

Urban sprawl assessment model in the context of sustainable development

MARIA ELISABETE S. SOARES¹; RUI A. R. RAMOS²; ANA MARIA D. B. FONSECA³

(1) Research Unit for Development of Interior* - Polytechnic Institute of Guarda
Av. Dr. Francisco Sá Carneiro, n.º50, 6300-559 Guarda - PORTUGAL

esoares@ipg.pt, <http://www.ipg.pt/>

(2) Department of Civil Engineering, University of Minho – Engineering School
Campus de Gualtar – 4710-057 Braga -PORTUGAL

rui.ramos@civil.uminho.pt, www.civil.uminho.pt/c-tac/

(3) LNEC, National Laboratory for Civil Engineering, Lisboa -PORTUGAL.

anafonseca@lnec.pt, www.lnec.pt/

Abstract: The disordered urban growth may prove catastrophic for the future of cities if preventive measures are not taken. The increase of built-up areas, the growing need for implementation of urban infrastructures, the resulting increase in soil sealing, the excessive consumption of natural resources, the elevated need for car use on daily travels, the increase in travel distances, etc., are examples of the negative effects caused by urban sprawl. In order to implement measures to halt or avoid the damage caused by urban sprawl on the environment, society and economy, it is necessary to know which areas to intervene. In this sense, a multicriteria analysis model is presented that combines sustainable development indicators, with the main objective of calculating an index of sustainable urban expansion. This model, developed according to the Analytical Hierarchy Process, comprises three levels of analysis. At the first level, the indicators of urban sustainable development are aggregated and associated with six criteria. The weighted aggregate of composite indicators, which constitute the second level of analysis, allows evaluating different scenarios and studying the level of influence of urban sprawl on the diverse dimensions. In the last level of analysis, an index is calculated, resulting from the aggregation of all indicators considered along the hierarchical structure. Thus, the proposed model allows quantifying the level of sustainability of urban sprawl, according to the lines of sustainable development defined for this work, serving as a tool to support urban planning interventions.

Key-Words: urban sprawl, sustainable urban development, indicators of urban sustainability, multicriteria analysis model

*- with support from the Portuguese Foundation for Science and Technology (FCT)

1 Introduction

According to the European Environment Agency (2006) more than a quarter of the European Union's territory has now been directly affected by urban land use and the total consumed space per person in cities of Europe more than doubled in the last 50 years. This fact, motivated by lifestyle and changes in consumption patterns, is commonly referred to as urban expansion. For EEA [1] the urban expansion is defined as a phenomenon that occurs when the rate of affectation of land for urban use exceeds the population growth for a given area over a period of time. Even where there is low or no population pressure, a variety of factors are still driving expansion. There is the desire to experience new lifestyles in suburban environments. The preference for a one-family house and the many negative aspects of the inner-city areas, including poor environment, environmental quality problems, social problems, safety issues, lack of green areas

and spaces to practicing sports, drive many families out of the city [1, 2]. The emergence of new urban areas with low population density results in higher consumption. The residential scattering and the economic activities in part related to the development of the transport network and urban infrastructures, and improved transport connections and personal mobility, are reasons for expansion of cities. EEA [1] referred that presently the planning policies reflect the logic of the market, but it would be better to reflect a vision of urban development, in which considerations of environmental and social nature were fully integrated into spatial planning policies at all stages of its cycle, from identification of problems and design policies to the stages of implementation and subsequent evaluation. Also in the report of PNPOT [3] a set of problems related to planning have been identified, grouped in the following areas: a) insufficient protection and enhancement of natural resources and inefficient risk management; b) disorderly urban expansion and

resulting effects on the fragmentation and disqualification of urban space and surroundings; c) inefficiency and economic and environmental unsustainability in transport and energy; d) lack of infrastructure and support systems to competitiveness, connectivity and international projection of the economy; e) inadequate territorial distribution of infrastructures and community facilities in relation to the dynamics of population change and social needs; f) absence of a civic culture of land use planning and inefficient information systems, planning and land management. Against this background it is urgent to intervene. This action involves knowledge of the causes of the problem to be corrected or avoided and the use of tools to support urban planning and territorial management. In this context, a multicriteria analysis model is presented that aggregates indicators of sustainable development, with the main objective of calculating an index of sustainable urban expansion.

