Land Use Policy 83 (2019) 424–434

Contents lists available at ScienceDirect

Land Use Policy

journal homepage: www.elsevier.com/locate/landusepol

Integrating GIS spatial dimension into BREEAM communities sustainability assessment to support urban planning policies, Lisbon case study

Joana Pedro[a,*], Carlos Silva[a], Manuel Duarte Pinheiro[b]

[a] IN+ Center for Innovation, Technology and Policy Research, Instituto Superior Técnico – Universidade de Lisboa, Avenida Rovisco Pais 1, 1049-001, Lisbon, Portugal
[b] Department of Civil Engineering, Architecture and Georesources, Instituto Superior Técnico – Universidade de Lisboa, Av. Rovisco Pais 1, 1049-001, Lisbon, Portugal

ARTICLE INFO

Keywords:
Sustainable urban planning
Sustainability assessment
Urban development
BREEAM-Communities
GIS

ABSTRACT

Local governments face increasing pressure to define land-use policies to enhance local sustainable development. This requires the development of urban planning tools that can help them in selecting measures and priority intervention areas within their cities.

The tools currently available only address this problem partially. Geographical Information Systems (GIS) have been widely used in urban planning for handling spatial data but have limited capacities for representing choice and priority among the conflicting objectives for sustainable urban planning. Meanwhile, urban sustainability assessment systems, such as BREEAM-Communities (BREEAM-CM), can help to choose the most sustainable measures under such conflicting objectives, although they are typically non-spatial by assuming a spatial homogeneity within the study area, therefore, they cannot be used to identify priority intervention locations.

This paper proposes bridging the gap between urban sustainability assessment and spatial analysis by combining GIS and BREEAM-CM. Instead of the traditional use of BREEAM-CM to assess a single neighbourhood, we applied this system to all Lisbon city subsections with the support from GIS. It resulted in the identification of priority intervention areas for sustainable development within the city including: attracting new businesses to the north area; implementing energy efficiency strategies and new green areas in the old town and central avenues; and improving public transport links in the north and western areas. These findings show that the proposed model can be a valuable tool for evaluating and defining local sustainable development strategies.

1. Introduction

Over recent years, the rapid growth of cities and their increasing demand for scarce resource have opened the debate on the role of local government in enhancing sustainability (Broto, 2017; Reckien et al., 2017). The concept of sustainable development was first introduced in the Brundtland report in 1987 (WCED, 1987), which defines sustainability as the "appropriate rate of development that meets people's standard needs without compromising future generations". Subsequent to this report, the Rio Conference 1992 (UN, 1993) introduces the relationship between economics, science and the global environment within a political context. Since then, there have been notable efforts made by member states to incorporate sustainability principles into international actions and agreements (Adinyira et al., 2007), including the 2020 Smart Strategy for Sustainable and Inclusive Growth (European Commission, 2010), and the 2030 Agenda for Sustainable Development (UN, 2017) that established 17 global objectives to be adopted by all parties of the United Nations. These international agreements set a shared plan of action to ensure social cohesion, environmental protection and prosperity worldwide. Nevertheless, the implementation and success of these plans will rely on local governments own sustainable development policies, plans and programmes (Broto, 2017; Reckien et al., 2017; Yigitcanlar and Kamruzzaman, 2018).

In light of this, urban planning becomes an essential tool that can help local governments define land-use policies to enhance local sustainable development (Eraydin and Tasan-Kok, 2015; Etingoff, 2017). From the perspective of urban planning, sustainable development is a spatial decision problem that requires selecting which measures and where to implement them in a context of often conflicting objectives (Cajot et al., 2017; Della Spina et al., 2017). For instance, selecting the most suited incentives and priority intervention areas to achieve energy

* Corresponding author.
E-mail addresses: joana.m.pedro@tecnico.ulisboa.pt (J. Pedro), carlos.santos.silva@tecnico.ulisboa.pt (C. Silva), manuel.pinheiro@tecnico.ulisboa.pt (M.D. Pinheiro).

https://doi.org/10.1016/j.landusepol.2019.02.003
Received 12 September 2018; Received in revised form 17 January 2019; Accepted 1 February 2019

reduction targets at minimum investment costs. Solving this type of problem requires collecting, sorting and linking vast amounts of spatial and non-spatial data. However, most of the currently available tools only address one part of this problem (Ferretti and Montibeller, 2016; Greene et al., 2011; Malczewski and Rinner, 2015).

On the one hand, Geographical Information Systems (GIS) have been widely used over the past 20 years in urban planning as support for collecting and storing spatial data based on their geographic coordinates. Yet they have limited capacities for representing choice and priority among the vast number of objectives in the context of sustainable urban planning (Malczewski and Rinner, 2015).

On the other hand, recent efforts to integrate sustainability into urban planning has led to the development of several multi-criteria assessment support systems like BREEAM-Communities (BREEAM-CM), LEED-Neighbourhoods (LEED-ND) or CASBEE-Urban development (CASBEE-UD) (Haapio, 2012; Sharifi and Murayama, 2013). These systems are designed to assess the sustainability performance of urban areas based on a set of environmental, social and economic criteria. Nevertheless, these tools are typically non-spatial, in the sense that they assume a spatial homogeneity within the study area, often assigning the same goals and criteria weight to every alternative location. Therefore, these tools cannot be used to identify the most suitable locations or priority intervention areas within a city (Malczewski and Rinner, 2015; Pedro et al., 2017).

This paper aims to bridge the gap between urban sustainability assessment systems and spatial analysis tools by testing the hypothesis of combining BREEAM-CM and GIS. Instead of the traditional application of BREEAM-CM to the certification of a single neighbourhood, we tested its application to all neighbourhoods of a city simultaneously with the support from GIS. This approach makes it possible to compare neighbourhoods and understand the relationships between them, which can provide the basis for determining benchmarks and identifying priority intervention zones within a city. In this work, we use Lisbon (Portugal) as a case study to test this approach and to identify its applicability as a support tool to assist local governments making urban policies and planning the sustainable development of their cities. In this paper, we build our model based on BREEAM-CM because it is the most used in Europe with a version for urban assessment (Venou, 2014), which makes it a good fit for our case study. The combination of GIS and other systems like LEED has been previously tested (Pedro et al., 2017), yet the model can be also tested with other systems. The comparison of the results can bring new insights on the advantages and disadvantages of each sustainability assessment system.

This paper is structured as follows. Section 2 introduces both BREEAM-CM and GIS, addressing the need for combining both. Section 3 describes the assessment approach and data used for the case study of Lisbon. Section 4 presents the results and discusses possible urban planning strategies that can be withdrawn from this study. Finally, Section 5 presents the concluding remarks.

2. Theoretical background

At the urban planning level, sustainable development involves deciding the optimal allocation and management of many different land use options (García et al., 2017; Malczewski and Rinner, 2015). This type of problem has been often encountered in the field of spatial planning and has triggered the development of several methodologies for Spatial Decision Support Systems (SDSS) (Ferretti and Montibeller, 2016; Greene et al., 2011; Malczewski and Rinner, 2015). Particularly since the early 1990s, there has been a growing number of theoretical and applied research on SDSS particularly focussed on integrating GIS and multi-criteria models attributed to the need to expand the decision support capabilities of both (Malczewski and Rinner, 2015). On the one hand, GIS is specially designed for spatial analysis but has limited capacity for handling multiple objectives. On the other hand, multi-criteria models are particularly focused on the decision-making process but lack the spatial dimension. Building upon this, our study explores the hypothesis of combining GIS spatial analysis and the multi-criteria model BREEAM-CM to provide guidance in solving problems related to making land use decisions for enhancing the sustainable performance of urban areas.

2.1. The use of GIS in solving spatial analytic problems

GIS tools were initially developed for collecting, storing and visualizing data based on their geographic coordinates (Rogerson and Fotheringham, 1994). Despite the widespread recognition that the analysis of patterns and relationships should be the central function of GIS, its capabilities to address complex spatial decision problems is still limited, for instance in representing choice and priority among a vast number of objectives (Greene et al., 2011; Malczewski and Rinner, 2015). For this reason, previous studies have explored the hypothesis of combining multi-criteria systems and GIS to solve spatial analysis problems in the field of urban planning, including but not limited to: site search or selection; location-allocation; land suitability; scenario evaluation; resource allocation; transportation or vehicle routing and scheduling; impact assessment (Malczewski, 2006). This paper aims to contribute to the literature in the field of urban planning by exploring the combination of multi-criteria systems and GIS in the context of sustainability assessment.

