Coupling Artificial Neural Networks and Genetic Algorithms in Redesigning Existing Cities for Flood Resistance

Gene Oliver Cruz[1], Florencio Ballesteros, Jr.[1], Ariel Blanco[2]
[1]Environmental Engineering Graduate Program
[2]Department of Geodetic Engineering
University of the Philippines
Quezon City, Philippines
gene_cruz@yahoo.com, {balleste, acblanco.updge}@gmail.com

Abstract **– Cities are becoming more vulnerable to natural hazards due to increasing concentration of urban population and resources as well as to changing weather patterns caused by climate change. Adding to the aggravation of urban vulnerability is the socio-economic conditions of its population. More often, the poor are those who are severely affected and have no economic means to recover. Eventually, the local government takes the responsibility of providing services to restore and rehabilitate affected communities. This impacts the cities' economic base by reducing their ability to grow and raise revenue. In order to minimize economic losses caused by a disaster, it is important to assess the communities' vulnerabilities and plan ahead before a disaster strikes. This paper explores the use of neural networks and genetic algorithms as support tools for an integrated urban development and disaster risk reduction planning and decision making.**

Keywords-artificial neural networks; genetic algorithms; land use; disaster preparedness.

I. INTRODUCTION

Disaster risk is a key threat to dense urban spaces as evidenced by events in the past [1]. Experiences of the United States of America from the devastation of Hurricane Katrina in 2005 only revealed that even in highly developed countries, buildings and infrastructure, flood risk preparations and well-resourced emergency services can be overwhelmed. Such concern is not an indication of climate change yet but rather a proof of vulnerability of urban areas and settlements to extreme weather events [2]. Disaster risk arises when hazards interact with physical, social, economic and environmental vulnerabilities. Disasters, often, hold back urban development and impact the economic base of urban areas by reducing their ability to grow and maintain carrying capacity. Urban areas, particularly in developing countries, are faced with the challenges brought about by climate change. It is foreseen that a significant amount of residential developments will be required which would shape future spatial patterns of these urban areas. It is, therefore, important that the direction of spatial pattern and climate change adaptation of urban infrastructures are planned [3].

Lately, there has been a gradual awakening to the fact that disaster risk reduction and climate change adaptation are not separate specialized fields of activity alongside poverty reduction and sustainable development efforts. The growing concerns on the impacts of climate change bring about the importance of integrating land use planning, disaster management and climate change to address disaster risk issues holistically [4]. One of the things that link them is their common need to understand livelihoods and obstacles to people gaining access to what is needed to stabilize their livelihoods and make them hazard resistant [5]. Understanding spatial and temporal processes of urban development and its corresponding social-environmental consequences deserve serious study due to its direct and imminent impacts on human beings [6]. This study explores an integrated urban land use and disaster risk reduction approach proposing the use of evolutionary computing algorithm for a holistic planning and decision making process.

The paper is presented as follows: Section II discusses the rationale behind the proposed research. Section III presents the temporal and geographic scope. Section IV outlines the research methodology which is divided into four major activities. Last, since the research is still in progress, this section presents initial results and challenges faced in doing the research.

II. RELEVANCE

In the past, land use management and disaster risk management were treated as almost, if not completely, two separate disciplines. The gradual recognition of their relationship to the city's economic growth and development prompts interest to integrate the two fields. Current integrated approach, if there is any, is usually manual and subject to the whims of the planners and decision makers requiring subjective consideration of various characteristics of the city.

Numerous studies exist on computer supported land use simulation [6][7][8][9][10] but approaches that specifically consider disaster management aspects are rare. The research proposes an automated integrated analysis of land use and disaster risk through processing of geospatial and statistical data to better understand and assess the city's current and future state which aids in effective planning and decision making. The proposed approach views disaster mitigation as an integral part of land use management that does not only addresses the current requirements of the city

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but also the effects of such decisions on shaping future land use patterns and communities' vulnerability.

III. SCOPE

Metro Manila is the primary core of Philippine politics and commerce. It is a result of integrating seventeen previously distinct territories which includes Marikina City located at the eastern border. Marikina City is consist of sixteen communities or *barangays* and is regarded as a highly urbanized first class city. It has high exposure though to recurring floods due to its proximity to Pasig and Marikina rivers. In 2009, the city was inundated by torrential rains brought about by Typhoon Ketsana damaging properties and claiming lives. Since then, the city has been active in disaster mitigation and preparedness.

Marikina City is selected as a case study for assessing the effectiveness of the proposed integrated approach. Using historical empirical data consisting of the site's physical and socio-economic attributes for the past twenty years with a ten year interval, future land use pattern is simulated at an interval of ten years considering the boundary effects of surrounding cities and municipalities.

Vulnerability indices of *barangays* are also measured using same data sets with the assumption that vulnerability degrades as urban growth is realized. While simulating future land developments, the study also examines the effects of such development to the vulnerability of the *barangays* to flooding over time. The study then proposes a physical arrangement of *barangays* resulting to lesser vulnerability. The results from this simulation can be considered during planning for both land development and disaster mitigation.

