

Methodology based on qualitative reasoning: measuring the evolution level of sustainability in a city

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Abstract

The purpose of this paper is to present a new Artificial Intelligence Methodology based on Qualitative Reasoning to establish the evolution level of sustainability in a city and which actions and measures should be done to achieve a more sustainable development. The results of this methodology will provide a helpful tool to design the Local Agenda 21.

Depending on the purpose sought, we propose different facilities, an Integral Model of the City for the Analysis of Sustainability, a Sectorial Model of the City for the Analysis of Sustainability and the Management Model of the City for the Analysis of Sustainability. The model gives the following functionalities: diagnosis, strategy, impact evaluation and adaptability.

The description of the variables, the relation between them and the structure equations are integrated in a system of Qualitative Reasoning, which give us a qualitative index of sustainability.

As a conclusion, this tool allows the city decision-makers to know whether the management has been developed in a sustainable manner, and which are the actions to implement if the result of the diagnosis is negative. This method also brings the possibility of predicting the evolution of the sustainability in terms of new projects to be implemented.

1 Introduction

The studies of CODIMA have been conceived and carried out on the basis that the sustainable development of a community has already reached its maturity, as

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a theme of great concern among the different organisations responsible of its administration.

Consequently, the local, regional or national governments are claimed to elaborate strategies focused on the measurement, analysis and management of the sustainable development of the city (e.g. Munashinge and Shearer [1]).

However, the political identification of the problem and the real capacity of acting in a scientific and rigorous way during the formulation of the right actions are two very different things. In this sense, and having examined the existing bibliography on this field, the following conclusions are reached:

In the first place, a unified conceptual database is not available at an international scale regarding to what must be accepted as Sustainable Development (e.g. McLaren and Simonovic [2]).

In the second place, partly as a result of what has been previously said, a metrics for measuring Sustainable Development does not exist. The main cause of this situation lies in the difficulty of measuring the environmental and social domains in homogeneous unities (e.g. Hammond and Matthews [3]).

In the third place, the Information Technologies have been mainly focused on quantitative information, whereas the real world is described in qualitative terms. We realize the need of creating new models based in qualitative information.

We are consequently facing a situation that must be solved for its significance in the evolution of life itself on the Earth, but which has not an easy or immediate solution.

The starting point is set up by the opportunities brought forward by the New Information Technologies, in particular in the field of the Artificial Intelligence, and within it, in the field of Qualitative Reasoning, which accepts as a working hypothesis a qualitative modelling of the world around us (e.g. Kuipers [4]). This tool will allow us to perform a mathematical model (including quantitative and qualitative information) expressing a reality perception that at first only includes qualitative valuations.

2 Theoretical base

Summarising, our survey envisages the solution to the problem of measurement, analysis and management of sustainable development under the following hypothesis:

It is applied to a particular city, which counts with a Local Government for its Management.

This conceptual scheme (fig. 1) shows the main elements involved in the analysis of urban sustainable development.

2.1 Methodology of analysis

All the agents involved in Sustainable Development are considered, following the methodology of analysis proposed by Pezzey [5]. The relations between the

different elements involved in sustainable development are modelled through qualitative equations, which are governed by Qualitative Reasoning.

