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Sustainable System Modelling for Urban Development Using Distributed Agencies

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1. Introduction

Developing a sustainable simulation system consists essentially of generating sustainable, artificial worlds with the capacity to produce results similar to those observed in the real world. This allows for varying parameters in a controlled, reusable experimental environment, something that cannot be easily achieved through mathematical models. The field of simulation is broad and multidisciplinary and has had an impressive growth since the 90's. While the area of simulation has been expanding to new horizons in traditional systems research, there are yet a series of unsolved epistemological issues David et al. (2010).

On the other hand, the social sciences face challenges that go beyond their capabilities of processing information. By using modern techniques such as computer agents and other methodologies, it is possible to aid in the testing and the formulation of theories Davidsson (2002).

Computer agent techniques are having a greater acceptance in recent years in different fields of science, and as a result, they have begun to be implemented as a simulation technique. Agent techniques consist on using small, independent programs called agents that are modeled to represent the social actors, be it people, organizations or corporations. Agents are designed to react to changes in their environment, which is also modeled to represent real world conditions that the actors would encounter in the given situation of interest Gilbert (2007).

A fundamental characteristic of agent based models is the ability for agents to interact, that is, they are able to transmit informative messages to other agents and can act based on the information received. Messages can represent spoken dialog between people or other indirect forms of communication. Information on actions such as observation of other agents or the perception of actions taken by other agents can also be acquired through messages. When modeling computer agents, specifying how they handle their interactions with other agents and the environment is one of the main differences with other computational models Gilbert (2007).

The complexity level of using these techniques increases as the number of agents increases. Even though it has been mentioned in the multi-agent community the need to develop and implement methodologies, surprisingly, very little has been done and therefore many areas of science have been excluded.

The motivation for this work is the need to establish a methodology for the study of sustainable systems in situations where conventional analysis cannot provide satisfactory information on the complexities of social phenomena and social actors. In general, the proposed methodology describes the use of several computational techniques and interdisciplinary theories. This growing consensus must be capable of describing every aspect of a sustainable system, as well as serve as a common language in which different theories can be juxtaposed.

1.1 Sustainable systems

Sustainability refers to the equilibrium between a species and the resources in its environment. By extension, this can apply to the exploitation of resources bellow the renovation limit.

Sustainability is generally associated with the definition of sustainable development, which refers to being able to satisfy the needs of the present without compromising the ability to satisfy the needs of the future generations. The concept of sustainability applies to the systems composed of human beings and nature. The structures and functionality of the human component in terms of society, economy, and rights among others should be such that they self-enforce and promote the persistence of the structures and functionality of the natural components—such as the ecosystem, biodiversity and biogeochemical cycles—and vice versa Cabezas et al. (2005). Therefore, one of the research challenges on sustainability resides in the link between the form of functioning of the ecosystems towards the structures and the functionality of the associated social system. This is why the information theory based indicators can grasp the human nature and the elements of the system and make sense of the disparity of the variables in the system Márquez, Castañon Puga & Suarez (2010).

2. Sustainable system modeling

Sustainable development is about assuring a good quality of life for the present and future generations. This can be achieved through the three strands of social equality—which are social, economical, and environmental—which recognize each other's needs, can maintain stability in these levels—with special attention to economic development and employment—and responsibly manage the natural resources available while protecting the environment Márquez, Castanon-Puga, Castro & Suarez (2010). Sustainability is even necessary among systems to ensure coexistence. As an example, the economic performance in regard to the expense of the community is not sustainable; without effective environmental protection, the economic activities will be obstructed. Sustainability does not require a perfect solution; it is in essence a goal or a vision that organizations should strive to achieve Ciria (2009).

Studies have been done on this focus such as the ones on sustainable agriculture, which is a philosophy that guides the development of agriculture systems in a multidisciplinary way in the areas of economy, environment, and social impact. Sustainable agriculture requires a global focus, one that is oriented towards solving the problems of the food industry and fibers industry Williams & Dollisso (1998).

And so, liking the different levels that are required in order to create a sustainable system is a challenge that is yet to be solved, from a countries economy in relation to its available resources and the existing population to the availability of those resources to individuals and their economic status. These social, economical and environmental variables are analyzed with a bottom-up approach based on how a social structure functions.

2.1 Social system

When dealing with social systems, certain basic characteristics in the organization must be met. One of these is that the consequences of the social systems are probabilistic and non-deterministic. Furthermore, as human behavior is not entirely predictable due to its complexity, dealing with consumers, suppliers, regulation agencies and others cannot wait for a predictable behavior Suarez et al. (2007). Organizations are seen as systems within systems. Said systems are complex, producing a whole that cannot be understood by only analyzing the individual parts. They must be dealt with as a system that is characterized by all the essential properties of any social system Yolles (2006). For this reason, the following properties must be taken into consideration when modeling organizational systems:

2.1.1 Interdependent pieces

A change in any of the components will have an effect on the other components. The external and internal interactions of the system reflect different stages of control and autonomy.

2.1.2 Homeostasis or firm state

An organization can achieve a firm state only when two requirements are met, unidirectionality and progress. Unidirectionality means that in spite of changes, the same results or established conditions will be obtained. Progress referring to the desired outcome, is a degree of progress that is within the set boundaries determined as tolerable.

2.1.3 Borders or limits

It is the marker that determines what is inside and what is outside the system. It need not be a physical marker; it consists of a closed area surrounding the selected variables that have the most interaction with the system.

2.1.4 Morphogenesis

The organizational system, distinct from the mechanical and biological system, has the capacity to modify its basic structure. This ability is identified by Buckley as its main identifying characteristic Boulding (1956).

One of the objectives of this research is to predict social behavior by using models. Social behavior is a behavior that favors those that conform to the group, producing cooperation and self-organization Jaffe & Zaballa (2010). According to Ross Ashby Ashby (2004), the word organization has a multitude of meanings, specifically, its use in the areas of computation and neural science is of great importance to this research. In social systems, the question arises of what is the behavior of individuals when in a group (cities, groups or networks), and why they exhibit such behavior.

2.2 Economic systems

Another component in a sustainable system is the economy that reigns in a city, the market economy. Salary rates are normally regulated by contracts and are subjected to the market's rules in the middle and long term. Goods and services needed for daily urban life are also affected by the market's rules.