IV. METHODOLOGY

The study is divided into four parts: 1) assessing the vulnerability over time, 2) developing a land use model and simulating future land use patterns, 3) optimizing the resilience of predicted land use against flooding, and 4) conducting sensitivity analysis and determining effects of controlling attributes on future resiliencies. Figure 1 illustrates the framework of the research design.

Artificial Neural Networks (ANN) [7] and Genetic Algorithms (GA) [12] are used in this study due to their capability of capturing the complexity, non-linearity, heterogeneity, and at times, chaotic and unpredictable behaviour of both urban growth and community resilience. These can accommodate and process volumes of data and identify which of these data are significant. Initially, the study focuses on loosely linking ANN and GA. Each method is independently performed on individual platforms with the intention of integrating them seamlessly in a form a program simulation.

A. Land Use Simulation Model

This subsection undertakes the development of a land use simulation model that defines the probability of land use transition. Historical empirical data are used to determine the relationship between site attributes and urban development. To achieve this, the geographic map of Marikina City is initially broken down into acceptable grid or cell sizes (e.g., 50 meter by 50 meter grid). Future state or development level of each cell is predicted by considering both its current site attributes and development state (residential, commercial, industrial, etc.) and of its neighboring cells. Collectively, the cells generate the predicted land use pattern of the city.

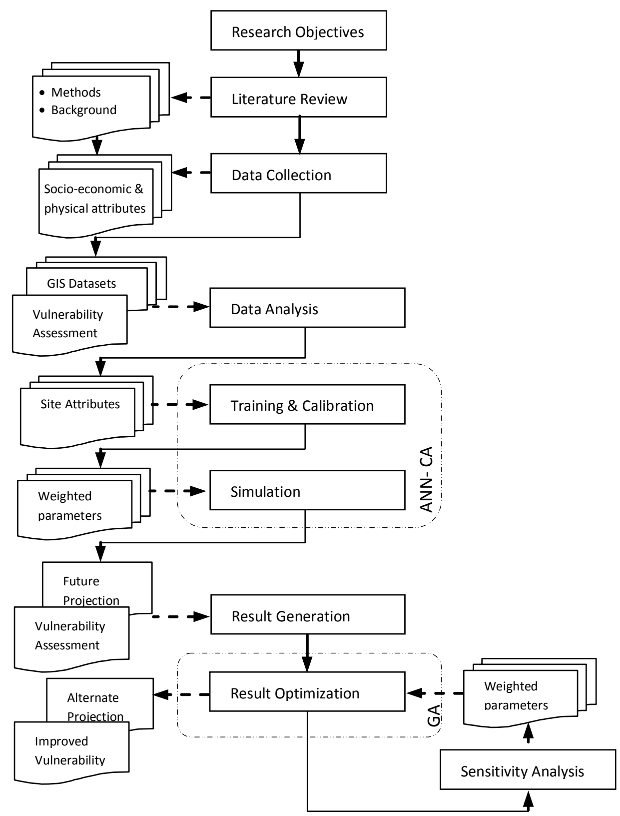

Figure 1. Research Methodology

Geographic Information System (GIS) data layers of site attributes (S'_n) influencing land use change such as socio-economic data (e.g., population growth, population density, etc.) and physical characteristics (e.g., slope, proximity to infrastructures, etc.) from three epochs or periods (1990, 2000 and 2010) of Marikina and its neighboring areas are collected and processed for purposes of data clean-up, conversion and extraction of data layers. Physical attributes related to geographic proximity and accessibility are also extracted using GIS software (e.g., ArcGIS) [10] common analysis functions such as buffer and overlay. Socio-economic statistics are also entered into the software as a data layer. There are two ways in handling the historical site attribute for training. One approach is to assume that development proceeds based on historical trends. The other approach is to modify the data following a set of planning criteria [7].

ANN is employed in determining parameter values for the transitions rules of the proposed land use model. There are two parts of developing the model: training by ANN and simulation by Cellular Automata (CA) [6][7], as illustrated in Figure 2. The neural network is composed of three layers: an input layer, a hidden layer and an output layer. The input layer has *n* neurons representing *n* site attributes obtained from GIS. Similarly, the hidden layer has *n* neurons. The output layer has only one neuron indicating the development probability. At each iteration stage, the neural network determines the development probability based on the input site attribute. The algorithm derived from ANN is used for CA simulation.

In order to achieve the best generalization, the data sets are split into three parts [8]:

- The training set which is used to train the neural network, and its error is minimized during training;
- The validation set which is used to determine the performance of a neural network on patterns that are not trained during learning; and,
- The test set which is meant for checking the overall performance of a neural network.