2.2. The use of BREEM-CM for sustainable urban planning

Over the past two decades, the construction industry has been progressing toward the integration of sustainability principles by developing several standards and environmental assessment methods for managing the environmental impacts of construction projects. This has resulted in the development of several multi-criteria models to assess the sustainability performance of buildings like BREEAM (UK, 1990), LEED (USA, 1998), CASBEE (Japan, 2001), DGNB (Germany, 2008), or LIDERA (Portugal, 2005) (Doan et al., 2017). These sustainability assessment systems provide a set of environmental, social and economic criteria for evaluating and selecting among a set of alternative options to be implemented in a project (Haapio and Viitaniemi, 2008). Particularly in the last decade, these sustainability assessment systems have updated versions for urban planning, such as BREEAM-Communities, LEED-Neighbourhoods, CASBEE-Urban development, DGNB-Urban districts, mostly covering the neighbourhood scale and a few attempts to the city level. Enlarging the scale of analysis opens new opportunities for sustainable urban planning by making it possible to maximally explore the synergies among buildings and their surroundings. For instance, taking advantage of economies of scale for the benefit the of district energy solutions, local water management, community engagement (Ameen et al., 2015; Berardi, 2013; Dixton et al., 2014; Doan et al., 2017).

While these tools have brought clear advances in guiding the development of sustainable communities, they also have common limitations (Haapio, 2012; Sharifi and Murayama, 2014a; Tam et al., 2018; Wallhagen et al., 2016). One of the critiques most often found in the literature is the need to find a consensus on the definition and concepts of sustainability (Lin and Shih, 2018; Sharifi et al., 2016; Tam et al., 2018). In addition, these tools often face the problem of overlapping criteria and bias weighting assumptions (Ali-Toudert and Ji, 2017; Kaur and Garg, 2018; Wallhagen et al., 2016). Other studies highlight that these systems place emphasis on ecological and environmental criteria, while economic and social aspects of sustainability are partially ignored (Berardi, 2011; Verovsek et al., 2018). Finally, there is a need for greater flexibility and local context adaptation, in order to account for the specific needs and attributes of each location (Berardi, 2015; Braulio-Gonzalo et al., 2015; Sharifi and Murayama, 2014b).

Adding to this last point, our paper focuses on the need to address spatial diversity. As most multi-criteria models are non-spatial,

Table 1
BREEAM-Communities categories and sub-categories.

BREEAM-Communities	w (%)		w (%)
Governance	9.3	**Resources & Energy**	21.7
GO 01. Consultation plan	2.3	RE 01. Energy strategy	4.1
GO 02. Consultation and engagement	3.5	RE 02. Existing buildings & infrastructure	2.7
GO 03. Design review	2.3	RE 03. Water strategy	2.7
GO 04. Community management of facilities	1.2	RE 04. Sustainable buildings	4.1
		RE 05. Low impact materials	2.7
Social & Economic Wellbeing	42.7	RE 06. Resource efficiency	2.7
SE 01. Economic impact	8.9	RE 07. Transport carbon emissions	2.7
SE 02. Demographic needs and priorities	2.7		
SE 03. Flood risk assessment	1.8	**Land use and Ecology**	12.8
SE 04. Noise pollution	1.8	LE 01. Ecology strategy	3.2
SE 05. Housing provision	2.7	LE 02. Land use	2.1
SE 06. Delivery of services, facilities & amenities	2.7	LE 03. Water pollution	1.1
SE 07. Public realm (social activities)	2.7	LE 04. Enhancement of ecological value	3.2
SE 08. Microclimate	1.8	LE 05. Landscape	2.1
SE 09. Utilities	0.9	LE 06. Rainwater harvesting	1.1
SE 10. Adapting to climate change	2.7		
SE 11. Green infrastructure	1.8	**Transport and Movement**	13.8
SE 12. Local parking	0.9	TM 01. Transport assessment	3.2
SE 13. Flood risk management	1.8	TM 02. Safe and appealing streets	3.2
SE 14. Local vernacular	0.9	TM 03. Cycling network	2.1
SE 15. Inclusive design	1.8	TM 04. Access to public transport	2.1
SE 16. Light pollution	0.9	TM 05. Cycling facilities	1.1
SE 17. Training and skills	5.9	TM 06. Public transport facilities	2.1
Total w = 100%			

assuming a spatial homogeneity within a study area, assigning the same significance of factors and goals to each individual location of a given map, they present a major limitation. This becomes particularly noticeable at the urban scale because, while at the building level the focus is on selecting *what* measure to implement, at the urban level it is also important to identify *where* to implement these measures. However, some systems have already made attempts to address spatial diversity as in the case of BREEAM-CM used in this paper.

BREEAM-CM, developed between 2008–2012 by BRE Global in the UK (BRE Global, 2015), is one of the most widespread sustainability assessment systems for the neighbourhood scale, particularly used in European countries (Venou, 2014). It proposes a set of criteria to evaluate urban sustainability performance for projects at the master plan level. As shown in Table 1, these criteria are organized within five major categories: Governance (GO); Social and Economic Wellbeing (SE); Resources and Energy (RE); Land use and Ecology (LE); Transport and Movement (TM), as shown in Table 1. The criteria have different weights (w) depending on the relevance assigned to each specific aspect of the overall scoring system.

The system addresses spatial diversity by assigning regional weights to the sustainability criteria under evaluation (BRE Global, 2012; Callway et al., 2016; Sharifi and Murayama, 2013). This means that the base weights can be adjusted in accordance with the priorities of each region. Nevertheless, the weight adjustment is usually limited to a regional macro-level (based on national development targets) and do not consider weight variation at neighbourhood micro-level. Consequently, it is not possible to identify, for instance, priority intervention locations within the same city.

In response to this problem, previous studies suggest combining multi-criteria systems and GIS (Malczewski and Rinner, 2015), in particular combining LEED-ND with GIS-models (Chrysochoou et al., 2012; Pedro et al., 2017; Talen et al., 2013). However, studies using other sustainability systems are still missing. Therefore, further testing of the combination of BREEAM-CM and GIS can bring new insights into the advantages and disadvantages of each sustainability assessment system, as well as comparing differences in the results according to other methodologies. Thus, addressing this research gap can yield new opportunities in the field of sustainable urban planning.

3. Methods and data

This section presents the methodology used to evaluate the sustainability level of a city based on applying BREEAM-CM system with the support of GIS modelling using Lisbon as a case study.

3.1. Site description and scope of the analysis

Lisbon is the capital and largest city of Portugal with a resident population of approximately 547 thousand inhabitants within an administrative limited area of 100 km^2 (CML, 2017c). In the last few years, the City Council became strongly committed to enhancing sustainable land-use policies into their strategic development plans. After achieving a 50% reduction in C02 emissions between 2002 and 2014, reducing energy consumption by 23% and water consumption by 17% between 2007–2013, Lisbon was the first capital in Europe to sign the New Covenant of Mayors for Climate Change and Energy in 2016 (European Comission, 2018b). These commitments also triggered the development and release of the City Council Strategy for Managing Adaptation to Climate Change in 2017 (CML, 2017a). More recently, the efforts in the sustainability arena made Lisbon earn the title for European Green capital 2020 (European Comission, 2018a). This setting makes Lisbon a suitable case for our study, in the sense that we can contribute to these on-going efforts by determining benchmarks and identifying priority intervention areas that can be used by the local governors to guide Lisbon's sustainable urban development agenda.

To determine the unit of analysis, this study considered the lower Lisbon's administrative statistical divisions defined by the National Statistics Institute (INE). INE provides population and housing census data within two aggregation levels: sections and subsections, as represented in Fig. 1. The section level comprises 24 units corresponding to a continuous area of a single parish with approximately 300 dwellings. The subsection level comprises 3657 units that correspond to the smallest homogeneous territorial areas and represent an urban block with generally up to 100 dwellings (INE, 2011b). This study uses the subsection level as the main unit of analysis since it is the smallest urban unit with statistical data available for Lisbon, therefore providing a higher resolution of the spatial analysis.