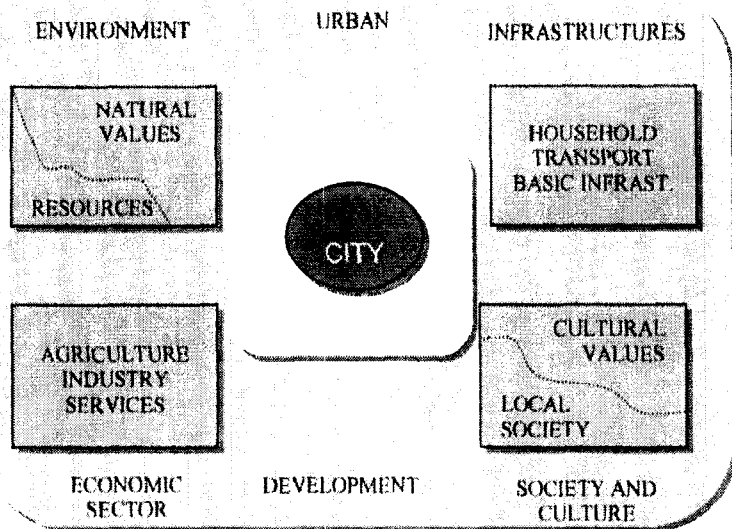


Figure. 1 Analysis of urban sustainable development

Qualitative Reasoning is a sub-area of Artificial Intelligence attempting to model human reasoning, which is entirely qualitative and non-numerical, what will make possible the evaluation of possible solutions to some real-world problems. The use of a qualitative approach is due to situations where there is either a lack of quantitative data descriptions or the information is imprecise or even when there is an excess of quantitative data. Many real systems are made up of common and inter-connected quantitative and qualitative components which can be integrated in qualitative reasoning.

The four main fields defining sustainability (economical, environmental, social and cultural) are integrated and interrelated in the model through a set of differential equations.

These main fields are characterized by variables, which are grouped in sectorial indicators, which at the same time are grouped in aggregated indicators to set up the sustainability indicators (for a comprehension of the measure methodology, see figure 2).

The variables are measured within a period of time; they should be clearly defined and easily measured. They are defined within a qualitative range of five values, with the purpose of studying systems (physical, economic, social, technologic, etc.) in order to obtain a qualitative description of them.

3 Sustainability conditions

From a series of equations, Pezzey formulates the territory sustainability as the fulfilment of two conditions over elements of the general model (preservation of

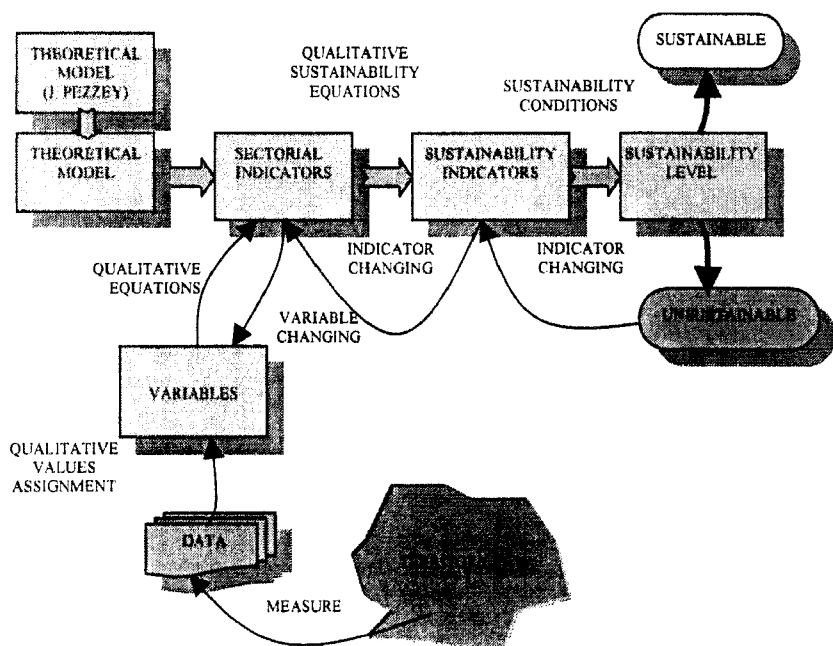


Fig. 2 Measure methodology

the quality of life (utility) and sustainable consumption of resources) (e.g. Pearce [6]). Differing from the work done by Pezzey, we think it is necessary the addition of a further condition, the preservation of the development level of the city, which can be considered as a previous condition in order to maintain the carrying capacity of the city; this would assure an adequate quality of life for all the inhabitants.