The industrialization process and the concentration of investment due to work specialization and the use of economies of scale generate the process of urbanization. The activities that thrive in the urban center generate job positions that are primarily occupied by the locals but also attract outsiders that are looking for better conditions. This generates a cycle that leads to sustained population growth and the demand of public services, which in turn requires taxation to keep up with demand, improved service and proper administration of tax revenue.

2.3 Environmental systems

As it is now, the market economy does not always lead to an efficient allocation of resources in the provision of public services. In order to determine optimal distribution of public investment, it is necessary to have a cost-benefit analysis, prioritizing the social aspects and considering the externalities, tending towards a balance between economies of agglomeration and diseconomies produces by clustering. To exemplify, the investments in basic sanitation (potable water and sewage systems) should not be weighted on the basis of the end-user's income, but instead on the benefit produced by lowering the mortality and disease rates which increases productivity in the population, income and quality of life.

3. Distributed agency modeling

Agent based models are an increasingly potent tool in social systems simulations as they can represent phenomena that is difficult to describe using other mathematical formalisms. However, these models have had a limited involvement in formulating social systems owing to the fact that their distinct abilities are more useful in situations where the future is unpredictable. In said situations, traditional analysis methods applied to simulation models are less efficient in the decision making process. The use of models such as policy simulators provides significant aid in taking decision in the public and private sector. This is of special relevance as these models have had to date limited impact in influencing decisions.

The application of agent based models in studying heterogeneous behavior has been successful as it allows for each agent to have different information, different rules and be faced with different situations that allows the study of the behavior at a macro level in the global system.

This modeling technique has been used to combine the anthropological data on the behavior of individuals and groups in society with detailed information of the effect of climate change on the environment Lempert (2002).

When faced with a complex sustainability problem, such as deciding what actions need to be taken to deal with global climate change, a broad range of possible scenarios must be considered. At the least, a rigorous analysis needs a way to identify and define the most important and likely scenarios. Advanced made in viable agent model simulations has also allowed new methods in decision analysis to adapt to these types of problems. Uncertainty arises when parts of a decision will not or cannot agree over one or several key components in a decision analysis to be used in non predictable models such as: the system model, the a priori statistics of any parameter describing the system model, and the value of the function used to classify the model's results. These multi-scenario simulation models provide a systematic and quantitative orientation for which scenarios information should be reviewed and extracted.

Although the use of agents in the social sciences has been stated in the field of artificial intelligence Gilbert (2007), as it is one of the first areas to have studied this topic Russell & Norvig (2004) and more precisely, in distributed systems. By themselves, agents are not enough to model a real social system, nevertheless, distributed agency based systems is an active area of research with promising results in the fields of engineering and social sciences. These types of systems also reduce the barrier between physical and sociological systems as the perceived view of the world is nonlinear.

It must be stated that this research does not use the conventionally defined agent model—which defines agents as atomic concepts or actors—but instead uses the distributed agent model or distribution agents—which does not define independent actors but instead considers the organism that extends throughout the whole of the system. Agents can be any process, it can change any system based on the independently contained information.

The idea behind a distributed organism modeling language derives from a vision of the world in which appearance is omnipresent, where compounds are irreducible to their components and exist in different dimensions where different rules apply Suarez et al. (2008). Distributed agencies attempt to solve problems between groups of agents, finding the solution within the result of the cooperative interaction between agents.

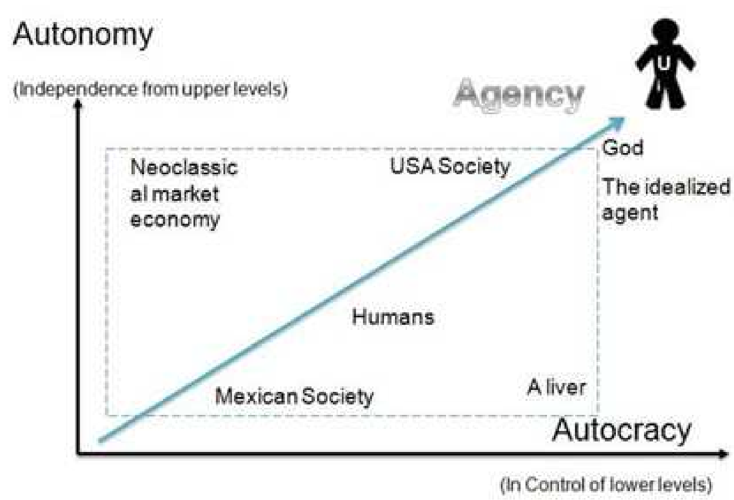

Fig. 1. Levels agents represented hierarchically

Communication facilitates cooperation; the degree of cooperation between agents can be from full cooperation to hostile. In the first case there is a high cost for the total communication between agents. In the second case some agents could block the objectives of others. To have the cooperation and coordination mechanisms in an agent system succeed, an additional system must exist that enables the members of the system to reach agreements when each individual agent is defending its own interests. This system should reach mutually beneficial solutions, taking into consideration all points of view. Such a system is known as negotiation Gilbert (2007).

Applications of this technology are considered very useful for distributed industrial systems development such as process control, e.g., automatic management of intelligent buildings with private security and resource management. Other areas have developed applications for air traffic control used in airports like Sydney, Australia Julian & Botti (2000). Distribution agents is a promising strategy that can correct an undesirable centralized architecture Russell & Norvig (2004). Throughout the focus of traditional multi-agent systems and utility maximization, actors choose the best alternative given the set of possibilities that is found in each level.

The main distinction from the proposed focus is that the phase space includes the transformations made by an upper level. On the other hand, an agent is composed of subcomponents belonging to a lower level that can possess their own agencies. It is an agent's responsibility to present its subcomponent's individual phase spaces with optimal solutions that are acceptable to the parent upper level agents. In other words, agents found in subcomponents optimize the phase spaces in their parent agents, while the parent agents must consider the manipulation of this world of possibilities in order to reach the desired global behavior. To this effect, if an agent were to be considered a corporation, this level would be composed of the subdivisions that form the company, and these in turn are directed by groups of people. The company as a whole is also located in a level that is ruled by legislation relating to industrial practices, which are a component of an upper level that forms a specific society.

