64 > 0.46), while in the need results, those demanded by users in the case of Granada are slightly higher than in the case of Pachuca.

The testing procedure of the BUES index-methodology in both
neighbourhoods from Mexico and Spain, demonstrates the operation of the assessment model for vulnerable environments by displaying the deviation between different variables and dimensions, and also between technical and participatory results for each case study, thereby fulfilling the research gap highlighted towards obtaining efficient decision support systems for the built environment as promoted by the Sustainable Development Agenda or the European Agenda for Sustainable Buildings as well as it was also concluded on its gap in review articles such as the one developed by Nielsen, Jensen, Larsen, and Nissen (2016). Subsequently, the main implication that this assessment model incorporates for policy-makers and urban planning under this global crisis context is that it establishes an assessment mechanism through weighted indices of multiple variables that allow to compare the impact of regeneration strategies through a sensitivity analysis, adjusting action strategies to the limited economic funds, extensive technical requirements and aiming to reduce social impacts, thereby organising these proposals in different action levels, as already proposed Olsson et al. (2016) and Mjornell, Femenías, and Annadotter (2019) in their research.

The outcomes of this new model and the application and testing in two representative neighbourhoods of each country, Mexico and Spain, with a different socioeconomic context, demonstrates the validity of the results in their different status scenarios, along with the suitability for sensitivity analysis of obtaining these final values and trends displayed in the proposed graphs, being this graphical display of results another contribution that fulfils the research gap that Liang et al. (2016) and Moghtadernejad, Chouinard, and Mirza (2018) enhanced to improve and expand in their conclusions. Furthermore, these weighted results go beyond the models developed by Riera Pérez et al. (2018) or Bolis, Morioka, and Szelwar (2017), offering a multidisciplinary approach of 32 variables that provides a comprehensive performance of the built environment from the perspective of technicians and users, incorporating important outcomes and applicability in vulnerable neighbourhoods and the regeneration of urban environments, as pointed European Commission (2017).

![Fig. 3. Results on the value performance of each variable according to discipline for each case study.](image-url)
5. Conclusions

The proposed BUES index-methodology for decision-making in the built environment provides a dual and multidisciplinary procedure to weight and discuss the diagnosis and performance of existing environments, in order to detect and classify technical priorities and needs from users as a decision support mechanism. This new assessment model fulfils current urban, architectural and social challenges that demand new approaches for decision-making in existing housing and neighbourhood scales, considering the added difficulties that the global health crisis on Covid-19 will entail in the distribution of economic funds in emerging countries when modelling a route towards an efficient and sustainable urban regeneration in the most vulnerable areas.

The research contributes defining 32 required variables, organised in 4 key dimensions, to assess the suitability of the built environment, also establishing required technical inspection sheets and participatory models and, lastly, designing weighting procedures for obtaining a multidimensional diagnosis in vulnerable areas of emerging contexts. The new assessment model and its graphical display of results incorporates important outcomes for policy-makers, promoters and private firms to sensitivity discussed which are the priorities and level of needs of certain variables and scales, in order to adjust the action proposals and ensure decision-making. The obtained indexes for the vulnerability assessment enable the identification of technical priorities and main users’ needs when establishing the different scenarios for urban regeneration and renovation proposals in the building, urban environmental and social dimension.

The innovation of this index-methodology is that it assess the state and suitability of the built environment by combining technical inspections and participatory surveys, and also it establishes a new way of quantifying all these variables through a weighting procedure for obtaining multidisciplinary indexes, providing key findings of this BUES index-methodology for designing and adjusting urban regeneration policies, funds distribution and sustainable guidelines that could promote a higher efficiency and satisfaction in the interventions.

The paper goes further with respect other related research referenced in literature review since it considers that, technical priorities due to design shortcomings or regulatory breaches need to be combined with arising demands from residents when distributing funds for renovating urban spaces or residential buildings, which is a reason why this methodology establishes a weighting procedure for both technicians and users along with providing graphs to appropriately discuss and determine which renovation proposals are more prioritise. Actually, the graphical output of results that incorporates this assessment model is already considered one of the key outcomes of this vulnerability assessment method since it allows to detect the points of weakness or strength each neighbourhood according to the technical requirements and the social demands, facilitating the design of urban planning of cities and urban regeneration of built environments to the corresponding administrative, technical and social entities.

The application and test of the proposed methodology in two representative neighbourhoods from Mexico and Spain have been useful...
to demonstrate the operation of weighting procedure, to test the contribution of the graphical output of results along with to enhance the replicability of the model in different socioeconomic contexts with diverse architectural typologies and urban models, all of them belonging to the built environment. The results obtained for both cases show deviations in the weighted values obtained from technicians and users, and also valuable information regarding particular variables and dimensions which guarantee a final report which can be translated in action proposals with a higher satisfaction and suitability for each case. The key contributions obtained from applying the BUES index-methodology fulfill the research gap regarding multidisciplinary decision support system to ensure an appropriate management of cities.

The advantages of using this decision support model allow to identify the key variables and consequently the major demands of the residents for each case study before determining urban regeneration and renovation proposals, offering new theoretical insights on the benefits of combining urban and social disciplines when quantifying the assessment of multiple dimensions of the built environment. In fact, the complexity of ensuring a holistic management in vulnerable neighbourhoods implies limitations to be overcome in further studies, so this study generates a starting point as a new methodological basis for decision-making to be improved in future works, by addressing emerging limitations, mainly focus on incorporating new technical variables related to conservation status, like foundations or structural damages; deep into social participation mechanisms that increase the participation rate; or new assessing scales that demonstrate the flexibility and adaptation of this index-methodology to adapt to particular approaches from every socio-economic context and urban environment.

Finally, this model generates an opportunity to ensure feasible action in the built environment and promote new renovation guidelines by previously assessing the building, urban, environmental and social scales in vulnerable areas. The incorporation of this index-assessment model into policy agencies or administration entities will entail important contributions towards a feasible, sustainable and satisfactory management of social housing in existing cities.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.scs.2021.103082.

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