Furthermore, this study focuses on the assessment of pre-existing

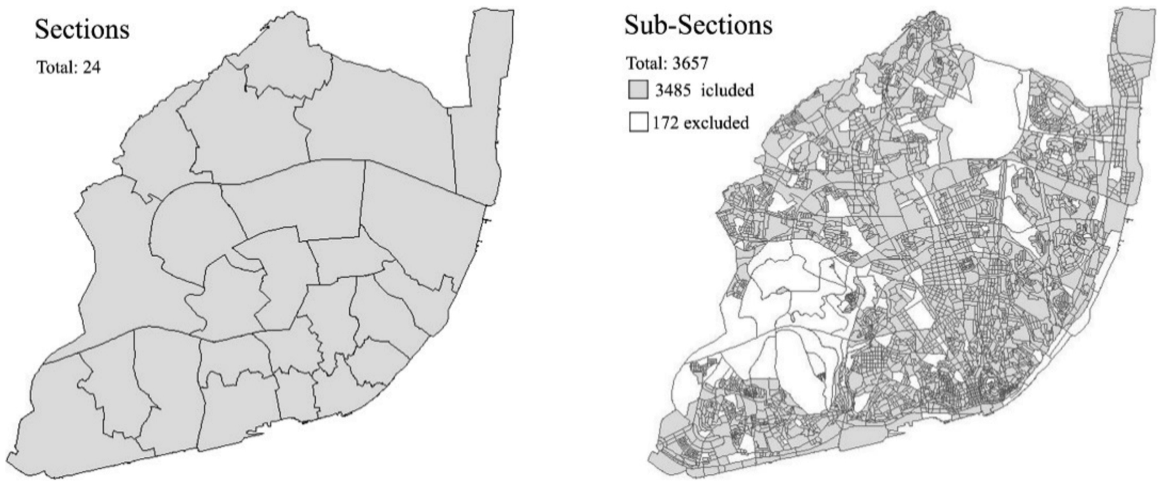

Fig. 1. Lisbon sections and subsections.

urban areas where new construction or redevelopment projects can be implemented. The analysis excludes subsections that contain protected green areas (e.g., Monsanto Natural Park) or consolidated special infrastructure areas (e.g., airport), where construction is restricted according to the Municipality Director Plan *(*CML, 2012*)*. Therefore, in total, 172 subsections were excluded from the study, as shown in Fig. 1.

3.2. Assessment approach

In this study, instead of the conventional application of BREEAM-CM to the analysis of a single neighbourhood, we applied it to all Lisbon subsections (3485 units) with the support of GIS using ArcGIS® software. This process was made in three steps: 1) Collect and sort the data, 2) Rank the neighbourhood's sustainable performance, 3) Estimation of the global sustainability score.

3.2.1. Collecting and sorting the data

This step consists of collecting and sorting the data required to evaluate the sustainability performance of all city subsections in accordance with BREEAM-CM guidelines. We created a flow model of inputs and outputs (Fig. 2). The outputs were given by the BREEAM-CM guidelines for each of the 5 categories (GO, SE, RE, LE, TM), the intermediate flows were measured based on the 40 subcategories (GO01-04, SE01-17, RE01-07, LE01 to LE01-06, TM01-07), and the inputs were defined based on the statistical data available for Lisbon city at the subsection level (V1-V25). The data were collected and processed with the support of ArcGIS® software whenever necessary to perform calculations and measurements in the map of the geo-referenced elements. See Appendix Table A.1 in Supplementary materials for more detail on the calculations and sources used for this study.

For the Social and Economic Well-being (SE) section, this study considers the analysis of the subcategories SE01 to SE13 as follows:

- SE01) economic impact – calculating the employment rate (V1) (INE, 2011b) and business density (V2) (DATALUSO, 2016).
- SE03) flood risk assessment – a flood risk assessment (V3) using municipality maps (CML, 2012).
- SE04) noise pollution – considering daytime (V4) and night time (V5) noise zones from municipality maps (CML, 2012).
- SE05) housing provision – based on the average housing cost (V6) calculated at the parish level as no data was available for the subsection level (INE, 2017) and the House patrimonial tax (V7) (AT, 2016).
- SE06) delivery of services – calculating the weighted average distance to amenities (V8) including supermarket or grocery store, cash services, sports facilities, leisure facilities, outdoors public parks, postal facilities, health services, schools (CML, 2016a).
- SE08) microclimate – based on verifying the heat island intensity level (V9) in risk assessment maps (Baltazar, 2014; Alcoforado et al., 2014).
- SE10) adapting to climate change – considering the previously mentioned flood risk assessment (V3), the heat island intensity level (V9), as well as soil erosion vulnerability (V10) (CML, 2012), and wind vulnerability (V11) from municipality maps (CML, 2017a).
- SE11) green infrastructure –calculating the distance to public green areas (V12) (INE, 2011b).
- SE12) local parking – based on estimating car parking ownership (V14) (INE, 2011b).
- SE13) flood risk management – including the previously calculated flood risk assessment (V3), as well as the verification of existing drainage systems (V15) (CML, 2015) and V16 average surface water run-off (INE, 2011b).

For the Resources and Energy (RE) section, this study considers the analysis of the subcategories RE01 to SE07 as follows:

- RE01) energy strategy – considering the percentage of non-residential units with energy certificates above the 'B-' level (in a range from F to A+ +) (V17) and the percentage of residential units with energy certificates above this same level (V18) (ADENE, 2016).
- RE02) existing buildings and infrastructure – based on identifying the number of buildings in need of repair (V19) calculated at the parish level as no data was available for the subsection level (INE, 2011a), and verifying the existence of urban rehabilitation areas with financial support assigned (V20) (CML, 2016b).
- RE03) water strategy – considering the average daily domestic water consumption (V21) calculated at the parish level as no data was available for the subsection level (EPAL, 2015).
- RE07) transport carbon emissions - calculating the weighted average distance to bike sharing points (V22) (CML, 2017b), cycle lanes (V23) (CML, 2016a), electric car chargers (V24) (CML, 2016a), and public transport links (CML, 2016a)

For the Land use and Ecology (LE) section, this study considers the analysis of the subcategories LE03 and LE04 as follows:

- LE03) water pollution – based on the verification of the existing drainage system (V15) (CML, 2015) and V16 Av. surface water run-off (INE, 2011b).
- L04) ecological value – considering the distance to green areas (V12) previously calculated (INE, 2011b), and the green areas ratio (V13) (CML, 2016a).