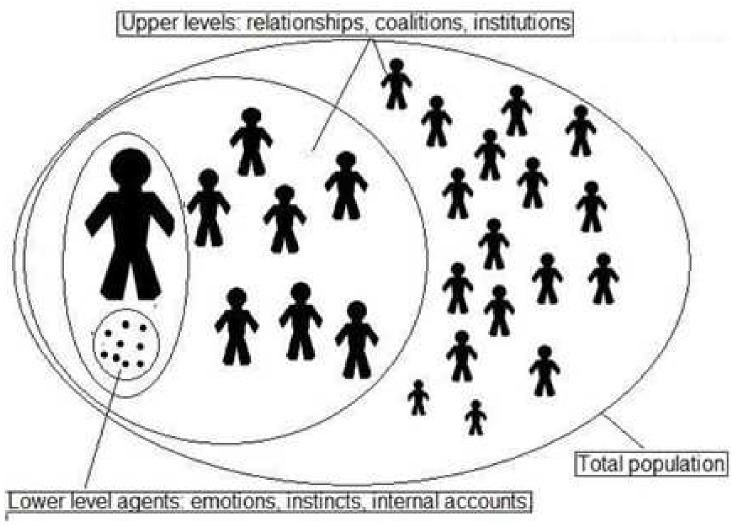

Fig. 2. Multiple levels of identity of distributed agency

4. Case study

Urban simulation that considers sustainability has remained an interesting topic in research for many years. Aspects such as urban growth, congestion, and segregation have a high demand in advanced modeling focuses. Each of the focuses and techniques that have been applied present advantages and drawbacks. Even as aggregation techniques have been criticized for their poor results in these types of models, they have been receiving renewed attention in recent times Benenson & Torrens (2004). Among these techniques, the agents based models are considered the most promising as they provide a detailed understanding of the structure and processes of urban systems Márquez, Manuel & Saurez (2010). Combining these techniques with geographic information systems (GIS) will greatly improve urban simulation.

There has been greater acceptance of agent modeling of urban systems in the last decades Gilbert (2007). Agent based models and artificial societies are very similar being the same techniques in dynamic systems, cellular automatons, genetic algorithms, and distributed agent systems. The differences are centered in the simulation of systems and in research program design Drennan (2005).

The location being studies is Ciudad Juarez, a Mexican city in the northern part of the state of Chihuahua in a region known as El Paso del Norte and bordering with El Paso, Texas in the United States of America. Its geographic environment can be delimited by the municipality of Juarez, which extends for 3,599 km^2.

The city is settled between the Sierra de Juarez and the valley of Juarez in a geographical area historically formed by fluvial deposits originating from the stream of the Rio Bravo. Its terrain is rugged to the west over the hills of the Sierra de Juarez and with smooth slopes with an east to west direction in the valley area. The heights of the most elevated terrains located in the Sierra de Juarez are above 1,800 meters over the mean sea level (msl). The inhabited area over the hills in the mountainous range consists of elevations between 1,250 and 1,350 msl. Most of the urban sprawl is located between the elevation of 1,150 and 1,200 msl and distributed in the valley of Juarez and extending to the south.

Therefore, for our proposed work-in-progress case study, if we consider a municipality an agent, this upper-level agent is composed by subcomponents, which in our case study of the city of Juarez, Mexico, will be represented by the AGEBS that compose this city. AGEBS is the terminology used to describe the different areas of the city that are in turn are composed of neighborhoods. The data set of the city of Juarez is divided into 549 areas, known as AGEBS. “The urban AGEB encompass a part or the totality of a comunity with a population of 2500 inhabitants or moreâĂę in sets that generally are distributed in 25 to 50 blocks” INEGI (2006)

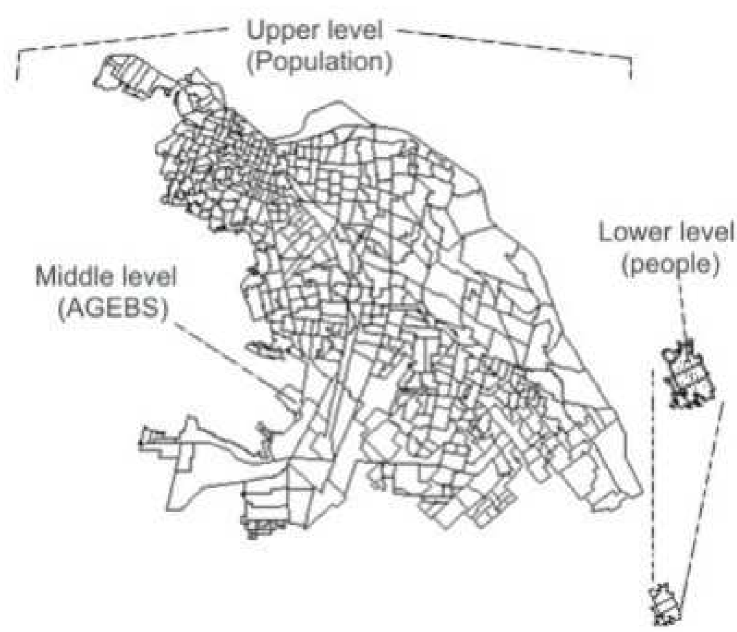

Fig. 3. Levels of agents represented on the City of Juarez

A city has several qualities that align with the definition of complexity. That is why performing a simulation of a city requires the study of a complex system and emergence. The use of simulations in the study of a city’s urban growth helps perform social experiments while avoiding costs and risks. Simulation tools are already readily available that apply different techniques and models to study growth. This research applies the distributed agency methodology on a sustainable system for a city located in Mexico, creating a model of a sustainable system for urban growth as a secondary objective.

To develop the simulation methodology, the concept of a city and its influencing processes must be understood. The concept of a city according to Camagni Camagni (2004) is based on generalizing process that begins from the historical and geographical existence of the cities and continues to consider the city as a significant whole, an autonomous socioeconomic entity Camagni (2004). A city constitutes a production entity, in which a group of goods and services are internally produced; all of these internal and external processes that engulf it can be represented by distributed agencies offering the ability to represent the surrounding environment, take autonomous actions and simulate actions such as consumption and productive activities among others. The use of distributed agencies to create an urban simulation describes satisfactorily the processes of cooperation, communication, and decisions.

5. Proposed methodology

The methodology to be implemented represents an innovative focus on creating a simulation architecture. Named Distributed Agency (DA), this methodology represents a general theory of collective behavior and the formation of structures; it redefines the level of agency in two forms. Primarily, there are no obvious agents; each of these entities that represent an emergent force is the result of organized sub-agents in the lower levels. In the second form, agents can belong to different levels . The language of distributed agency expresses the observed behavior as the result of agents maximizing their objective functions Suarez et al. (2009).