2 Urban sprawl

Urban sprawl is the term commonly used to describe the physical expansion of urban areas and is associated with poor control of land use planning and the consequent disorder of the territory [1, 2]. EEA [1] describes sprawl as the physical model of low-density expansion of large urban areas under specific market conditions, particularly around the agricultural areas. Christiansen & Loftsgarden [2] reported that there is not a single definition of urban sprawl, however there are common denominators to them all, as low density and inefficient land use. The urban sprawl takes different forms and varies for different countries and regions [2, 4], so successful policies applied in a given region may not be as successful in other regions due to different dimensions of expansion. Christiansen & Loftsgarden [2] considered that the urban sprawl is more significant in cities dominated by economic activity, which normally is not located in the city center. The low cost of agricultural land on the periphery in relation to urban areas in the city center and lower pendular costs, are important factors to take into account as a cause of urban sprawl [1, 2]. The city's development is uneven, scattered and directed outwards, with a tendency to discontinuity [1]. According to Christiansen & Loftsgarden [2] there are four driving forces of urban sprawl: economy, society, transport and political governance. The urban sprawl has social, economic and environmental impacts. The impact on the environment and natural resources, on the protected

areas, on the quality of life, on the health and even the impact of transport infrastructures on the landscape, soil sealing which increases the damage caused by floods and fragmentation natural areas, are examples of harmful effects caused by excessive urban expansion [1]. Some of the most visible impacts are reported in countries or regions with rapid economic growth and benefited from European Union regional policy, as is the case of Portugal [1, 2]. Urban development involves the consumption of many natural resources, especially non-renewable resources, and changes the soil properties. The loss of water permeability of soils, loss of soil biodiversity and reductions of the capacity of the soil to act as a carbon sink, are important impacts to consider. The predominance of car transportation in sprawling cities increases energy consumption, contributing to an increase in CO₂ emissions to the atmosphere. Among the factors that influence the emissions of CO₂ are the road type, the extension of systems transport and the modal split between public and private transport [1]. Sprawl also increases the length of trips required to collect municipal waste for processing at increasingly distant waste treatment plants and this increases greenhouse effects. Thus, the sprawl contributes to poor air quality and high levels of noise which affect the quality of life and community health. The environmental impacts of sprawl are evident in a number of ecologically sensitive areas located in coastal zones and mountain areas. Even where the direct advance of urban land on natural and protected areas is minimized, the indirect fragmentation impacts related with transport and other urban infrastructure development create barrier effects that degrade the ecological functions of natural habitats [1]. Reworking and removal of the soil surface by construction can unbalance watersheds and landscapes, contributing to the loss of biological diversity, ecosystem integrity and productivity, as well as to land degradation and erosion [1]. Urban areas are becoming increasingly vulnerable to geo-problems controlled by geological processes. The total cost of these problems to society ranges from major hazards, such as volcanic eruptions, earthquakes, floods, land subsidence, landslides, to minor hazards such as local swelling or shrinking of clays in foundations. In coastal zones there are risks associated with sea level rise and flooding. Although it is not a specific issue generated by urban sprawl, the management of these risks and planning for an adaptation will be made more complicated if urban sprawl is not controlled [1]. From a social perspective, urban sprawl generates segregation of residential development

according to income [1]. Consequently, it can exacerbate urban social and economic divisions. From an economic perspective, urban sprawl is at the very least a more costly form of urban development [1]. This view is mainly due to increased household spending on commuting between home and work over longer and longer distances, the cost to business of the congestion in sprawled urban areas with inefficient transportation systems, the additional costs of the extension of urban infrastructure including utilities and related services, across the urban region. Moreover, the urban sprawl inhibits the development of public transport and the provision of alternative choices in transportation that are essential to ensure the efficient operation of urban environments. For the EEA [1] the failure to control urban sprawl at the local level, despite the policies and tools that are available, supports the case for the development of new initiatives and new policy visions to address the regional and urban planning to meet all these challenges.

2.1 Measures to combat urban sprawl

Combat urban sprawl includes the definition of initiatives in accordance with the principles of sustainable development, which are coherent and built around measures to ensure integration of policies through close coordination and cooperation between different levels of administration [1]. The authors believe that there is now a growing awareness of the benefits of considering urban territory as an integrated unit for stimulating better coordination of policies and analysis of its economic, social and environmental impacts. Knowing that managing cities is a complex and interrelated task, the solution to one problem at a given scale is often the cause of another problem at a similar or different scale. It is important to recognize that while the city is the main focus of socio-economic activity, the associated pressures and the impacts of the environment, it cannot be managed in isolation from forces and decisions. Another dimension relates to the review of policies at local level. Thus, a new model of planning as response to urban sprawl should be built following principles that recognize what is conducted locally and what is conducted by the European Union [1]. The articulated vision of sustainable urban and regional development can contextualize a variety of integrated mutually reinforcing policy responses, offering new coherent measures to be implemented at all levels. The identification of the necessary spatial trade-offs between economic, social and

