Simulation Of Land Development Planning Process Through Agent Based Modeling

Project Report submitted in partial fulfillment of the

degree of

Bachelor of Technology.

in

Computer Science & Engineering

May 2015

under the Supervision of

Prof. Deepak Dahiya

By

PARUL HOODA (111309)

DEPARTMENT OF COMPUTER SCIENCE & ENGINEERING

JAYPEE UNIVERSITY OF INFORMATION TECHNOLOGY
WAKANAGHAT.

CERTIFICATE

This is to certify that project report entitled **"Simulation Of Land Development Planning Process through Agent Based Modeling"** submitted by **Parul Hooda (111309)** in partial fulfillment for the award of degree of **Bachelor of Technology** of Jaypee University of Information Technology, Waknaghat, Solan has been carried out under my supervision.

This work has not been submitted partially or fully to any other University or Institute for the award of this or any other degree or diploma.

Signature of Guide:

Name of Guide: **Prof. Deepak Dahiya**

Designation:

Date: **May 2015**

ACKNOWLEDGEMENT

The project in this report is an outcome of continual work over the period of one year & intellectual support from various sources. It involves a lot of direct and indirect contribution from a lot of people. It is difficult to express adequately the debts owed to all of them who have been instrumental in imparting this work a successful status.

We are extremely indebted to our esteemed mentor and supervisor **Prof. Deepak Dahiya** who was always there to tell us how to go about our project in a systematic manner and who always took out time to help us with our technical and non-technical doubts at various stages of the project.

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We would also like to express our thanks to all the staff in general who cooperated with us in this project. And last but not the least we would like to thank our friends to help us at various times of our difficulties .

Date: May 2015 PARUL HOODA (111309)

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Abstract

Simulation:

Simulation is the imitation of the operation of a real-world process or system over time. The act of simulating something first requires that a model be developed; this model represents the key characteristics or behaviors/functions of the selected physical or abstract system or process.

Agent Based Model:

An **agent-based model** (ABM) is one of a class of computational **models** for simulating the actions and interactions of autonomous **agents** (both individual or collective entities such as organizations or groups) with a view to assessing their effects on the system as a whole.

Agents:

A program that performs some information gathering or processing task in the background. Typically, an agent is given a very small and well-defined task.

Prof. Deepak Dahiya

Project Supervisor

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Chapter :1

SUMMARY

The summary to the project starts as:

The land development planning process is the type of complex systems where “Agent based models” can provide the ABMs are an abstraction of real-world entities called agents having typically the following properties: they are autonomous, they control their own decisions and actions; they are social and can negotiate and cooperate with one another; they are able to perceive changes in the environment and react to them; they have goals and are able to take initiative to achieve them. ABMs are typically discrete, disaggregate, dynamic and spatially explicit, meaning that they simulate the processes that occur over time between individual agents that interact and act upon a simulated geographic region. Over the past fifteen years, ABMs have contributed to modeling in the natural and social sciences support.

The objective of this research is to develop an ABM to simulate the land development planning process.

The land development planning process includes the Land-use Re-designation and Outline Plan process as shown in Fig. 1. The model will then be used to investigate the impact of changes to governmental regulations, planning policies, design standards and stakeholder goals on land-use resources. For the purpose of this research, land-use resources are defined as parcels of land having a potential for development that currently do not have the land-use designation to allow for development but that could be re-designated.