This research intends to develop a sustainable system methodology using various mathematical and computational theories that are not conventionally used in the social sciences and provide a new focus for the creation of computer simulation architectures. The research shows how the DA methodology in combination with other techniques can be used to simulate social behavior, using agents with limited reasoning capacity and complex interactions. The simulations expand the knowledge available on social complexity, setting the basis for a nonlinear methodology to study the scenarios that have been developed using existing traditional methods. With this multi-focus study, it is intended to show how agents interact in their environment, their behavior and the relationships between different levels imitating the ones found in the real world.Márquez, Castanon-Puga, Castro & Suarez (2011). The DA methodology consists of eight steps that are :

5.1 Determining the agency levels and their relations

This phase analyses the existing relations in the social system and determines the levels of the system. In order to accomplish this, the problems that need to be solved are identified and their functions are described for each level in a physical frame. The decision and parameter input and output variables are also identified. An intrinsically holistic philosophy must be pursued without reducing the system to its basic components, since no phenomena can exist by itself in a sustainable system, where each node is defined by its link with other nodes Heylighen (2008). That is why it is necessary to establish the objective functions of each level of agency and the prevalent nodes and links.

Taking the case study of the sustainable development of Ciudad Juarez, the total population, and all related factors such as immigration and birth rate, is to be analyzed at a macro level with a top–down approach. The micro level interactions such as spouse selection, decision to start a family, and number of children depending on the education and social level is analyzed with a bottom–up approach.

To achieve this reproduction modeling a macro system, dynamic systems are used. A dynamic system allow the representation of all the elements and relations of the sustainable system's structure and the evolution of the system in time Márquez, Castañon Puga & Suarez (2010). It also outputs the mathematical equations of the macro level model, the results of these equations define the characteristics of the macro agency level. Another part will be determining the mid level agencies, an agent's actions in its environment and the relation between agencies this way allowing the observation of micro level cases.

Some proposed classifications that have been defined by researchers involved in urbanism define a structure with different layers or levels, depending on the interactions and the different structures. The graph shown in figure 1 has been referred to as "Camagni's wedding cake" which shows three layers or levels (international, regional, and local) and various structures (hierarchical, non hierarchical, and mixed). The elements in each layer are interrelated, forming a network in each level, in a similar way cities are interrelated forming a complex set of link.

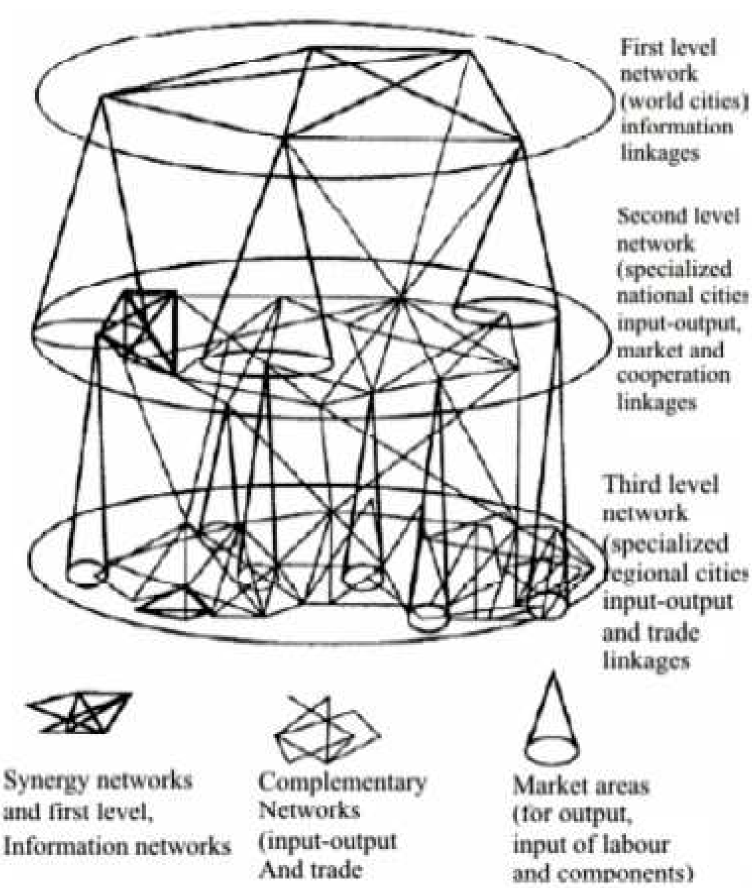

Fig. 4. Camagni's wedding cake

The highest level in this case study is the sustainable system, the proceeding three levels are the economic, environmental and social systems.

5.1.1 Social systems

A city's urban growth is composed of "vegetative growth + migration balance". Both elements are studied by the tools provided by demographics. A city's growth is driven by economic

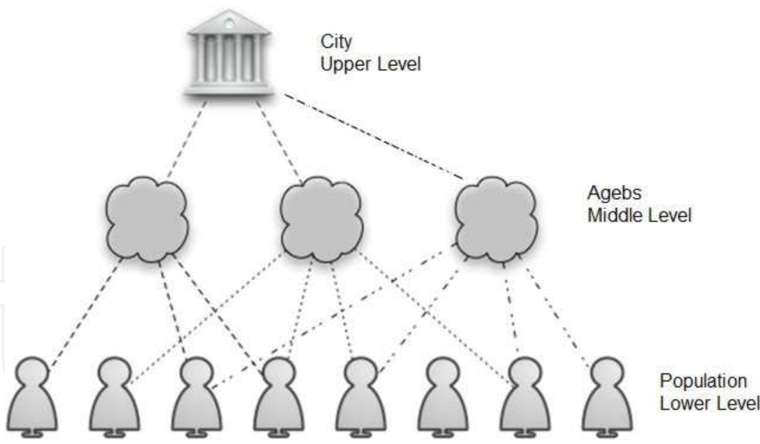

Fig. 5. Multiple levels represented

growth. Growth and optimal size of a city can be studied through simplified theoretical models. With the growth of population, the scale of production and job market rises, and the technological development and public service efficiency increase. Simultaneously, the diseconomy also increases, leading to higher unemployment, congestion, pollution, crime and social distortion. These factors are detrimental externalities that have little effect on the ones taking the decision Márquez, Castanon-Puga, Magdaleno-Palencia & Suarez (2011).