environmental objectives and the key requirements for the sustainable development of cities, requires an improved regional contextualization of the respective assets that should be maintained, restored or enhanced [1]. Policy guidelines must be produced focused on balance and territorial cohesion, better regional competitiveness, access to markets and to knowledge, as well as prudent management of natural and cultural resources [1]. Polycentric spatial development is the main concept underpinning the aims of territorial cohesion. According to EEA [1] this concept can be described as a bridging mechanism between economic growth and balanced development. Mobility and accessibility are essential factors for territorial cohesion and to improve the quality of life of communities, but remain a critical challenge for management and urban planning. Thus, the road and rail infrastructures should be part of a global approach directed to the development of local economies and urban areas, according to a polycentric and balanced growth that reduces the environmental damage [1]. According to EEA [1] it is fundamental to understand, in both functional and operational terms, the unsustainable development patterns of cities so that future unsustainable development can be corrected or avoided. This is a challenge even for experts studying the most sustainable forms of urban development.

2.2. Assessment of urban sprawl in the context of sustainable development

The first definition of sustainable development emerged in 1987 and was proposed by World Commission on Environment and Development, and it is also one that brings greater consensus to date and is stated as follows: “*Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs*” [5]. Originally, it included three dimensions: environmental, social and economic. More recently a fourth dimension has been introduced and the concept of sustainability now has four dimensions: environmental, social, economic and institutional [6-8]. According to Tanguay et al. [5] the lack of consensus on the creation of sustainable development indicators stems fundamentally from ambiguity in the definition of sustainable development, objectives for the use of such indicators, the selection method and the accessibility of quantitative and qualitative data. It is important to clarify the difference between indicators and data or observed variables. A datum or observed variable

becomes an indicator only after its role for the evaluation of a phenomenon has been established [5]. An indicator of sustainable development results from a variable or set of variables that reflect one or more attributes of sustainability [9]. According to Kasanko et al. [10] indicators that measure in absolute terms different classes of land use, generally are not comparable between different cities since these are easily influenced by the size of the study area. For Mega & Pederson [11] indicators should point out which aspects of the city are improving compared to others and according to specific goals. Organizations involved in the development of indicators seem to agree that its significance extends beyond those obtained directly from observations. Their properties are required to be clear, simple, scientific, verifiable and reproducible. It is also required that they are significant, helpful in the comparison, evaluation, forecasting, construction and reconciliation of the database, in order to promote local information and decision making, taking into account that the indicators can measure the success of and even stimulate an action, but do not indicate the type of action to be applied. If possible, indicators should cover all sectors and thus contribute to a more visible and transparent city and also to the sustainable development process [1]. The objectives of the thematic indicators are defined at the city level and in accordance with the priorities of each city. Thus, decision-makers, citizens and inhabitants have at their service a wide variety of instruments of urban intervention. For urban policies it is essential to know how citizens value the different fields of action and intervention, because their willingness to pay for achieving sustainability goals is very important when decisions are taken to provide a public service or infrastructure or to increase the level of environmental amenity [11]. The transition from thematic indicators for a performance index of political sustainability of cities is a complex task. An index of sustainable development, or composite indicator, is a summary of indicators, based on a model, and results from the aggregation of variables or from environmental, social, economic and institutional indicators [5, 9, 12]. In the context of sustainable development, the index should measure multidimensional concepts, facilitate meaning and interpretation of indicators for a given phenomenon, and cannot be structured by a single indicator [5, 12]. The indicators have to be weighted by their contribution to sustainable levels and all previous levels of aggregation should be taken into account. In accordance with Tanguay et al. [5] an effective approach to sustainable development consists

of identifying the respective integrated dimensions, as broadly as possible, while ensuring that possible overlapping between these dimensions are clearly specified. However, limitations in the accessibility and availability of data are recurrent problems in the municipality, which may influence the number of active indicators to be used in achieving sustainable development throughout the city [5].

3 Multicriteria Analysis Model

In a context supported by the references, in order to study the urban sprawl in Portuguese cities and develop a tool that fulfils indicators of sustainable development, a multicriteria analysis model is presented (Fig.1) which main objective is the calculation of sustainable urban expansion index, showing the analysis of urban planning in an integrated and sustainable context.