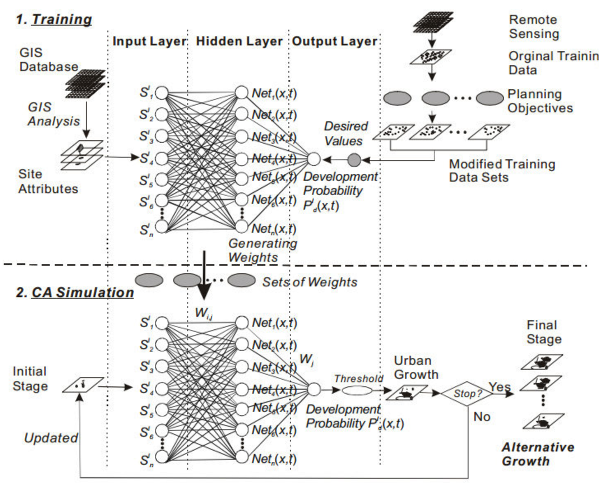

Figure 2. Simulation of urban form using ANN based CA model [7]

Historical data of 1990 and 2000 are used as training data to calibrate the neural networks. Training or learning is then stopped when the validation set error reaches its minimum. After concluding the learning phase, the net should be finally checked with the third data set – the test set, i.e., actual land use of 2010. CA simulations are carried out for the three periods so that land use transitions can be compared and evaluated against the actual development of 2010.

ANN is employed to estimate the development probability at each iteration stage of the CA simulation. The existing variables of a cell and its neighboring cells are the input values and the neural network determines the development probability at the output layer at each iteration stage. Before keying the values into the neural network, variables are scaled to treat them as equally important inputs and to make them compatible with a sigmoid activation function [7]. The parameters or weights are significant in defining the final signals. Back propagation algorithm is adopted as an iterative learning procedure to minimize the error function. In this process, the parameters undergo continuous adjustments by comparing the calculated outputs against desired outputs [9][10][11].

A random seed number, an arbitrary constant determined through trial and error, is determined and used to initialize the weights. The errors, computed as the difference between calculated and desired output neuron, are propagated backwards to refine the weights. The adjustment of the weights is iterated or repeated until such time that the errors are within the acceptable thresholds. This completes the training process of the neural network making it ready for simulation.

Another consideration of this study is to validate also the results against two major analytical characteristics of spatial analysis: spatial autocorrelation and spatial heterogeneity [11]. Once training is completed and appropriate weights are obtained, the data are entered and processed into the neural network based CA simulation model. The model is implemented in a GIS platform by integrating neural network and GIS. A graphical result of the model is presented in GIS format.

B. *Vulnerability Assessment of Current and Future Land Use Change*

Spatial planning with the aid of GIS has also been regarded as becoming one of the most important tools in disaster risk reduction. Spatial data, together with non-spatial ones, can be analyzed in obtaining information on geo hazards and hazard prone areas which can be used as planning and decision making tools.

Using a “weighted average” technique, vulnerability assessment of Marikina’s *barangays* is performed to provide insights on the historical trend of their vulnerability. Socio-economic variables are processed into weighted variables using data analysis software (e.g., MATLAB) and used in establishing vulnerability index over periods of time. The results are then compared and validated against other risk assessment models. Using the same method, vulnerability of the predicted land use pattern is measured. The predicted pattern is also superimposed into a geo hazard map to determine which settlements would likely be affected. Its vulnerability is assessed using parameters such as loss of life, property, livelihood and infrastructure.

C. *Alternative Future Land Use Change Scenario*

Using GA, a proposed urban arrangement having the lowest possible vulnerability is generated using a cost fitness function as a chromosome. Desired result is achieved through crossover, selection and mutation of its best attributes and producing a desired attribute. The method is similar to Charles Darwin’s evolution of species by survival of the fittest whereby a new individual evolves by the crossover of genetic information of two parents.

The measured vulnerability is compared against current vulnerabilities to determine whether there is significant improvement on the communities’ resilience.

D. Sensitivity Analysis

Since proposed arrangements are machine generated results, there is a need to validate and assess their practicality following land use planning principles. A sensitivity analysis is performed by controlling or altering attributes as a representation of current city planning or remediation by entering the modifications into the simulation model. The results provide insights to planners and decision makers on the relationship of attributes and the effectiveness of existing measures to reducing communities' vulnerabilities.

V. DISCUSSION AND CONCLUSION

The study is currently on-going. Historical data have been collected from the cluster of cities and municipalities which includes Marikina City, Quezon City, San Mateo, Antipolo City, Cainta and Pasig City. As expected, obtaining complete, up to date and accurate data poses a challenge. This is primarily due to the inability of the local government to retain historical information, particularly in the 1990s where computers were not yet widely used to store data. Most documents were kept in hard copies and retained for a certain period of time, for example, five years after which these are disposed. As a result, additional work is carried out in tracing back historical land use pattern through differentiating available data sets and focusing only in areas where changes occurred.

The number of parameters or attributes to be considered in land use planning and disaster risk management is abundant. Some of these attributes take first precedence over the others and some of these attributes may not be significant at all. For a human to process all available information, it would take much time and effort and by the time results are derived new sets of change have occurred. The research intends to verify the usability of identified problem solving methods in obtaining valuable information for planning and decision making in an integrated holistic approach.

The research also recognizes that the computational requirements may be extremely resource consuming. As such, the research intends to further investigate in the future the use of other computational methods to compare which are more efficient.

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