With the appearance of industrialization, the development process and population growth in cities is accelerated. This is a job creating process but also demands services since the people that fill the job positions should be located close to their place of work. These people will demand housing, urban services, food, clothing and furniture among other goods and services. Urban agglomerations then arise with the demand of the inhabitants to perform their activities and receive goods and services.

Aside from vegetative growth, the urban phenomenon is bolstered by migration flows. These flows are made up of people that are constantly arriving in cities looking for better conditions and opportunities. They generally have a rural background or originate from less developed countries. Because of the broad effect that population has in the development of a city, the total population of Ciudad Juarez is the variable that is extracted from the social system.

5.1.2 Economic systems

Economic theory states that as population increases, the scale of production and job market increases. In the study of a city's urban growth, it is important to analyze the process from its foundation without losing sight of important events as the industrialization process, migration flows. Factors such as rent rates, public service demand are intrinsically intertwined with job creation which is the variable extracted for the economic system.

5.1.3 Environmental systems

The variable that is taken into account for this system is the water supply being an essential part of any economy and society. Therefore, the sustainable management of this resource is a necessary condition for a sustainable society and economy. The sustainable use of water is defined as the use of an amount capable of sustaining a society and can develop in an indefinite future without altering the integrity of the hydrological system or the ecosystems that depend on it Gleik et al. (1996) .It is increasingly difficult to achieve this balance, but still, to approximate sustainable growth, all converging factors must be studied.

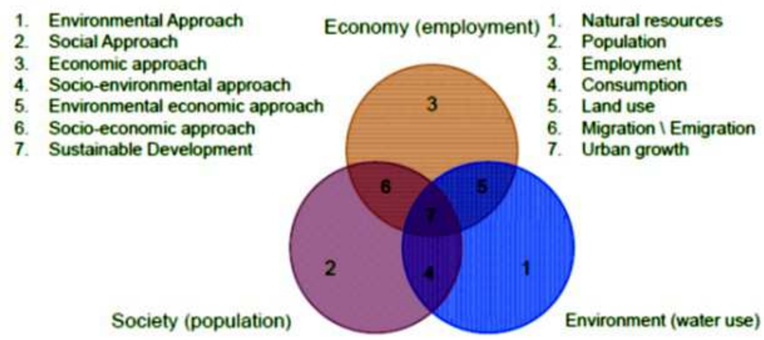

Fig. 6. Sustainable system

5.2 Data mining

The continuous increase of available information, originating from existing projects such as data bases necessary for the simulation of sustainable systems makes the use of data mining indispensible. Sustainable development requires a great deal of data to generate reliable models. To determine the data relevant to the three inherent systems of sustainability, it is necessary to review real statistical and geographical data originating from government institutions such as the National Institute of Statistic and Geography (INEGI by its name in Spanish, Instituto Nacional de Estadística y Geografía) and the National Population Council (CONAPO, by its name in Spanish, Consejo Nacional de Población). These institutions provide the necessary quantitative information for the social system. Data for the economic system is provided by the National Survey on Occupation and Employment (ENOE by its name in Spanish, Encuesta Nacional de Ocupación y Empleo) and for the environmental system the data is obtained from the Municipal Committee of Water and Disinfection of Juarez (JMAS by its name in Spanish, Junta Municipal de Agua y Saneamiento de Juarez).

Data mining is an implicit method of extracting information, such as weather patterns, with the intention of gaining knowledge Dubey et al. (2004). Significant progress has been achieved in this field during the last fifteen years; most of the research effort has been focused on the development of efficient algorithms capable of extracting knowledge from data, leaving the philosophical basis neglected Peng et al. (2008). The selection and processing of information leads to the use of high performance computing, with exploits such as social simulation and tools that give meaning and use to the information obtained. For this reason, it is important to pay attention to the conceptual frames and use it as the basis for developing the proposed methodology.

5.3 Rule generation

Using the Neuro-Fuzzy system to automatically generate the necessary rules, this data extraction phase using a fuzzy system becomes complicated as it is necessary to determine the necessary rules and what variables to consider. Implementing the Nelder-Mead (NM) search method, being more efficient than other methods such as genetic algorithms, more precise and compact models can be created as it was demonstrated in other experiments **?**. It is a numerical method designed to minimize an objective function in a multi-dimensional space, approximately searching for an optimal local solution in an N variable problem when the objective function has smooth variations Stefanescu (2007).

To generate the rules, the following markers must be considered:

5.3.1 Total population

Population growth, as previously mentioned, consists of "vegetative growth + migration balance" illustrated in the following formula:

$$PT = [N - M + I - E] \tag{1}$$

Where:

PT: Total population

N: Birth rate

M: Mortality rate

I: Immigration

E: Emigration

5.3.2 Employment

To measure employment, the result of both the work force and total population is considered. Employment rate is determined by fifteen variables, one for each AGEB .

$$FL = \frac{PEA}{PT} \tag{2}$$

$$Po = P2 + P3 + P4 + P5 + P6 + P7 + P8 + P9 + P10 + P11 + P12 + P13 + P14 \tag{3}$$

$$TE = \frac{Po}{PEA} \tag{4}$$

Where:

FL: Work Force

PEA: Economically Active Population

PT: Total Population

TE: Employment Rate

Po: Occupied Population

P2: Occupied population in the secondary sector

P3: Occupied population in the tertiary sector

P4: Occupied population as employee or working-class

P5: Occupied population as day laborers

P6: Occupied population that is self-employed

P7: Occupied population that works up to 32 hours a week average

P8: Occupied population that works from 33 to 40 hours a week average

P9: Occupied population that works 41 to 48 hours a week average

P10: Occupied population that does not receive compensation for their work

P11: Occupied population that works or less than the monthly minimum wage

P12: Occupied population with an income of 1 to 2 minimum monthly salaries

P13: Occupied population with an income of 2 to 5 minimum monthly salaries

P14: Occupied population with an income greater than 5 minimum monthly salaries

PEA: Economically Active Population

5.3.3 Water consumption

Considering the proposed markers for water consumption made in studies by Cervera Cervera (2007) and proposing environmental damage variables based on JMAS, INEGI, the XII general population census and Vivienda 2000 , the following equation is obtained :

$$D = VD_1 + VD_2 \tag{5}$$

$$CA = \frac{VAFUDM}{TOVP} - D \tag{6}$$

Where:

VAFUDM/year = Annual volume of water billed for domestic use in cubic meters = 115,633,582.