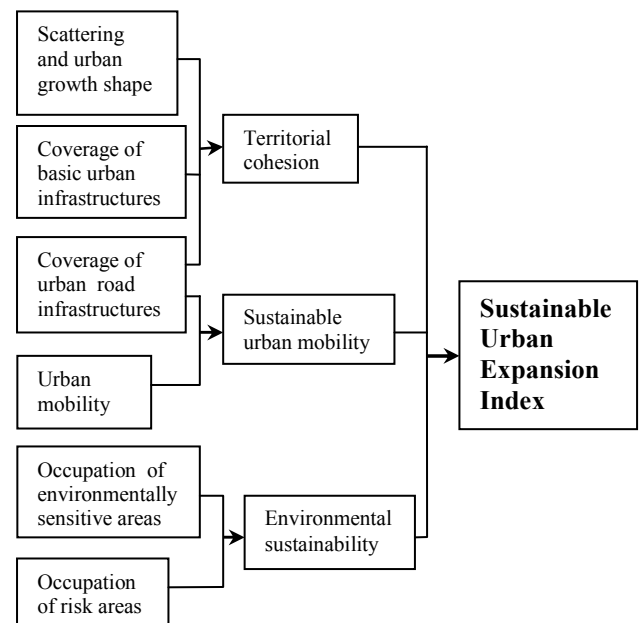


Fig.1 – Flowchart of the multicriteria analysis model

To facilitate analysis among the different dimensions, the multicriteria analysis model is structured along the hierarchical approach known as Analytic Hierarchy Process (AHP) [13]. The dimensions of sustainability are introduced into the model through sustainable development indicators that comprise the first level analysis. Whereas the institutional dimension of sustainability has no place in the required research, the model is directed to the remaining three dimensions of sustainability: environmental, social and economic. For model development and analysis according to this approach to sustainable development of urban sprawl six leading criteria were chosen, which in the

opinion of the authors and also according to the literature, are the main actors regarding the problem of urban sprawl. To better structure the multicriteria analysis model, the indicators relating to accessibility and mobility were separated, forming two criteria relating to transport. In this way, the determination of sustainable development indicators and their integration into the model was facilitated. Thus, the main set of criteria is, as shown in Fig. 1: scattering and urban growth shape, coverage of basic urban infrastructures, coverage of urban road infrastructures, urban mobility, occupation of environmentally sensitive areas and occupation of risk areas. Therefore, the first level of the hierarchical model is composed by sustainable development indicators related to these six criteria. The indicators are developed from a geospatial and statistical data base. These data reveal the morphology and shape of the urban core and type of urban sprawl, territorial and organizational aspects, to identify types of land cover, to locate restricted environmental areas and risk areas and their respective occupations, and also to characterize urban mobility. Before their integration into the model it is necessary to standardize the values to a common scale, since these come from different sources with different units and dimensions. Aggregation of the indicators of the first level results on a set of composite indicators. These are designated in this study as territorial cohesion, sustainable urban mobility and environmental sustainability. The territorial cohesion indicator allows evaluating the level of integration of built-up areas with the basic urban infrastructures and transport networks, as well as the degree of dispersion in the occupation of urban land. The sustainable urban mobility indicator allows evaluating the adequacy level of public transport and the respective cost to the population, the level of traffic congestion in the urban zone, the level of traffic pollution, the integrity of intermodal connections, urban road accident rates, and the level of integration of the road structure in urban territory. It should be noted that sustainable development indicators for the criterion “coverage of urban road infrastructures”, are common to achieve the composite indicators “territorial cohesion” and “sustainable urban mobility”, given the influence of transport on both topics. The third indicator called “environmental sustainability” allows the assessment of the compliance with environmental and safety rules imposed by land occupation, including urban land, as well as the existence of hazard situations. A sectoral analysis of composite indicators and assessment of different scenarios

allows distinguishing and quantifying the contribution of each dimension for sustainable urban development. It is also possible to evaluate each composite indicator separately, calculating indexes related with each one. The weighted aggregation of the composite indicators of the hierarchical model calculates a sustainability index of urban expansion, which represents the final stage of the model.