These equations are expressed as qualitative causal relations between the variables that form the theoretical model.

City development is sustainable during the period studied if the three conditions that follow are fulfilled:

1. The development level of the city has not decreased
2. The Quality of Life of the local population has not decreased
3. The natural resources have been used in a sustainable way

3.1 First criterion (development level)

Definition: Development level is the capacity of the city to assure an adequate Quality of Life for all population. What should be considered are the changes suffered by a specific area and period of time, not the comparison of the development level between different cities. The main problem lies in the fact that some concepts are of difficult measurability.

3.2 Second criterion (Quality of Life)

Definition: Quality of life is the welfare average degree of the population, which means the capacity of each individual to satisfy its physical and intellectual needs in an appropriate environment.

As in the previous criterion, the point is not to compare the Quality of Life of different zones but consider the changes suffered in a specific area and period of time.

Once more, we are talking about a completely subjective concept, but in which some qualitative criteria can be taken into account. They are valid because we treat the individuals as a whole, and we only search the variation of this standard of living.

In order to obtain a sustainable development, the population's standard of living must improve or at least remain the same, since this is, or should be, the main target of any social or economic development.

3.3 Third criterion (resources)

Definition: City development is sustainable if the resources are used in a sustainable way, that is, if the carrying capacity of the system is not exceeded, which is equivalent to not using the resources beyond the regeneration limit of the own system. In this case, a crucial factor is the resources' management, since it permits a much more efficient regeneration of these resources.

4 Sustainability equations

The sustainability conditions are mathematically represented as follows:

First criterion: The development level of the city has increased or at least has remained constant;

$$\dot{A} \geq 0$$

Second criterion: The quality of life of the local population has increased or at least has remained the same;

$$\dot{U} \geq 0$$

Third criterion: The natural resources have been used in a sustainable way;

$$E_R \geq 0$$

It has to be pointed out that the three conditions must be fulfilled in the period of time under study. At first sight it could seem a set of simple conditions, but within the context and considering the structure equations, they will be the starting point of rich and not at all trivial consequences.

5 Measuring sustainability: relation between the qualitative equations of sustainability and the indicators

To be able to measure if a city is having a sustainable development, we need to be able to value if the three conditions of sustainability are fulfilled. We have to develop a series of equations from each of the sustainability conditions. When having these sets of equations, we will be able to calculate the level of the sustainability's evolution. As an example we analyse the case of Quality of Life condition.

We start from the following condition:

$$\dot{U} \geq 0$$

U depends on economical, environmental and cultural factors (figure 3):

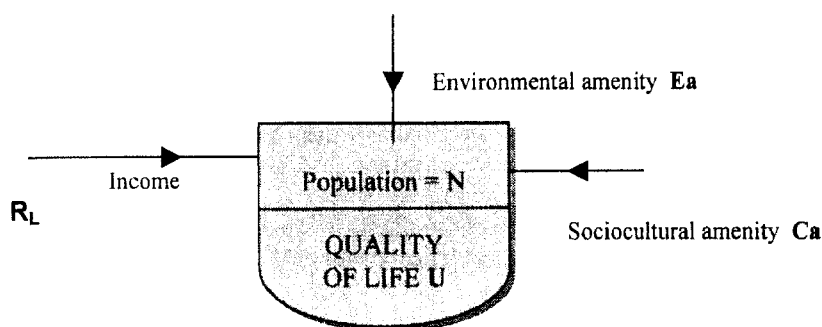


Fig. 3 Quality of life

Which mathematically means

$$U = U(\overset{+}{R_L}, \overset{+}{E_a}, \overset{+}{C_a},)$$

$$\dot{U} = \frac{\partial U}{\partial R_L} \dot{R}_L + \frac{\partial U}{\partial E_a} \dot{E}_a + \frac{\partial U}{\partial C_a} \dot{C}_a$$

We will have to construct the following functional relationship:

$$\dot{U} = \dot{U} \left(\overset{+}{\dot{R}_L}, \overset{+}{\dot{E}_a}, \overset{+}{\dot{C}_a}, \omega_r, \omega_e, \omega_c \right)$$

Where ω are weights that depend on R , E_a and C_a (they measure how much these variables determine the value of U).