VAFUDL/day = Annual volume of water billed for domestic use in liters per day.

TOVP = Total number of occupants in residence.

D: Environmental damage or degradation

VD1: Private residences with pluming connected to sewage, ravine, river, lake or sea.

VD2: Private residences without water, pluming or electricity.

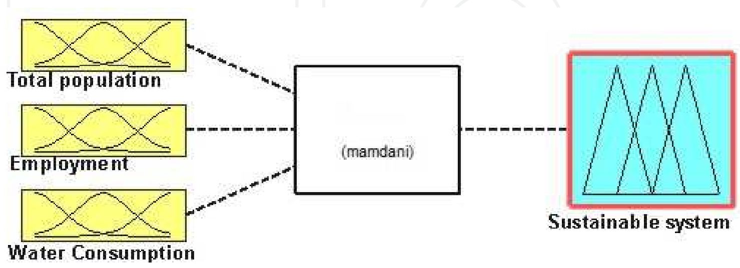

Fig. 7. Sustainable system

Most models with agents applied to natural resource management are structured with two elements, the agents that represent the entities in the modeled system and a simple cellular automaton as the spatial representation. The sole use of cellular automatons in general has limited the modeling possibilities since this abstraction process can be restrictive Galán-Ordax et al. (2006). By combining different modeling techniques, more realistic representations can be obtained, which is why the initiative to integrate fuzzy logic to extract rules from statistical data in data bases, all is needed is to input the equation and the necessary agency rules will be generated.

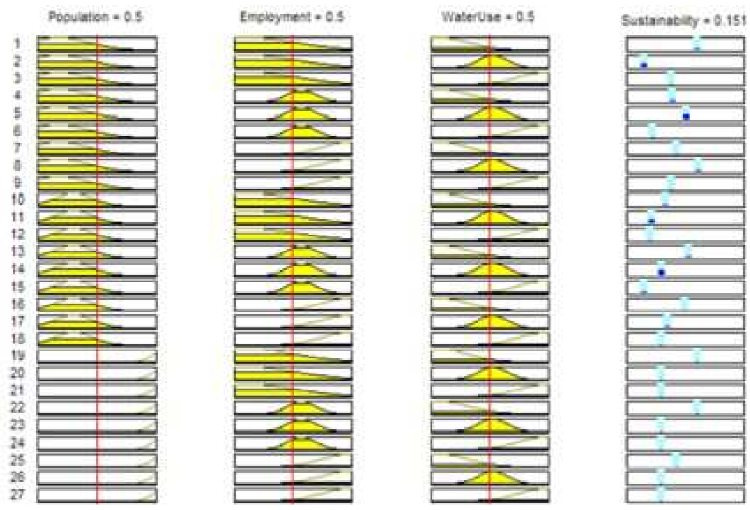

Fig. 8. Generated sustainability rules

5.4 Distributed agency model

Existing relations are very important in complex systems modeling, as they intertwine the system. A phenomenon can only be conceived in relation to another phenomenon and no phenomenon can exist by itself. The nodes are defined by their relations with other nodes and links through which they connect. This is an intrinsically holistic philosophy, it is not possible to reduce a system to individual components Heylighen (2008).

Undertaking the simulation of a sustainable system implies a holistic analysis, carrying out a multi-level analysis. The goal is to establish a mechanism in which different levels can be referenced within a reality with a general methodology. Each level is different from the rest, this means that by grouping several agents from a lower level, this group will behave as a single entity.

The implemented methodology represents a new approach to creating a simulation architecture. This distributed Agency (DA) methodology represents a general theory of collective behavior and the formation of structures. The DA approach treats agents as something agent-like, contrasting with traditional approaches where entities are or are not considered agents Suarez et al. (2009) .

5.5 Implementation

Months of work can be required to gather information, build, verify, and validate models, to design experiments, evaluate, and interpret results. The cost of a simulation is high, as it depends on the gathering of different types of information, from qualitative to quantitative. The initial foundation work and maintenance of simulation capabilities involves having trained personnel, software, and hardware among other costs Benenson & Torrens (2004). Another issue faced is the use of a tool that could simulate the different levels of a model in a single software.

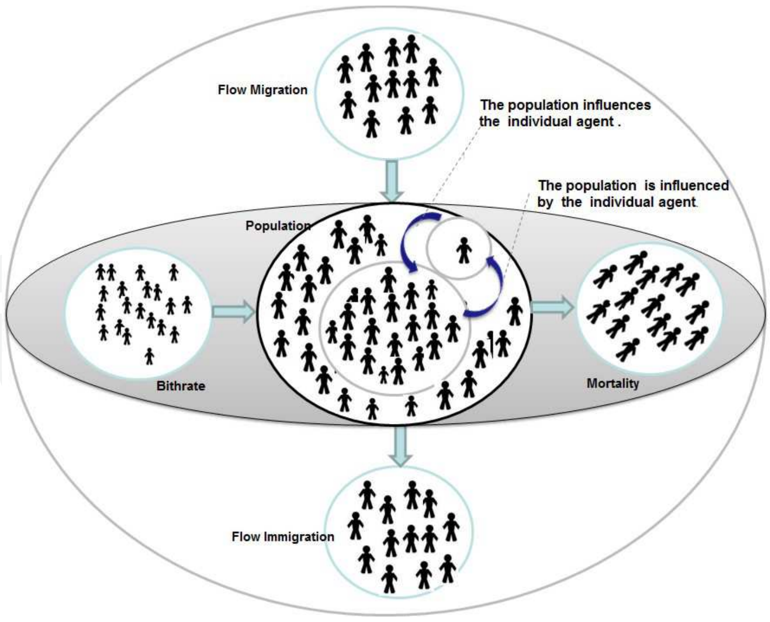

Fig. 9. Bottom-up and top-down model of the population

As an example, in the simulation of Ciudad Juarez, to represent the lowest levels of agency, 1,313,338 independent particles (the city's population in 2005) and their interactions must be managed if the upper level is to be used endogenously. The model that is presented in this work is based on the main sustainable relations between demographics, employment, the consumption of potable water, and the changes in land use caused by these factors.