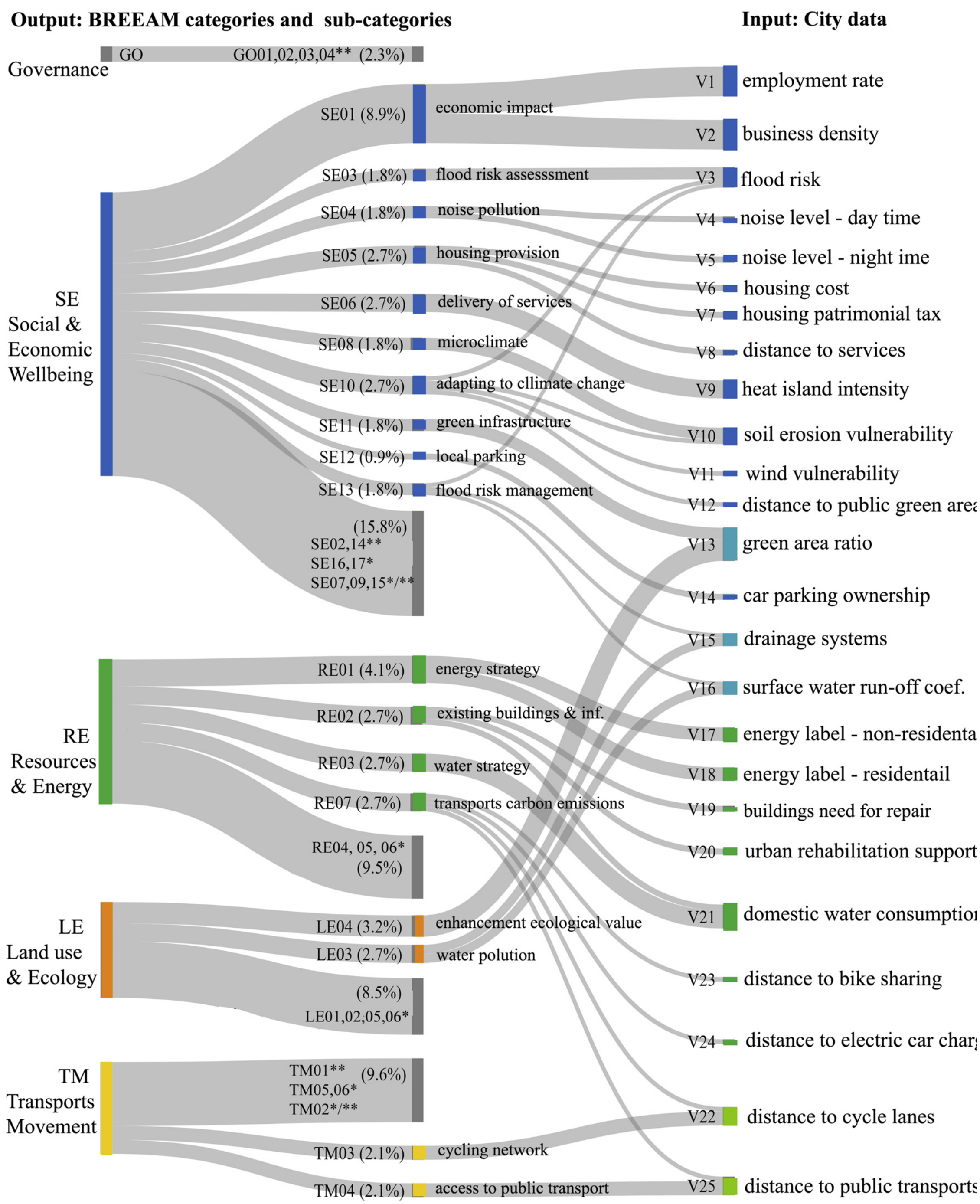

Fig. 2. Model diagram: BREEAM-CM categories and city inputs.
Note1: this study excludes subcategories where data was not available for the study area (*) or the assessment process was dependent on prescriptive guidelines (**).
Note 2: see Appendix Table A.1 in Supplementary materials for more detail on the assumptions and sources used for this study.

Finally, the Transport and Movement (TM) section, this study considers the analysis of the subcategories TM03 and TM04 as follows:

- TM03) cycling network – based on the previously calculated distance to cycle lane (V22) (CML, 2016a).
- TM04) - access to public transport - consisting of calculating the weighted average distance to public transport links (V25) including bus, metro, train, and ferry services (CML, 2016a),

Based on the foregoing, from the 40 BREEAM-CM subcategories, 18 were analysed in this study using the statistical data available at the city subsection level possible (equivalent to 48% of the total weight). The remaining subcategories were excluded due to two main reasons:

First, BREEAM-CM certification process requires very detailed project information. However, at the city scale finding high-quality and high-resolution statistical data was not possible for all subcategories. Therefore, this study excludes the categories where data was not possible to obtain for Lisbon subsections with the same level of detail or quality (marked as "*" in Fig. 2)

Second, BREEAM-CM offers a mix of prescriptive and descriptive guidelines to assess the urban sustainability of urban projects (Korhonen, 2007; Starrs, 2010). In general, a prescriptive approach focuses on the process and it offers a step-by-step guide, where the designer follows exact instructions (e.g., in TM01 the designer needs to

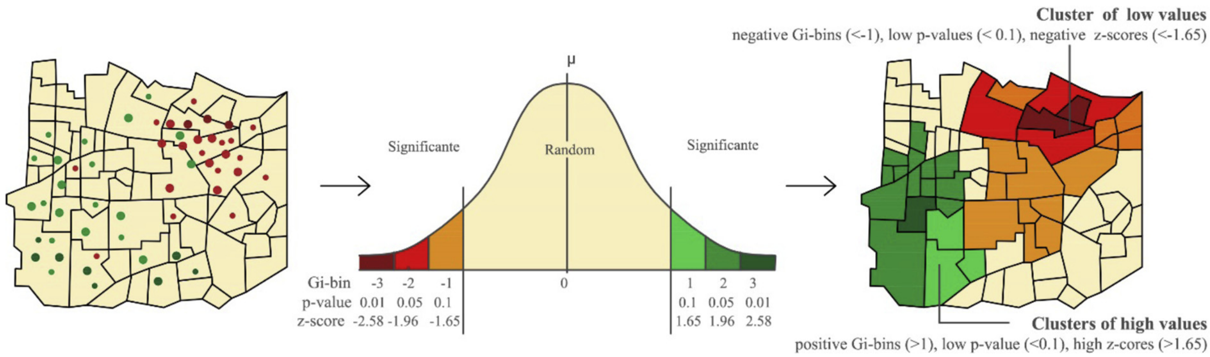

Fig. 3. Generic diagram of the clustering process, Gi-Bin, p-value and z-score.

follow the steps: first assign an expert to perform a transport assessment, then develop a travel plan, then verify that the plan positively influences the transport system). While a descriptive approach focuses on the result (e.g., in RE01 the designer can select any energy efficiency solution to achieve a fixed reduction target). The prescriptive approach is suited for the certification of a single neighbourhood where the decision maker has very detailed information on the project in its current stage and expected next steps of development. Nevertheless, when extending the analysis to a large set of neighbourhoods, the information required is not equally available. In particular, there are many uncertain variables when considering future conditions. This makes it difficult to evaluate the project on a step-by-step basis. Consequently, this study also excludes the subcategories dependent on pure prescriptive guidelines (marked as "**" in Fig. 2).

3.2.2. Ranking the neighbourhood's sustainable performance

This step consists of evaluating to which extent neighbourhoods would comply or not with the BREEAM-CM requirements for each category and subcategory.

The BREEAM-CM scheme is an evaluation process based on a yes/no nominal-scale (does it comply with the standard? yes/no). This binary scale is usually enough for the single project certification process, assuming very detailed information is available with lower degrees of uncertainty, where it is possible to provide a clear yes/no reply. However, in this study, we apply BREEAM-CM to the simultaneous analysis of many neighbourhoods, which imply relying on the statistical data and estimating proxies when the existing data was not available. This lack of availability introduces a higher degree of uncertainty and precise classification of yes/no is often not possible. To overcome this limitation, rather than using a yes/no nominal-scale we use an interval-scale instead. The major difference between them is that the nominal-scale does not consider the distance between the two values yes and no, while the interval-scale also captures the distance between these two values by measuring the degree of compliance (how far from achieving yes/no). Therefore, we classify the neighbourhoods according to the probability of complying with BREEAM-CM standards. The lowest-performance neighbourhoods have a lower probability of complying with the standard (they are far from achieving yes), and the highest-performance neighbourhoods have a higher probability of complying with it (they are closer to achieving yes).

To calculate the probability of being the lowest-performance or highest-performance neighbourhood we used ArcGIS® statistical toolset for spatial cluster analysis. There are many different clustering techniques to identify urban patterns and autocorrelation (Fischer and Getis, 2010; Longley and Batty, 1996; Ord and Getis, 1995). These techniques are usually divided into two categories: global and local techniques. Global techniques are used to identify whether there is a cluster or not. The local techniques also provide information on where the cluster is located (Fischer and Getis, 2010). This paper uses a local technique called Getis-Ord G* as the goal was to identify the specific location of urban clusters.

Getis-Ord G*, also known as hot-spot analysis, identifies statistically significant spatial clusters of high values (hot spots) and low values (cold spots), by distributing the data into homogeneous groups that consider the degree of spatial autocorrelation between features and quantify the statistical significance of identified clusters (Longley and Batty, 1996; Peeters et al., 2015), computed as described in Eq. (1).

$$G_i^*(d) = \frac{\sum_j W_{ij}(d)\, X_j}{\sum_j X_j}, \quad (1)$$

where: $G_i^*(d)$ is the indicator of local autocorrelation computed for the feature (i) at distance (d); Xj is the attribute value of each neighbour; Wij is the spatial weight for the target neighbourhood i and j pair.

The Getis-Ord G* statistic tool included in ArcGIS® returns a z-score (standard deviations), p-value (statistical probabilities), and Gi_Bin confidence level (90%, 95%, 99%), these confidence levels are provided within a seven-level scale {-3, -2, -1, 0, 1, 2, 3}, where positive G-bins correspond to clusters of high values, and negative G-bins correspond to clusters of low values as illustrated in Fig. 3.

A cluster of a high value is not necessary for a high-performance neighbourhood as it depends on the type of variable. For instance, for input variables like employment rate, the higher the value the better the performance (positive trend line). Meanwhile, for input variables such as flood risk level, the lower the value the better the performance (negative trend line). Hence, in addition to cluster analysis, the type of variable is identified, then whether they present a positive or negative trend.

In order to assess the probability of complying to the BREEAM-CM standard, we account for both the probability value and type of variable, by converting all the input parameters into the same seven-level scale {1,2,3,4,5,6,7}, ranking the neighbourhoods from lowest-performance (1) to the highest-performance (7).