The qualitative relation between the quality of life $\dot{U}$ and the economical level, the sociocultural amenity and the environmental amenity is performed by using the algebra of qualitative operators (e.g. Garcia et al. [7]). At the same time, the qualitative relation defining these indicators is equally found in terms of the variables. Calculated the qualitative relation, we just have to know the variation of the economic level, the environmental amenity, the sociocultural amenity and their corresponding weights.

The other two indicators of sustainability, resources and development, are calculated following the same procedure. Arriving at this point we are ready to analyze the fulfilment of the sustainability condition.

6 Facilities of the model

The model is divided in three facilities that will provide different results depending on the necessity of each case. If the purpose is the analysis of a city in general terms and with the will of knowing the health of the whole system with reference to sustainability, we propose the Integral Model of the City for the Analysis of Sustainability. This tool considerates and integrates all the sectors defining a city through a set of indicators and variables which will give a certain level of the sustainability's evolution. But, if we want to focus on only one sector defining the city, e.g. the natural resources, the waste generated... we do not need to do the analysis of the whole system but just the one we need. The Sectorial Model of the City for the Analysis of Sustainability takes into account the sector under consideration with an amplified set of variables and indicators.

These couple of models would provide a strategy in order to acquire the desired level of sustainability. They are a very powerful tool; but when dealing with the city decision-makers we realize the limited scope of their competences. So it is important to perform a new model addressed to the real strategies to be done by the decision-makers of the city taking into account these limitations. Thus we propose the Management Model of the City for the Analysis of Sustainability.

7 Analysis

In order to perform the assessment of the sustainability's evolution in the city, we require the information in the initial and final (usually at current time) moment of the period under study. This study could calculate the evolution of the sustainability of the city by itself, or the analysis of how it has been managed in terms of sustainability. Independently of the model used, we find the next functionalities (see fig. 4):

Diagnosis. This is the evaluation of the evolution level of sustainability through the set of variables and indicators.

Strategy. After having determined the urban indicators which evolution is not sustainable, it is necessary the elaboration of a strategy to increase sustainability to the required level. These strategies are addressed to perform the Local Agenda 21.

When existing the forecast of the state of the city in the required areas, we are able to calculate the evolution of the sustainability from the current moment to the future. At the same time we are capable of assessing the impact that will be caused by a new project. This tool allows the prediction of measures and the modification of that project with the aim of increasing its sustainability. These are the functionalities (see fig. 5):

Impact. Permits the impact evaluation of sustainability of a new project to be performed in the city, giving elements to the decision makers of the city to decide whether the project has to be done in that way or not.

Adaptability. Once the impact evaluation is done, it permits the modification of the project implementing sustainable criteria until the required level of sustainability is achieved.