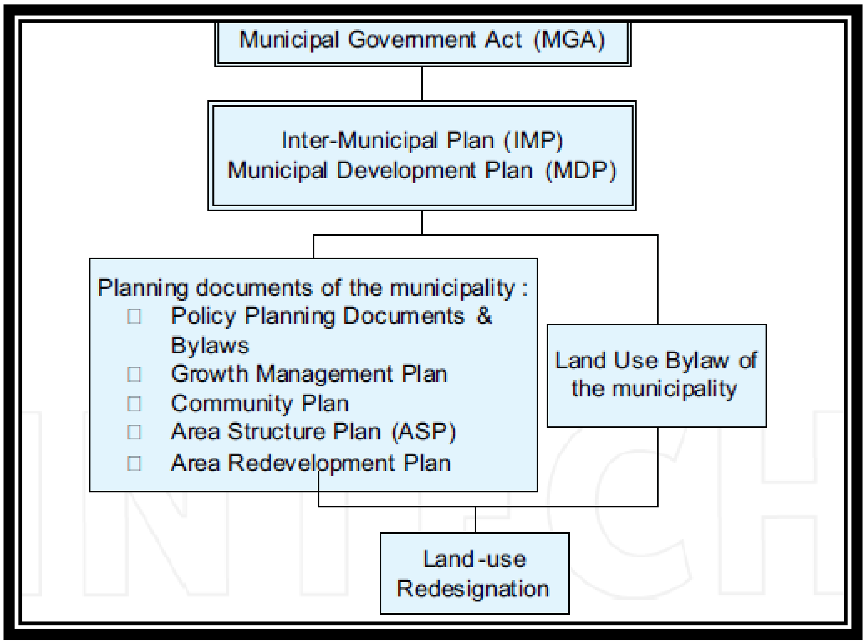

Fig.1

First, the landowner and/or developer attend a pre-application meeting with the city planning authority to discuss the proposed redesignation. Then, the landowner/developer voluntarily presents the plan to the neighbours and local community association. The landowner/developer submits the application for land-use redesignation and outline plan that he has worked on with professional planning and engineering consultants and sub-consultants, to the planning authority. Then, the application is circulated to the various City departments, the community association, the Alderman, and any applicable special interest groups and a notice is posted. The various planning authorities review the application and the comments and make a recommendation to City Council. Notices are sent to adjacent owners, a sign is posted, and an advertisement is placed in the local newspapers regarding a public hearing on the application. Finally, the proposed land-use redesignation and outline plan application are presented in a public hearing and the City Council makes its decision.

As one can see, this process involves many stakeholders including: the lwners, the developers and their engineering and planning consultants, the city/town authorities and their various departments, the neighbours and other citizens, the community associations, the city/town political figures, the utility providers, and other specialando interest groups. One can imagine each stakeholder or group of stakeholders having different visions, opinions and interest in the proposed development. The authorities must also have in mind the broader picture and overall goals of the city/town itself, and attempt to see how the proposed land development fits into the future plans of the community. Throughout the process, communication occurs between different stakeholders on many occasions, both within an organization and with other organizations. Communication also occurs at many formal and informal levels, including: pre-application meetings with city/town authorities, meetings with neighbours and community associations, meetings with private planning and engineering firms, open houses, application reviews by authorities and the public, decisions by city/town authorities, public hearings, and possible appeals.

Prior to these communication sessions, stakeholders are trying to devise ways to fit their goals into the proposed development. During the sessions, negotiations take place to balance goals and resolve issues and hopefully make decisions. As stakeholders make decisions, they might weigh social need, environmental impact, economic advantages or disadvantages and political support or opposition of a proposed land development.

Municipal and inter-municipal planners use various methods and tools to create a municipal plan that best suits the ideals, values and vision of the community in terms of future social need, economic feasibility, and environmental sustainability. These methods include forecasting based on present conditions using historical data, past success and failures. Some of the tools include statistical census analyses, and community economic models to predict employment creation. The growth plans and planning policy developed for a municipality set the direction of the community growth, which may leave limited choice for developers and citizens. One of the outcomes, which is the focus of this research, is a decision that changes land use allowing for development to occur on a particular parcel of land.

Despite the array of methods and tools available, these decisions are still often made in the face of uncertainty. The central issue addressed here is that town planners have a limited, although improving, ability to forecast the cumulative effect of individual decisions made by stakeholders having different goals on the overall environment over which they make their decisions. They need a tool that can model how environmental patterns and trends emerge from the intricate interactions and complex behaviour of several stakeholder groups who might have conflicting goals and views. Having access to such a tool would enable environmental impact forecasting of current goals, decisions and policies, and would allow stakeholders to perhaps modify their goals and analyze possible future impact before the implementation of their decision. Increasingly, computer simulation models, such as agent-based models (ABMs) are being used to support decision making in complex environmental management situations.

The land development planning process is the type of complex systems where ABM can provide this support.

ABMs are an abstraction of real-world entities called agents having typically the following properties: they are autonomous, they control their own decisions and actions; they are social and can negotiate and cooperate with one another; they are able to perceive changes in the environment and react to them; they have goals and are able to take initiative to achieve them. ABMs are typically discrete, disaggregate, dynamic and spatially explicit, meaning that they simulate the processes that occur over time between individual agents that interact and act upon a simulated geographic region.