3.2.3. Estimating the global sustainability score

The last step of our analysis consists of estimating the Global Sustainability Score (GSS) of the city subsections, based on computing the weighted sum of the analysed BREEAM-CM subcategories, as described in Eq. (2).

$$GSS = \sum_{i=1}^{n} \left[\left(\frac{100 * P_i}{7} \right) * W_i \right] \quad (2)$$

where: GSS is the global sustainability score (0–100%), P_i is the performance level for each subcategory (1–7); Wi is the given BREAAM weight of each subcategory (1–100%).

4. Results & discussion

This section presents the results obtained for the Lisbon case study and their implications for land-use policies. In addition, we discuss the

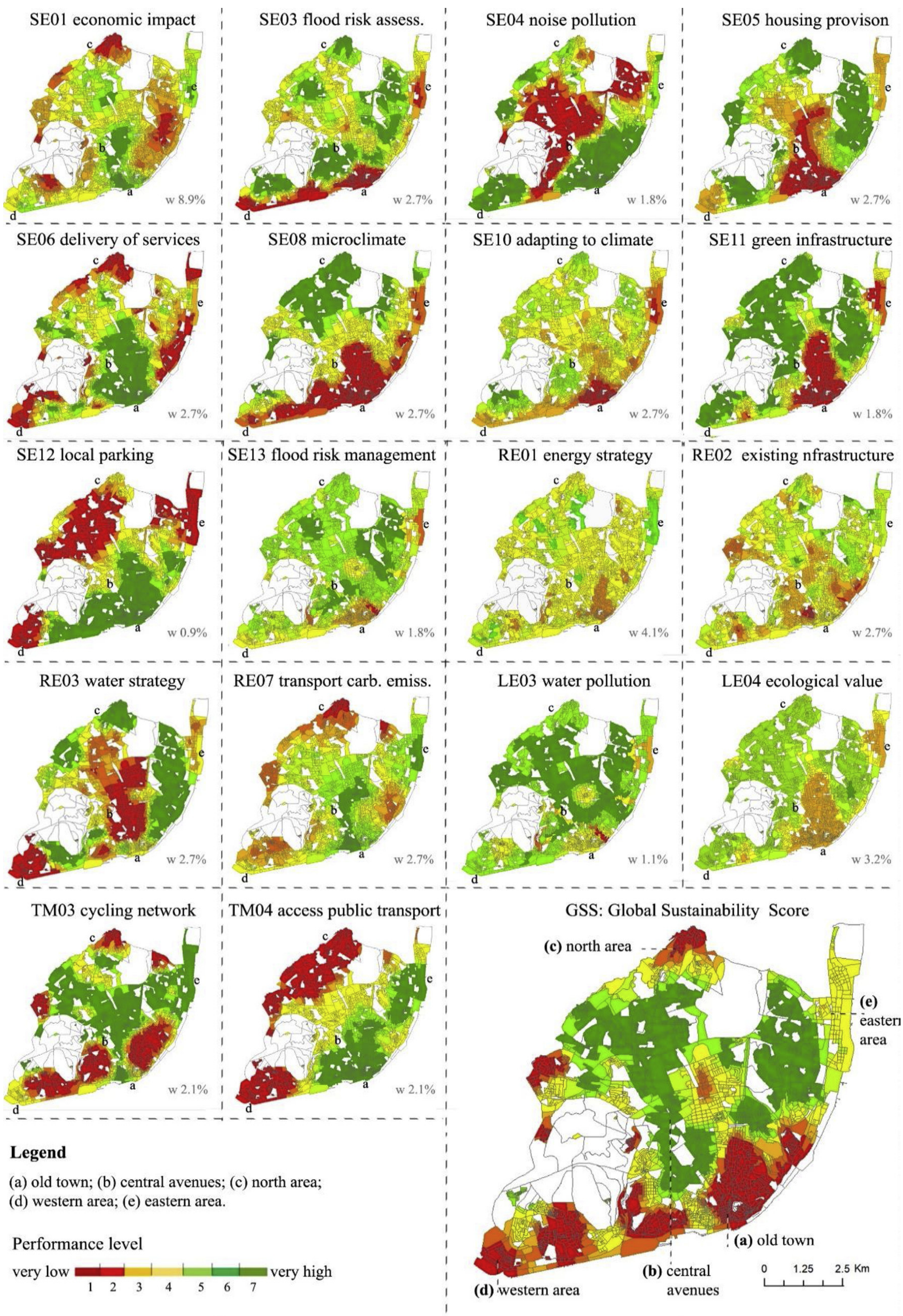

Fig. 4. Results: performance levels spatial distribution.

Table 2
Results: performance level threshold values.

C	SC	Input parameters	Units	Low-performance clusters x^{-*1}	High-performance clusters x^{-*7}
Social & Economic Wellbeing	SE01 Economic impact		zones	c	a, b, e
		V1 Employment	%	55	74
		V2 Business density	%	11	44
	SE03 Flood risk		zones	a, e	b, c
		V3 Flood risk assessment	0-4	4	0
	SE04 Noise pollution			b	a, d
		V4 Noise zone daytime	dB	70	55
		V5 Noise zone night time	dB	60	45
	SE05 Housing provision		zones	a, b	c
		V6 Housing cost	€/m^2	2636	1644
		V7 House patrimonial tax	€/m^2	120	48
	SE06 Delivery of services		zones	d, c, e	a, b
		V8 Distance to services	m	481	128
	SE08 Microclimate		zones	a, b	c
		V9 Heat island intensity level	1-6	6	1
	SE10 Adapting to climate change		zones	a, e	c
		V3 Flood risk	0-4	(see SE03)	(see SE03)
		V9 Heat island intensity level	1-6	(see SE08)	(see SE08)
		V10 Soil erosion vulnerability	1-4	4	1
		V11 Wind vulnerability	1/0	1	0
	SE11 Green infrastructure.		zones	a, b, e	d, c
		V12 Distance to green areas	m	436	107
	SE12 Local parking		zones	d, c, e	a
		V14 Car parking ownership	C/100people	21	4
	SE13 Flood risk management		zones	a	c
		V3 Flood risk	0-4	(see SE03)	(see SE03)
		V15 Drainage system	1/0	1	0
		V16 Av. surface water run-off	%	52	37
Resources & Energy	RE01 Energy strategy		zones	a	e
		V17 Energy label (non-residential)	%	0	29
		V18 Energy label (residential)	%	9	48
	RE02 Existing buildings & infrastructure.		zones	a	e
		V19 Buildings in need of repair	%	65	25
		V20 Urban rehabilitation support	1/0	0	1
	RE03 Water strategy		zones	b, d	c
		V21 Domestic water consumption	L/cap.	160	115
	RE07 Transport carbon emissions		zones	c	a, b, e
		V22 Distance to bike sharing	m	2144	265
		V23 Distance to cycle lane	m	753	210
		V24 Distance to electric car charger	m	921	199
		V25 Distance to public transport	m	(see TM04)	(see TM04)
Land use & ecology	LE03 Water pollution		zones	a	d, c
		V15 Drainage system	1/0	(see SE13)	(see SE13)
		V16 Av. surface water run-off	%	(see SE13)	(see SE13)
	LE04 ecological value		zones	a, b, e	d, c
		V12 Distance to green areas	m	(see SE11)	(see SE11)
		V13 Green area ratio	%	3	49
Transports Movement	TM03 Cycling network		zones	a, c	e, b
		V22 Distance to cycle lane	m	(see RE07)	(see RE07)
	TM04 Access to public transport		zones	c, d	a, b
		V25 Distance to public transport	m	2352	650
GSS		Global Sustainability score	Level	a, c, d	b
			1-7	1	7

Note 1: (a) old town; (b) central avenues; (c) north area; (d) western area; (e) eastern area.
Note 2: (*1) lowest performance clusters = level 1 (out of 7); (*7) lowest performance clusters = level 7 (out of 7).

limitations of this study and possible directions for future work.

4.1. Lisbon case results and land-use policies implications

The methodology applied to Lisbon case study provides a benchmarking analysis of the sustainable performance of the different city subsections based on the five BREEAM-CM categories analysed (SE, RE, LE, TM) and an estimation of their overall score (GSS). It identifies the lowest and highest performance urban clusters, as well as the key threshold values, as summarized in Fig. 4 and Table 2. We present here in more detail the results obtained in the subcategories with the highest weight on the overall score (SE01, RE01, LE04, TM4) and a set of guidelines to improve the lowest performance clusters identified within each of these subcategories.