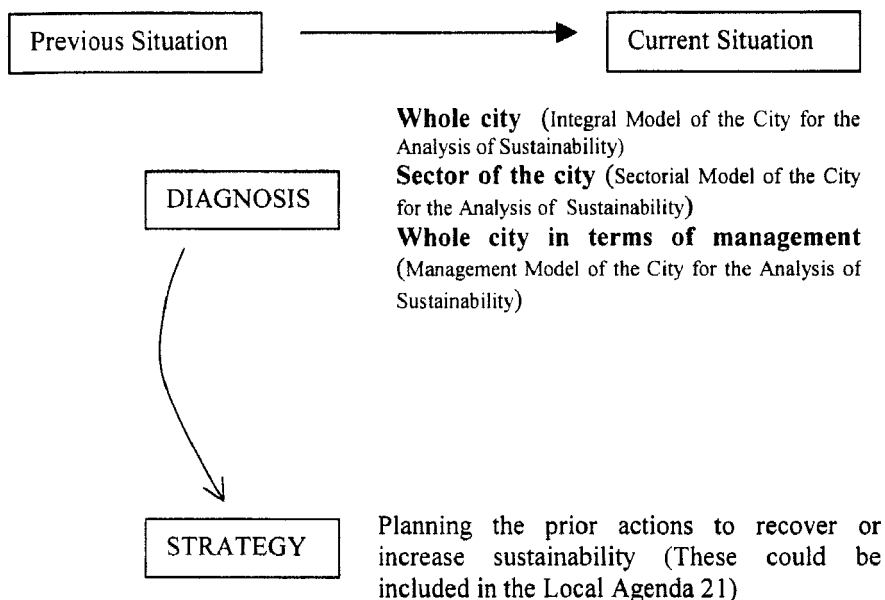


Fig. 4 Sustainability's evolution of the city

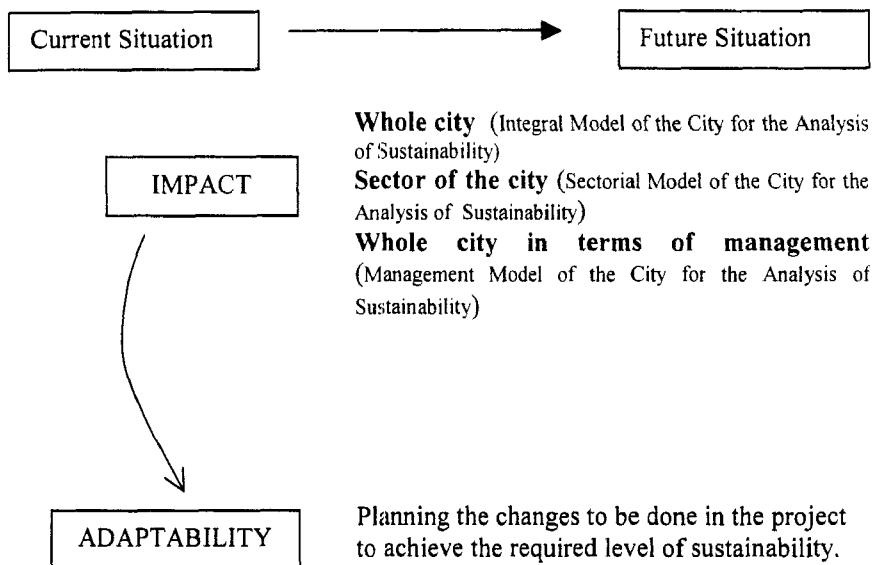


Fig. 5 Sustainability's forecast of the city

8 Conclusion

This tool allows the city decision-makers to know whether the management has been developed in a sustainable manner, and which are the actions to implement if the result of the diagnosis is negative. This method also brings the possibility of predicting the evolution of the sustainability in terms of new projects to be implemented. The results of this methodology will provide a helpful tool to design the Local Agenda 21.

Despite the difficulty of measuring the sustainability and having into account that there is not a unique method, we propose an integrated and comprised sight of the different sectors of the city. This approach gives rise to a more reliable and accurate index of sustainability.

To sum up, we can say that our models allow to objectively compute if the circumstances associated to a territory in two moments increase or decrease the sustainability of the city, through the resolution of qualitative equations with Artificial Intelligence techniques developed specifically for this study. These two moments are: an initial one where the historical information of the territory is compiled, and a future one in which there's a will to discover the sustainability state with hypothesis of values at that moment. This can be also applied to the past in order to analyse the evolution of sustainability up to now.

That is, we can determine with rigour if there is an evolution to a higher degree of sustainability or vice versa.

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