Over the past fifteen years, ABMs have contributed to modeling in the natural and social sciences in the areas of human/wildlife interaction, human/landscape interaction (Gimblett et al. 2001; Gimblett et al. 2002), urban pedestrian movement (Batty 2001; Waddell 2002), water/forest/agriculture resource management spatial planning (Ligtenberg et al. 2001),and land - use and land-cover change (Lim et al. 2002; Parker et al. 2002; Monticino et al. 2007; Moreno et al. 2007; White et al. 2009). When used for spatial planning, ABMs are often linked to a cellular automata model (Parker et al. (2002). In such a case, the ABM component represents humans making decision and interacting over their environment as agents. The cellular automata component is a cell based map that simulates the environment that agents view and act upon.

Chapter : 2

INTRODUCTION

<u>Computer simulation</u> is the discipline of designing a model of an actual or theoretical physical system, executing the model on a digital computer, and analyzing the execution output. Simulation embodies the principle of ``learning by doing'' --- to learn about the system we must first build a model of some sort and then operate the model. The use of simulation is an activity that is as natural as a child who *role plays*. Children understand the world around them by simulating (with toys and figurines) most of their interactions with other people, animals and objects. As adults, we lose some of this childlike behavior but recapture it later on through computer simulation. To understand reality and all of its complexity, we must build artificial objects and dynamically act out roles with them. Computer simulation is the electronic equivalent of this type of role playing and it serves to drive synthetic environments and virtual worlds. Within the overall task of simulation, there are three primary sub-fields: model design, model execution and model analysis.

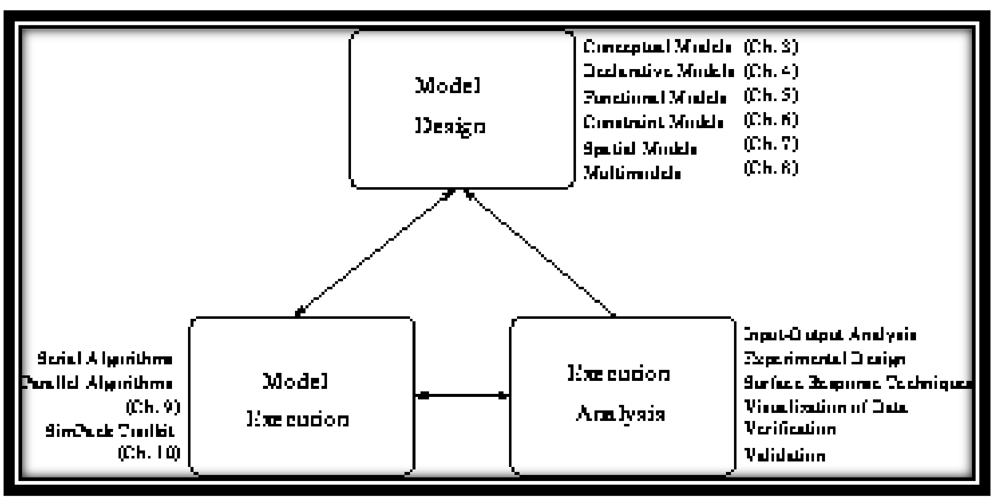

Figure 2: Three Sub-Fields of Computer Simulation.

To simulate something physical, you will first need to create a *mathematical model* which represents that physical object. Models can take many forms including declarative, functional, constraint, spatial or multimodel. A multimodel is a model containing multiple integrated models each of which represents a level of granularity for the physical system. The next task, once a model has been developed, is to execute the model on a computer --- that is, you need to create a computer program which steps through time while updating the state and event variables in your mathematical model. There are many ways to ``step through time." You can, for instance, *leap* through time using *event scheduling* or you can employ small time increments using *time slicing*. You can also execute (i.e., simulate) the program on a massively parallel computer. This is called *parallel and distributed simulation*. For many large-scale models, this is the only feasible way of getting answers back in a reasonable amount of time.

2.1

Fundamental Concepts in Simulation

Learning the language is a key task facing everyone who is entering any new field of work, especially one such as simulation, which has both technical and educational aspects. When we are engaged in learning through use of a simulation we might find towards in any one of a number of quite different contexts. In one setting we may be taking part in a face-to-face role-based activity, drawing on individual interpretations of some aspect of real world conditions. In another setting we might have a role as a member of a team that has the task of using a technical simulation to create learning environments, using data obtained through analysis of the real world. Both of these are using 'simulation' to create a learning context and each uses the same core essentials to do so. However the visible setting may be quite different and reliance on different technologies may even obscure the similarities between them.