Regarding the economic performance (SE01), the results presented in Table 2 show that the employment rate (V1) ranging between 55–75% and the business density (V2) between 10–45% (Table 2). Additionally, Fig. 4 shows that the lowest-performance city subsections were found in the north area (c), and the highest performance in the old town (a). Therefore, the urban policies to improve the city's economic performance should target the north area. These incentives might include tax benefits, financial support, or benefits for hiring locally, with the intent to increase the employment rate and business density.

Regarding the energy performance (RE01), Table 2 shows that the percentage of non-residential units with energy label above "-B" (V17) varied between 0–29%, the residential units (V18) between 9–48%. Additionally, Fig. 4 shows that the lowest-performance subsections were found in the old town (a), while the highest-performance in eastern areas (e). Therefore, the urban policies to improve the city energy performance should target the old town area. These incentives might include tax benefits, lower interest rates for energy retrofits (e.g., insulation, windows lighting, equipment efficiency), creating awareness campaigns for enhancing responsible energy consumption behaviour, and other incentives to increase the number and level of energy certificates.

Regarding the ecological value (LE04), Table 2 shows that the distance to green areas (V12) ranged from 440 to 100 m, and the average green area ratio (V13) between 3% and 50%. Additionally, Fig. 4 shows that the lowest-performance subsections were found in the old town (a), central avenues (b) and eastern areas (e), while the highest-performance in the north area (c) and western area (d). Therefore, the urban policies to improve the city ecological value should target to the old town, central avenues, and eastern areas. These incentives can include establishing limitations on the right of construction or tighter standards for the minimum green area ratio in new construction or renovation projects, the creation of new public gardens in these areas to reduce the distance to green areas and increase the green area ratio.

Regarding the access to public transport (TM04), Table 2 shows that the average distance to public transports (V25) ranged between 650–2350 m. Additionally, Fig. 4 shows that the lowest-performance subsections were found in the north area (c) and western area (d), while the highest-performance in the old town (a), central avenues (b). Therefore, the urban policies to improve the city public transport services should target the north and western area. These incentives can include the creation or extension of the public transport network, as well as incentives for alternative transport modes such as the extension of the cycling networks in these areas to reduce the distance to public transports.

Furthermore, the results for the Global Sustainability Score (GSS) presented in Fig. 4 show that the city subsections located on the central avenues (b) achieve the highest performance, while the subsections located on the old town (a), north area (c) and western area (d) perform the lowest.

The outcomes of this work can be used differently depending on the stakeholder involved in the decision process and scale of intervention. From the city planning point of view, the local planning authorities can use this model to identify the urban clusters where the city is performing worst. As in the foregoing examples, considering the improvement of the economic performance (SE01), the urban policies should be targeted in the north area (a). Moreover, from a neighbourhood point of view, the urban planner or project manager has a specific site location and can use this model to identify the sustainability categories where these urban areas perform the worst. For example, projects in the city old town should contain measures (a), to reduce flood risk (SE03), support housing provision (SE05), favour microclimates (SE08), adapt to climate change (SE10), and increase green infrastructure (SE11).

4.2. Lessons learned, limitations and pathways for improvement

This study proposes combining BREEAM-CM and GIS to support land-use decisions in the context of sustainable urban planning. Applying this methodology to Lisbon as a case study resulted in the identification of the priority areas and threshold values that can be used by local governments to enhance urban sustainability. In light of these results, here we discuss the limitations and possible directions to extend the analysis beyond the case study.

One of the major challenges of this work was finding high-quality and high-resolution statistical data. This process required combining census data and multiple datasets, however, due to the lack of data availability, we could only compute 18 out of the 40 assessment subcategories (as explained in Section 3.2.1). Consequently, although the model can be used to analyse individual categories, an error associated with the overall sustainability score occurs since only 48% of its possible credits could be estimated. In addition, for the input variables on domestic water consumption (V21), and the number of buildings in need for retrofit (V21) the data was only available at the parish level (as explained in Section 3.2.1). This limitation influences the spatial resolution of the results in corresponding categories in the sense that data in a more aggregated format provides less distinction between clusters. In fact, the challenges of lack and uncertainty of data are often mentioned in similar studies, particularly when related to data availability for the neighbourhood level (Berardi, 2015; Codoban and Kennedy, 2008; Eliverable et al., 2014; Turcu, 2012). To this point, Carter et al (2015) highlight the importance of improving the spatial and temporal resolution in databases. Furthermore, Malczewski (2004) notes that improving the quantity and quality of data have a direct impact on planning and decision making. In order to overcome these data limitations, future work might consider the creation of public libraries and collaboration between statistical institutes from complementary research fields. Moreover, the method used could be applied to any other urban area, as long as the inputs of the model are known.

Second, the BREEAM-CM evaluation process depends on descriptive and prescriptive guidelines (as explained in Section 3.2.1). In this study, we are not able to assess the categories dependent on pure descriptive guidelines as this requires very detailed information that could not be obtained using statistical datasets. Therefore, we only analysed the categories dependent on prescriptive guidelines. This limitation has previously been encountered by authors such as Korhonen (2007), who describes the advantages of using a descriptive approach rather than a prescriptive one. In fact, BREEAM systems have already become less prescriptive in their newest versions (Berardi, 2015). Other assessment systems such as LEED-Neighbourhoods offer a more descriptive approach (Pedro et al., 2017; Starrs, 2010). In line with these arguments, future research should consider testing the use of GIS in combination with alternative multi-criteria decision support systems, as they may differ in the metrics or approach used.

Third, the interactive nature of GIS makes it possible to use in several tasks within the assessment process. These include the collection of information from different databases, cluster analyses, and visualizations of the results. GIS was particularly important because it enabled evaluating a large set of neighbourhoods simultaneously. This provided information on whether a neighbourhood is performing better or worse by comparison to the others. Nevertheless, this process can be very time consuming, especially for larger datasets with an increased number of input variables or assessment categories. Authors such as Graymore et al. (2009) argue that automating GIS tasks can shrink process time, allow input files to be easily updated to include new data or indicators, and the weights can easily be changed if indicator priorities change. Additionally, recent studies (Yeo and Yee, 2016) highlight that GIS-based models dealing with flexibility and optimization are still under development and efforts in this direction can open new doors to sustainable urban planning. In this sense, our work focused on identifying the data, tasks and workflows necessary for GIS analysis. The next steps can include automating this process. For example, this study can be used as a framework for the development and implementation of an ArcGIS® plugin for sustainability assessments. This would support urban planners and architects' decisions by enabling them to easily change the content and repeat the process for other cities or testing alternative scenarios for the same city.

5. Concluding remarks

This study proposes a methodology to help local governments in decision-making regarding the planning and implementation of urban policies for the sustainable development of their cities. With this purpose, we tested the combination of the urban sustainability assessment system BREEAM-CM and GIS-based spatial analysis. This methodology was applied to the analysis of 3657 administrative statistical subdivisions of Lisbon. The results highlight four main policy recommendations for this city: 1) foster economic activity particularly in the city north area; 2) implement energy efficiency strategies especially in the old town; 3) enhance the land ecological value particularly in the areas such as the old town and central avenues; 4) improve access to public transportation in the north area and western area.

These research results demonstrate that urban sustainability assessment tools, such as BREEAM-CM provide a robust set of criteria for the evaluation of the sustainable performance of an urban area, although the evaluation approach needs to be adjusted in case of extending the study area from the neighbourhood towards the city scale, to overcome challenges related to lack of data resolution and quality an account for the uncertainty levels associated with the evaluation results. Additionally, GIS-based spatial analysis enables the identification of urban patterns and interrelations between neighbourhoods. This approach makes it is possible to identify the key of parameters and priority intervention areas that can help local governments to develop and implement urban policies for the sustainable development of a city.

The present work constitutes a first step for the development of a decision support tool in the context of sustainable urban planning by identifying the data, tasks and workflows necessary for such an analysis. Future research includes expanding datasets, testing the combination of GIS with other multi-criteria decision support models and compare the results, automating the geo-referenced tasks to make the model flexible and adaptable to other geographic contexts.

Acknowledgements

The authors are grateful to the generous support provided by the Portuguese Foundation for Science and Technology (FCT), under the program MIT-Portugal – Sustainable energy systems, through the doctoral scholarship (PD/BD/113719/2015). Thank you to Anabela Reis for the constructive suggestions during the development of this research work. We would also like to show our gratitude to EPAL for enabling access to water consumption data, and ADENE for enabling the access to energy certificates data from Lisbon Municipality used in this study.

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.landusepol.2019.02.003.