4 Conclusions

The urban sprawl has environmental, social and economic costs to the city, forcing the application of measures by policy-makers and planners to ensure the sustainability of the territory. The multicriteria analysis model here presented enables the assessment of the urban sprawl in the context of sustainable development, identifying factors that contribute to the sprawl, thus constituting a tool to support the analysis of the problem. It is possible to know the level of territorial cohesion, the typology of urban expansion and its relation with urban development, and calculate indexes of urban expansion defined according to the dimensions of sustainability. It is also possible to know the current urban mobility and compare these data with the concepts of sustainable urban mobility, as well as analyse the level of integration and adaptation of the networks of urban infrastructures in urban territory. The negative aspects associated with the occupation of restricted environmental areas and risk areas are also identified. The final calculation of a sustainable urban expansion index allows quantifying the sustainability pattern practiced by the administration of the urban territory. In this way, the model helps to recognize and avoid some errors associated with land management and urban planning, hence providing a strong contribution to stimulate territorial competitiveness and innovation policies in cities. Finally, it should be mentioned that for the consolidation and validation of the formulation here presented, the multicriteria analysis model will be applied to one mid-sized Portuguese city, providing a case study. The implementation of the model in Geographic Information Systems will allow specific spatial analyses.

Acknowledgements: The authors acknowledge UDI/IPG - Research Unit for Development of the Interior, a R&D unit of Polytechnic Institute of Guarda, C-TAC - Centre for Territory, Environment and Construction, a R&D unit of University of Minho, and FCT - *Fundação para a Ciência e a Tecnologia*, for the support.

References:

- [1] EEA, Urban Sprawl in Europe - The ignored challenge. EEA Report - No 10/2006. 56pp., European Environment Agency. ISBN 92-9167-887-2., Copenhagen, 2006.
- [2] P. Christiansen e T. Loftsgarden, Drivers behind urban sprawl in Europe. Report 1136/2011. 29pp., Institute of Transport Economics - Norwegian Centre for Transport Research. ISSN 0808-1190., Oslo, February, 2011.
- [3] PNPO, Programa Nacional da Política de Ordenamento do Território, Anexo à Lei n.º58/2007, de 4 de Setembro que aprova o Programa Nacional da Política de Ordenamento do Território, rectificado pelas declarações n.º80-A, de 7 de Setembro de 2007 e n.º103-A/2007, de 2 de Novembro de 2007.
- [4] D. Arribas-Bel, P. Nijkamp e H. Scholten, Multidimensional urban sprawl in Europe: A self-organizing map approach, *Computers, Environment and Urban Systems*, No35, pp. 263-275, 2011.
- [5] G. A. Tanguay, J. Rajaonson, J.-F. Lefebvre e P. Lanoie, Measuring the sustainability of cities: An analysis of the use of local indicators, *Ecological Indicators*, No10, pp.407-418, 2010.
- [6] L.-Y. Shen, J. J. Ochoa, M. N. Shah e X. Zhang, The application of urban sustainability indicators - A comparison between various practices, *Habitat International*, pp.1-13, 2010.
- [7] T. Yigitcanlar e F. Dur, Developing a Sustainability Assessment Model: The Sustainable Infrastructure, Land-Use, Environment and Transport Model, *Sustainability*, No2, pp.321-340. ISSN 2071-1050., 2010.
- [8] A. Zilans e K. Abolina, A methodology for assessing urban sustainability: Aalborg commitments baseline review for Riga, Latvia, *Environ Dev Sustain*, No11, pp.85-114, 2009.
- [9] M. Marcelino, M. A. Espada, R. Vilão, T. B. Ramos, I. Alves, I. Gervásio e P. Liberal, Sistema de Indicadores de Desenvolvimento Sustentável - SIDS Portugal - Anexos, Agência Portuguesa do Ambiente. ISBN 978-972-8577-40-7, 2007.
- [10] M. Kasanko, J. I. Barredo, C. Lavalle, N. McCormick, L. Demicheli, V. Sagris e A. Brezger, Are European cities becoming dispersed? A comparative analysis of 15 European urban areas, *Landscape and Urban Planning*, No77, pp.111-130, 2006.
- [11] V. Mega e J. Pederson, Urban Sustainability Indicators, I. L. a. W. C. European Foundation, Ed., Luxembourg: Office for Official Publications of the European Communities, 1998.
- [12] OECD, Handbook on Constructing Composite Indicators: Methodology and User Guide, ISBN 978-9264-04345-9, 2008.
- [13] T. L. Saaty, *The Analytic Hierarchy Process: Planning, Priority Setting, Resource Allocation*, New York: McGraw-Hill, 1980.