2.2

Designing Instructional/Learning Components of Simulation

The initial design basis for all training/learning involving any use of a simulation is instructional design. The process does not begin with the technology, although sometimes it is hard to convince clients that the technology to be used is not the beginning point. In the past sixty years there have been tremendous advances in instructional design and simulation development and both of these must be taken advantage of as much as possible to create truly engaging learning environments. All sectors of the simulation design and construction process are becoming more aware of this as divisions separating engineering, learning and support are dissolving in the face of the need to address ever more complex learning outcomes through integrated use of face to face and technical simulation.

2.3

VV&A - Verification, Validation and Accreditation

Verification, Validation and Accreditation is a trio of concepts vital to assuring that any simulation meets relevant quality control criteria. They are used together as a means of putting a simulation ‘through its paces’ prior to committing it to use.

Chapter : 3

Conceptual Model

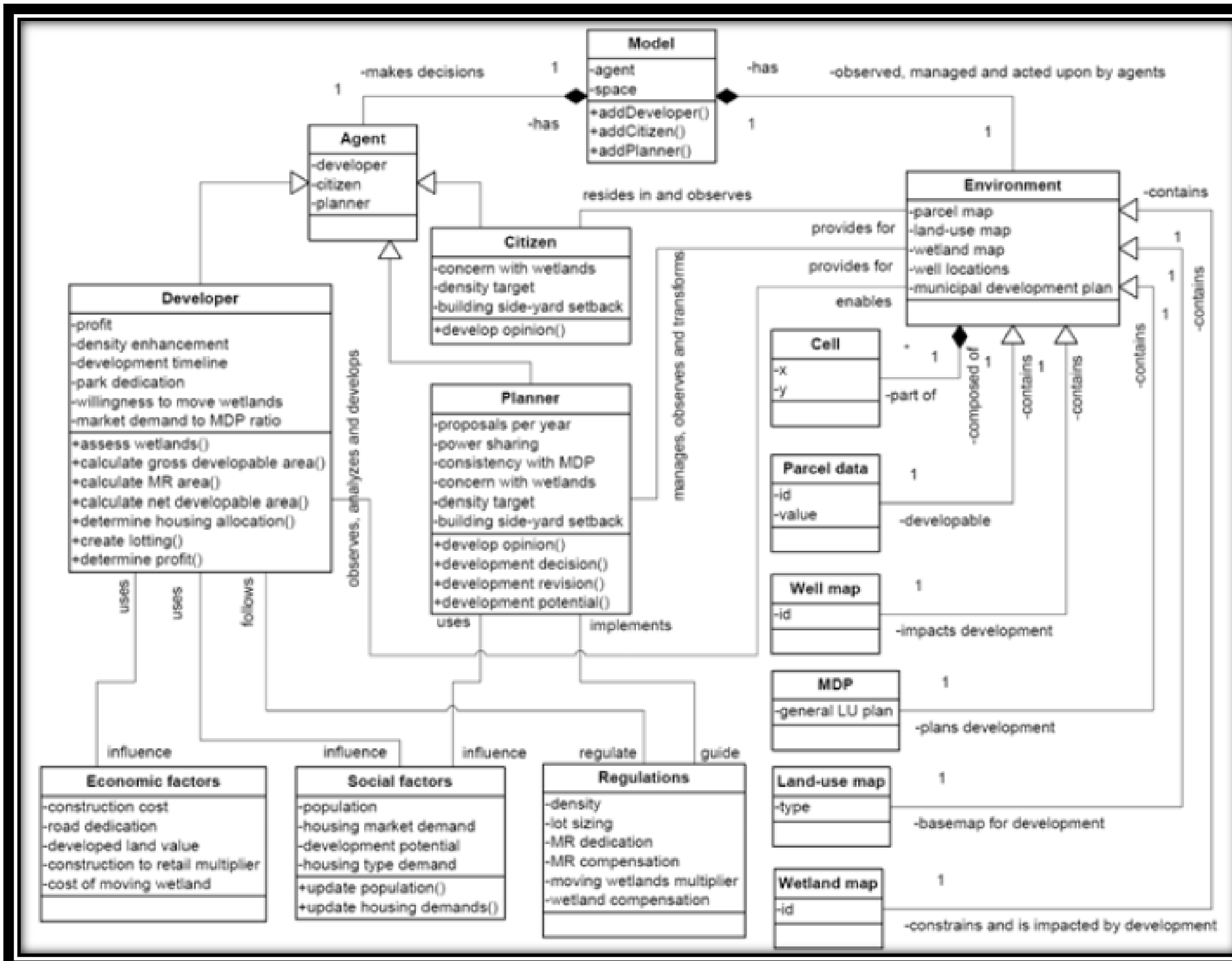

Fig.3

Chapter : 4

The Need for Agent-based Modeling

We live in an increasingly complex world.