References

ADENE, 2016. Sistema Nacional de Certificação Energética e Ar Interior Edificios [National System of Energy Certification and Indoor Air Quality of Buildings]. Retrieved January 2, 2016, from. http://www.adene.pt/sce/micro/certificados-energeticos.

Adinyira, E., Oteng-seifah, S., Adjei-kumi, T., 2007. A review of urban sustainability assessment methodologies. International Conference on Whole Life Urban Sustainability and Its Assessment 8. https://doi.org/10.1016/j.ecolind.2008.05.011.

Alcoforado, M.J., António, L., Alves, E., Canário, P., 2014. Lisbon heat Island. Statistical study (2004–2012). Finisterra-Revista Portuguesa de Geografia. Retrieved from. http://www.arcgis.com/apps/MapSeries/index.html?appid=9957359140af4fdb824bdf9783eef4e5.

Ali-Toudert, F., Ji, L., 2017. Modeling and measuring urban sustainability in multi-criteria based systems — a challenging issue. Ecol. Indic. 73. https://doi.org/10.1016/j.ecolind.2016.09.046.

Ameen, R.F.M., Mourshed, M., Li, H., 2015. A critical review of environmental assessment tools for sustainable urban design. Environ. Impact Assess. Rev. 55, 110–125. https://doi.org/10.1016/j.eiar.2015.07.006.

AT, 2016. SIMIMI - Simulador de Valor Patrimonial Tributário [Tax Patrimonial Simulator]. Retrieved January 11, 2018, from. https://zonamentopf.portaldasfinancas.gov.pt/simulador/default.jsp.

Baltazar, S., 2014. New bioclimatic maps of Lisbon. Spatial modelling of physiological temperature modeling. Finisterra - Revista Portuguesa de Geografia 98, 81–94. Retrieved from. http://www.scielo.mec.pt/scielo.php?script=sci_arttext&pid=S0430-50272014000200007&lng=pt&nrm=iso&tlng=en.

Berardi, U., 2011. Beyond sustainability assessment systems: upgrading topics by enlarging the scale of assessment. Int. J. Sustain. Build. Technol. Urban Dev. 2 (4), 276–282. https://doi.org/10.5390/SUSB.2011.2.4.276.

Berardi, U., 2013. Sustainability assessment of urban communities through rating systems. Environ. Dev. Sustain. 15 (6), 1573–1591. https://doi.org/10.1007/s10668-013-9462-0.

Berardi, U., 2015. Sustainability assessments of buildings, communities, and cities. Assessing and Measuring Environmental Impact and Sustainability. Elsevier Inc.https://doi.org/10.1016/B978-0-12-799968-5.00015-4.

Braulio-Gonzalo, M., Bovea, M.D., Ruá, M.J., 2015. Sustainability on the urban scale: proposal of a structure of indicators for the Spanish context. Environ. Impact Assess. Rev. 53, 16–30. https://doi.org/10.1016/j.eiar.2015.03.002.

BRE Global, 2012. BREEAM Communities: Technical Manual SD202-0.1:2012.

BRE Global, 2015. GN23 : BREEAM Bespoke Process, (August). Retrieved from. https://www.breeam.com/filelibrary/GuidanceNotes/GN23-BREEAM-Bespoke-Process.pdf.

Broto, V.C., 2017. Urban governance and the politics of climate change. World Dev. xx. https://doi.org/10.1016/j.worlddev.2016.12.031.

Cajot, S., Peter, M., Bahu, J.M., Guignet, F., Koch, A., Maréchal, F., 2017. Obstacles in energy planning at the urban scale. Sustain. Cities Soc. 30, 223–236. https://doi.org/10.1016/j.scs.2017.02.003.

Callway, R., Dixon, T., Nikolic, 2016. BREEAM communities: challenges to sustainable neighbourhood evaluation. Rics Cobra 2016 (September).

Carter, J.G., Cavan, G., Connelly, A., Guy, S., Handley, J., 2015. Climate change and the city- building capacity for urban adaptation. Progress Plann. 95, 1–66.

Chrysochoou, M., Brown, K., Dahal, G., Granda-Carvajal, C., Segerson, K., Garrick, N., Bagtzoglou, A., 2012. A GIS and indexing scheme to screen brownfields for area-wide redevelopment planning. Landscape Urban Plann. 105 (3), 187–198. https://doi.org/10.1016/j.landurbplan.2011.12.010.

CML, 2012. Manual Técnico do Plano Diretor Municipal de Lisboa [Technical Handbook on Lisbon Master PLan]. Retrieved from. Camara Municipal de Lisboa, Lisbon. http://www.cm-lisboa.pt/viver/urbanismo/planeamento-urbano/plano-diretor-municipal.

CML, 2015. PGD: Plano Geral de Drenagem de Lisboa [Lisbon General Drainage Plan]. Retrieved from. http://www.cm-lisboa.pt/participar/lisboa-em-debate/plano-drenagem.

CML, 2016a. Lisboa - Plataforma de Dados Abertos Georreferenciados [Lisbon - Georeferenced Open Data Platform]. Retrieved December 19, 2016, from. http://geodados.cm-lisboa.pt/.

CML, 2016b. Portal de dados abertos de Lisboa [Lisbon Open Data Portal]. Retrieved January 11, 2018, from. http://dados.cm-lisboa.pt/dataset.

CML, 2017a. EMAAC: Estratégia Municipal de Adaptação às Alterações Climáticas [Strategy for Managing Adaptation to Climate Change]. Retrieved from http://www.cm-lisboa.pt/viver/urbanismo/planeamento-urbano/estrategia-municipal-de-adaptacao-as-alteracoes-climÃ¡ticas. .

CML, 2017b. Lisboa ciclavel [Lisbon cycling]. Retrieved January 11, 2018, from. http://lisboaciclavel.cm-lisboa.pt/.

CML, 2017c. The Economy of Lisbon in Figures. Lisbon. Retrieved from. http://www.cm-lisboa.pt/en/business/investment/lisboa-in-figures/lisboa-economy-in-figures.

Codoban, N., Kennedy, C.A., 2008. Metabolism of neighborhoods. J. Urban Plann. Dev. 134 (1), 21–31. https://doi.org/10.1061/(ASCE)0733-9488(2008)134:1(21).

DATALUSO, 2016. Base de Dados de Empresas do Distrito de Lisboa [Database Companies of Lisbon]. Retrieved December 19, 2016, from. http://www.dataluso.com/loja/empresas-lisboa/.

Della Spina, L., Lorè, I., Scrivo, R., Viglianisi, A., 2017. An integrated assessment approach as a decision support system for urban planning and urban regeneration policies. Buildings 7 (4), 85. https://doi.org/10.3390/buildings7040085.

Dixton, T., Eames, M., Hunt, M., Lannon, S., 2014. Urban Retrofitting for Sustainability. Urban Retrofitting for Sustainability: Mapping the Transition to 2050. https://doi.org/10.4324/9781315850184.

Doan, D.T., Ghaffarianhoseini, A., Naismith, N., Zhang, T., Ghaffarianhoseini, A., Tookey, J., 2017. A critical comparison of green building rating systems. Build. Environ. 123, 243–260. https://doi.org/10.1016/j.buildenv.2017.07.007.

Eliverable, D.D., Mittermeier, P., Muas, V.P., Scotto, M., Appolonia, G.D., Giulia Barbano, R., 2014. FASUDIR: IDST Key Performance Indicators.

EPAL, 2015. Consumo de Água por Freguesia [Domestic Water Consumption by Parish]. Unpublished internal document. 2015 In: In: Eraydin, A., Tasan-Kok, T. (Eds.), Resiliense Thinking in Urban Planning Vol. 1 Springer, Netherlands. https://doi.org/10.1017/CBO9781107415324.004.

Eraydin, A., Tasan-Kok, T. (Eds.), 2015. Resiliense Thinking in Urban Planning (Vol. 1). Springer, Netherlands. https://doi.org/10.1017/CBO9781107415324.004.

Etingoff, K., 2017. Sustainable Cities: Urban Planning Challanges and Policy.

European Comission, 2018a. European Green Capital: Jury Report 2020. . Retrieved from http://ec.europa.eu/environment/europeangreencapital/egca2020egla2019finalists/.

European Comission, 2018b. European Green Capital. Retrieved January 4, 2019, from http://ec.europa.eu/environment/europeangreencapital/lisbon-is-the-2020-european-green-capital-award-winner/.

European Commission, 2010. Europe 2020, A Strategy for Smart, Sustainable and Inclusive Growth. https://doi.org/10.1007/s13398-014-0173-7.2.