Different aspects must be considered in order to choose a suitable platform. Among them is an orientation to creating agent based models which is necessary to simulate continuous events; most platforms are event based. The platform must also be configurable in various aspects such as the having individual selection and job management. Lastly, it must ease the development process, allowing researchers to quickly test models, theories and strategies in areas with dynamic and complex simulations.

Using the NetLogo platform, it is possible to simulate social phenomena, model complex systems and give instructions to hundreds or millions of independent agents all acting holistically Wilensky (1999). It also permits the use of a geographical information system with special and statistical data. These features make it possible to explore the relation and behavior of agents and the emergent patterns that arise from the interactions within a geographical space. NetLogo can be defined as a programming language for the modeling of multi-agent systems integrated with a social and natural phenomena simulation. The NetLogo environment can simplify exploring emergent phenomena Vidal (2007), and is also suitable for the modeling of complex systems varying in time, allowing or independent instructions to be given to the agents at the same time. The mentioned aspects can give the opportunity to discover the link between the micro level behavior of the individuals and the macro level patterns that arise from the interactions of the individuals Wilensky (1999).

5.6 Model validation

Real world simulations that include the population as an objective must include some form of validation. In econometrics, there is abundant data to verify population and economic studies while in other areas such as anthropology, there is a shortage of data. The supply of this data is a secondary concern. The main concern is for the data sets to adapt to an agent's architecture. An example of this is the study that centered on the cognitive origins from social theory Drennan (2005).

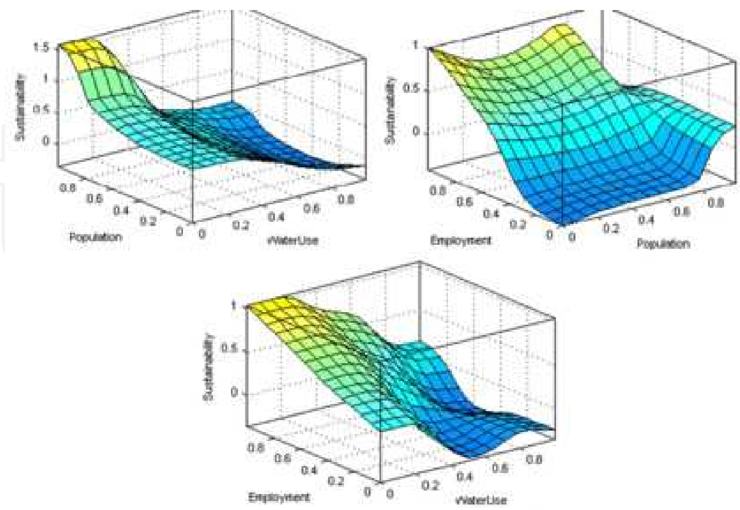

Fig. 10. Graphic representing the selected variables to measure the sustainable system

Aside from the population growth caused by vegetative growth and migration flows, employment is a marker that better reflects the relation between the economic and demographic factors. The primary occupation of Ciudad Juarez comes from the manufacturing sector (maquiladoras), which drives the changes in land use. By creating the maquiladoras, the demand for industrial usage has increased. With an increased job offer, migration increases and thus the population increases Romo et al. (2009). In consequence, the demand for residential land use is increased and results in the creation of new residential districts.

The use of natural resources such as water depends on the unique properties of the city. Ciudad Juarez has a dry arid climate, an annual mean temperature of 17.3 ^{o} C , an annual mean precipitation of 223.8mm, an average of 48.1 rainy days and an average of 1.8 snow days Sánchez (1997).

To evaluate the model of Ciudad Juarez, it is a fast growing city with an inherent demand for land and public services that has overwhelmed the urban planning schemes, in particular, in environmental issues such as water consumption. This growth phenomenon puts stress on the environment, manifesting itself as an increase in waist production, excessive gas emissions, vehicle congestion, and other effects. It all contributes to the degradation of the environment with effects in the air, ground and water Romo et al. (2009).

The superficial waters of the Rio Bravo that enter Ciudad Juarez are used in their entirety for irrigation in the valley of Juarez, an annual supply of 60 thousand acre-feet or approximately 74 million mm^3. The Rio Grande is the only renewable source of water for the Ciudad Juarez-El Paso region; Ciudad Juarez is entirely dependent on the aquifer called Hueco Bolson. Water extraction as increased in recent years, with an annual average rate of 2.5%. In 1990, 119.8 mm^3 of water was extracted, in the year 2000, an extraction of 153 mm^3 was reported and by the year 2005 the rate was 147.3 mm^3 . The approximate annual extraction is 175 mm^3 , this pumping provides a service capacity of 330 liters per inhabitant per day.

It is estimated that the Hueco Bolson aquifer has a surface of 260.89 acres (the approximate extension of the urban sprawl of Ciudad Juarez) JMAS (1997), and has an annual recharge rage of 35 mm^3 . This means that the extraction rate in Ciudad Juarez is approximately five times greater than the recharge rate provided by rainfall JMAS (2005). Nevertheless, the aquifer also receives subterranean recharges in a north-south hydraulic gradient coming from the U.S. side. These recharges have not been properly quantified.

5.7 Simulation and optimization

The initial simulation process has been carried out in two tiers, i.e., the macro and the micro levels. To illustrate we use the macro model of the dynamic systems from the top-down model. The dynamic systems allow us to depict all the elements and relationships from the sustainable system's structure. In addition, we will be able to visualize missing links or connections between the entities, and therefore adjust the corresponding mathematical equations in the model.