Ferretti, V., Montibeller, G., 2016. Key challenges and meta-choices in designing and applying multi-criteria spatial decision support systems. Dec. Supp. Syst. 84, 41–52. https://doi.org/10.1016/j.dss.2016.01.005.

Fischer, M., Getis, A., 2010. Spatial clustering. Handbook of Applied Spatial Analysis. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-642-03647-7.

García, G.A., Rosas, E.P., García-Ferrer, A., Barrios, P.M., 2017. Multi-objective spatial optimization: sustainable land use allocation at sub-regional scale. Sustainability (Switzerland) 9 (6). https://doi.org/10.3390/su9060927.

Graymore, M.L.M., Wallis, A.M., Richards, A.J., 2009. An index of regional sustainability: a GIS-based multiple criteria analysis decision support system for progressing sustainability. Ecol. Complexity 6 (4), 453–462. https://doi.org/10.1016/j.ecocom.

2009.08.006.
Greene, R., Devillers, R., Luther, J.E., Eddy, B.G., 2011. GIS-based multiple-criteria decision analysis. Geogr. Compass 5/6, 412–432. https://doi.org/10.1111/j.1749-8198.2011.00431.x.
Haapio, A., 2012. Towards sustainable urban communities. Environ. Impact Assess. Rev. 32 (1), 165–169. https://doi.org/10.1016/j.eiar.2011.08.002.
Haapio, A., Viitaniemi, P., 2008. A critical review of building environmental assessment tools. Environ. Impact Assess. Rev. 28 (7), 469–482. https://doi.org/10.1016/j.eiar.2008.01.002.
INE, 2011a. CENSOS 2011: Edifícios, segundo a época de construção, por necessidades de reparação [Census2011: buildings, according to the time of construction, by repair needs]. Retrieved from. http://censos.ine.pt/xportal/xmain?xpid=CENSOS&xpgid=censos_quadros_edif.
INE, 2011b. Censos 2011 - Importação dos principais dados alfanuméricos e geográficos (BGRI) [Census 2011 - Import of key alphanumeric and geographic data (BGRI)]. Retrieved December 19, 2016, from. http://mapas.ine.pt/download/index2011.phtml.
INE, 2017. Valor mediano das vendas por m2 de alojamentos familiares em apartamentos (€) [Average value of sales per m2 of family accommodation in apartments (€)]. Retrieved January 11, 2018, from. https://www.ine.pt/xportal/xmain?xpid=INE&xpgid=ine_indicadores&indOcorrCod=0009486&contexto=bd&selTab=tab2.
Kaur, H., Garg, P., 2018. Urban sustainability assessment tools: a review. J. Cleaner Prod. https://doi.org/10.1016/j.jclepro.2018.11.009.
Korhonen, J., 2007. Environmental planning vs. Systems analysis: Four prescriptive principles vs. four descriptive indicators. J. Environ. Manage. 82 (1), 51–59. https://doi.org/10.1016/j.jenvman.2005.12.003.
Lin, K.W., Shih, C.M., 2018. The comparative analysis of neighborhood sustainability assessment tool. Environ. Plann. B: Urban Anal. City Sci. 45 (1), 90–105. https://doi.org/10.1177/0265813516667299.
Longley, P., Batty, M., 1996. Spatial Analysis: Modelling in a GIS Environment. John Wiley & Sons.
Malczewski, J., 2004. GIS-based land-use suitability analysis: a critical overview. Progress Plann. 62 (1), 3–65. https://doi.org/10.1016/j.progress.2003.09.002.
Malczewski, J., 2006. GIS-based multicriteria decision analysis: a survey of the literature. Int. J. Geogr. Inf. Sci. 20 (7), 703–726. https://doi.org/10.1080/13658810600661508.
Malczewski, J., Rinner, C., 2015. Multicriteria Decision Analysis in Geographic Information Science. Analysis Methods. https://doi.org/10.1007/978-3-540-74757-4.
Ord, J.K., Getis, A., 1995. Local spatial autocorrelation statistics: distributional issues and an application. Geogr. Anal. 27 (4), 286–306. https://doi.org/10.1111/j.1538-4632.1995.tb00912.x.
Pedro, J., Silva, C., Pinheiro, M., 2017. Scaling up LEED-ND sustainability assessment from the neighborhood towards the city scale with the support of GIS modeling: Lisbon case study. Sustain. Cities Soc. https://doi.org/10.1016/j.scs.2017.09.015.
Peeters, A., Zude, M., Käthner, J., Ünlü, M., Kanber, R., Hetzroni, A., et al., 2015. Getis-Ord's hot- and cold-spot statistics as a basis for multivariate spatial clustering of orchard tree data. Comput. Electron. Agric. 111, 140–150. https://doi.org/10.1016/j.compag.2014.12.011.
Reckien, D., Creutzig, F., Fernandez, B., Lwasa, S., Tovar-restrepo, M., Satterthwaite, D., 2017. Climate change, equity and the sustainable development goals: an urban perspective. Environ. Urbanization 29 (1), 159–182. https://doi.org/10.1177/0956247816677778.
Rogerson, P.A., Fotheringham, A.S., 1994. Spatial Analysis and GIS. CRC Press.
Sharifi, A., Murayama, A., 2013. A critical review of seven selected neighborhood sustainability assessment tools. Environ. Impact Assess. Rev. 38, 73–87. https://doi.org/10.1016/j.eiar.2012.06.006.
Sharifi, A., Murayama, A., 2014a. Neighborhood sustainability assessment in action: cross-evaluation of three assessment systems and their cases from the US, the UK, and Japan. Build. Environ. 72. https://doi.org/10.1016/j.buildenv.2013.11.006.
Sharifi, A., Murayama, A., 2014b. Viability of using global standards for neighbourhood sustainability assessment: insights from a comparative case study. J. Environ. Plann. Manage. 1–23. https://doi.org/10.1080/09640568.2013.866077. 0(0).
Sharifi, A., Gentile, M., Tammaru, T., Van Kempen, R., 2016. From Garden City to eco-urbanism: the quest for sustainable neighborhood development. Cities 29 (5), 291–299. https://doi.org/10.1016/j.scs.2015.09.002.
Starrs, M., 2010. Breeam Versus Leed. Inbuilt Ltd https://educnet.enpc.fr/pluginfile.php/15200/mod_resource/content/0/breeamvsleed.pdf.
Talen, E., Allen, E., Bosse, A., Ahmann, J., Koschinsky, J., Wentz, E., Anselin, L., 2013. LEED-ND as an urban metric. Landscape Urban Plann. 119, 20–34. https://doi.org/10.1016/j.landurbplan.2013.06.008.
Tam, V.W.Y., Karimipour, H., Le, K.N., Wang, J., 2018. Green neighbourhood : review on the international assessment systems. Renew. Sustain. Energy Rev. 82 (August (2016)), 689–699. https://doi.org/10.1016/j.rser.2017.09.083.
Turcu, C., 2012. Local experiences of urban sustainability: researching housing market renewal interventions in three English neighbourhoods. Progress Plann. 78 (3), 101–150. https://doi.org/10.1016/j.progress.2012.04.002.
UN, 1993. Agenda 21: United Nations Programme of Action for Sustainable Development 5. pp. 300.
UN, 2017. Transforming Our World: The 2030 Agenda for Sustainable Development.
Venou, A., 2014. Investigation of the "BREEAM Communities" Tool with Respect to Urban Design. (Mater Thesis). KTH Royal Institute of Technology, Stockholm.
Verovsek, S., Juvancic, M., Zupancic, T., 2018. Widening the scope and scale of sustainability assessments in built environments: from passive house to active neighbourhood. Acad. J. Interdisc. Stud. 7 (1), 129–135. https://doi.org/10.2478/ajis-2018-0013.
Wallhagen, M., Malmqvist, T., Finnveden, G., 2016. Certification systems for sustainable neighbourhoods: what do they really certify? Environ. Impact Assess. Rev. 56, 200–213. https://doi.org/10.1016/j.eiar.2015.10.003.
WCED, 1987. World Commission on Environment and Development: Our Common Future.
Yeo, I.A., Yee, J.J., 2016. Development of an automated modeler of environment and energy geographic information (E-GIS) for ecofriendly city planning. Autom. Constr. 71 (Part 2), 398–413. https://doi.org/10.1016/j.autcon.2016.08.009.
Yigitcanlar, T., Kamruzzaman, M., 2018. Does smart city policy lead to sustainability of cities? Land Use Policy 73 (January), 49–58. https://doi.org/10.1016/j.landusepol.2018.01.034.