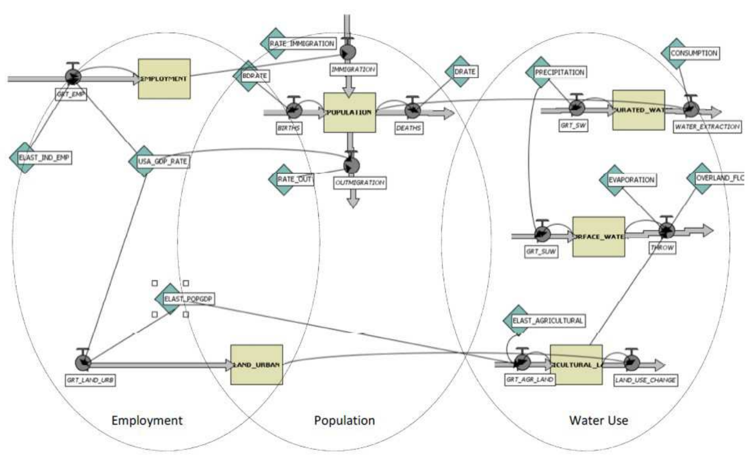

Fig. 11. Macro level sustainability implemented in NetLogo

On the other hand, obtaining the most relevant data will permit the representation of higher-level agents. In the context of this study, these will be: social, economic and environmental agents striving for harmony in all the aspects. The modeling process of this project is based upon methods and mathematical expressions, such that represent the theoretic behavior of the land use in the proposed representation. The simulation is presented in a geographical space using the NETLOGO framework. This software proves to be useful in representing geographical systems as well. Using agents during the modeling process provides a better comprehension of the structure and processes in urban systems. The integration of modeling with geographical information systems has dramatically improved the possibilities of urban simulations. We can visualize agents at the meso level , in the way they are affected by their surroundings and relationships within the same levels and the adjacent levels, i.e., superior and inferior levels.

5.8 Output data analysis

In the first part of the presented urban simulation model, the focus is on the social-environmental aspect. It can be observed how the sharp demographic growth from Ciudad Juarez has incremented along with the consumption of drinking water. Ciudad

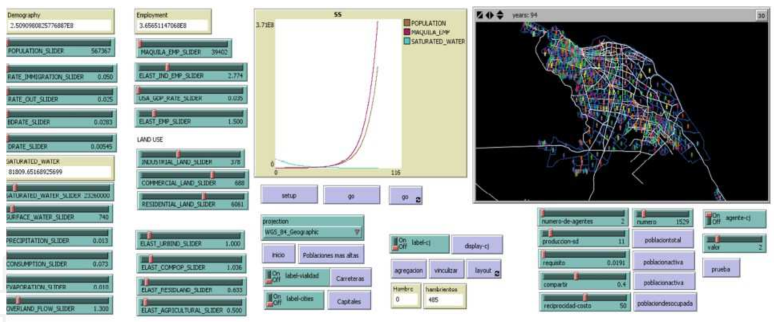

Fig. 12. Sustainability's meso level, implemented in NetLogo

Juarez's water system obtains its entire water supply from the Hueco Bolson aquifer, with an extraction rate that exceeds by many times the natural replenishment rate. Based on this information, the simulation model determined that in twenty years' time this resource will be insufficient to provide city's water needs. In parallel, the urban model simulation found that Ciudad Juarez is strongly linked to the American economy due to its nature of border town, situation that may lead in the future to financial crises. However, there is still data and relationships not clearly defined and required in the model. If the existing variables are accounted for in each system and linked between each other, an interesting output is obtained which need to be examined in the respective disciplines (social, economic and environmental). It should be noted that developing a sustainable model using different simulation techniques could prove to be a valuable instrument during planning stages. The usage of dynamic systems supported the construction of new theoretical models and contributed to expand our understanding of the connections within the systems. This partly to the availability of a global perspective of the situation and some concrete instances provided by the relationships in the lower agency levels.

6. Conclusion

Developing a methodology for a sustainable system may imply the use of different techniques, theories and the researcher's perceptions which often differ between each other. Usage of a unique statistical methodology in this context could be insufficient given the requirements of encompassing a complex system. The proposed methodology is developed using a holistic approach, analyzing the diverse levels of dimension and time, applying nonlinear dynamics where required, harnessing the emergent properties of the model, and the self-organizing processes and interactions between several levels in the manifold respective dimensions. The interdisciplinary nature of this field sets the main goal when using this methodology, to explore the relationship between the diverse social and computational theories linked to complexity sciences. The outcome of the use of the methodology provides a reliable alternative to complement, substitute and expand the traditional approaches in the context of social sciences from the point of view in which complex systems are studied to developing the techniques proposed in this work. Multidisciplinary connections and multi-leveled modeling is still an unexplored field in computational social sciences and in the context of social simulations as well. Currently, this methodology has proven to be a way to achieve further advances in the objectives set by scholars in the area of social studies. The accuracy of statistics used in social sciences, can be improved by extending the number of variables, and its validity is kept when analyzed at a single level, however, most of the social, economic and environmental issues are part of a higher complex system. Thus, it is a difficult task to embrace a general methodology for any complex system, not only by reason of the multiplicity of variables suitable for measurement, but also due to the nonlinear dynamics, self-organization and interactions between levels and dimensions. Hence, analyzing complex systems under the approach of complex systems and multi levels is greatly required. The use cases presented here can be linked together to the interactions between multiple levels only if the most significant relationships are clearly identified. The methodology applied to a sustainable system may imply a vast amount of information with different theories and computational techniques. The presented sustainable system used a diversity of simulation techniques being these key instruments for planning efforts of any type. The use of dynamic systems helped create new theoretic models and understand the underlying relationships within the system, visualizing these outcomes globally. Distributed agencies were helpful to represent particular use cases and the interpersonal associations between agencies. The proposed methodology was developed holistically, the analysis of the sustainable system, was studied at a macroscopic level determining all the processes in between job opportunities, population and water sources. This analysis provides a model that is simultaneously dependent and influential of lower levels. The intermediate hierarchies are considered given that most of the analysis ranges between boundaries without accounting for the middle sections. This can be accomplished by keeping in mind the relationships between components at different levels.

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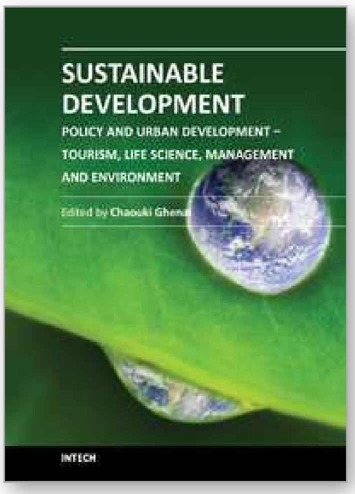

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The technological advancement of our civilization has created a consumer society expanding faster than the planet's resources allow, with our resource and energy needs rising exponentially in the past century. Securing the future of the human race will require an improved understanding of the environment as well as of technological solutions, mindsets and behaviors in line with modes of development that the ecosphere of our planet can support. Sustainable development offers an approach that would be practical to fuse with the managerial strategies and assessment tools for policy and decision makers at the regional planning level.