- Systems More Complex

– Systems that need to be analyzed are becoming more complex

– Decentralization of Decision-Making: “Deregulated” electric power industry

– Systems Approaching Design Limits: Transportation networks

– Increasing Physical and Economic Interdependencies: infrastructures (electricity, natural gas, telecommunications)

- New Tools, Toolkits, Modeling Approaches

– Some systems have always been complex, but tools did not exist to analyze them

– Economic markets and the diversity among economic agents

– Social systems, social networks

”

- Data

– Data now organized into databases at finer levels of granularity (microdata)

– can now support micro-simulations Computational Power

– Computational power advancing – can now support micro-simulations

What Is Agent-Based Modeling & Simulation?

- An agent-based model consists of:

– A set of agents (part of the user-defined model)

– A set of agent relationships (part of the user-defined model)

– A framework for simulating agent behaviors and interactions

(provided by an ABMS toolkit or other implementation)

”

Unlike other modeling approaches, agent-based modeling begins and ends with the agent’s perspective

When agent modeling?

- When there is a natural representation as agents

– When there are decision and behaviors that can be defined discretely (with boundaries)

– When it is important that agents adapt and change their behavior

– When it is important that agents learn and engage in dynamic strategic behavior

– When it is important that agents have a dynamic relationships with other agents, and agent relationships form and dissolve

– When it is important that agents form organizations and adaptation and learning are important at the organization level

– When it is important that agents have a spatial component to their behaviors and interactions

- When the past is no predictor of the future
- When scale-up to arbitrary levels is important
- When process structural change needs to be a result of the model, rather than an input to the model

Chapter : 5

METHODOLOGY

The following eight steps in creating the ABM have been applied in this research:

- Identification of the study area
- Abstraction of the real-world system through a conceptual model
- Collecting the information needed for the implementation of the model
- Implementation of the model
- The computational logic of the model
- Calibration and verification of the model
- Scenarios simulation
- Validation of the model results.

5.1 Study Area

The study area is a proposed hypothetical residential land development project corresponding to around 80-90 hectares of undeveloped piece of propery; located at about 0.5 Kms away from the main city.

The key stakeholders that were abstracted from the real-world land development planning process are the Developer, the Planner and the Citizens. The Developer combines those stakeholders that have financial interest in the development of the Development project: the land developer who will profit from the conversion of the land into developable lots, and the engineering and planning firm who was providing consulting services to the land developer who will profit during the planning and preliminary engineering stages.

The Planner combines those stakeholders that ensure the proposed land development follows governmental regulations with those in political positions that make decisions on the approval of proposed developments in the Town decided for development. They are the municipal planning department, the infrastructure department, the parks and recreation department, the emergency services department etc.

The Citizen includes those stakeholders that neighbour the proposed development, community associations, and other citizens in the City close to the area of Development . The citizens of the Town had particular environmental concerns regarding the new development and are therefore considered a key stakeholder.

Information used in implementing the model :

Five different types of information needed to represent the land developing process were gathered and implemented in the model:

1) Agent information
2) social factors
3) economic factors
4) government regulations
5) spatial datasets

Agent information:

Goals, decisions and factors influencing decisions

The first step in developing the agent-based model was to determine for each of the stakeholders, namely the Developer, the Planner and the Citizen, the specific goals they are attempting to fulfill, how they make decisions, the factors that influence their decisions, and how they communicate with each other.

For the Developer and the Planner stakeholders, information was gathered in three stages: through a questionnaire, a formal interview, and an unstructured interview. Individuals that were directly involved in the land development planning process included the Planner for the Town of Strathmore, and the land developer . A Professional Civil Engineer who was contracted by the developer to do the engineering for the proposed development and who is considered an expert in the field of land development, was also contacted to provide information insight on the land development planning process in the Town of Development, the governmental regulations affecting land development, and the land-use change allocation.

A questionnaire was prepared based on preliminary discussions with the Town Planner and the Professional Engineer. It was provided to each representative stakeholder to answer. The information collected from the questionnaire was used to guide the structured interview. An unstructured interview ensued allowing the representatives to talk freely about the planning process, their goals, how the decision process occurs, the information they use to make their decisions and how the *land development planning process* was going with the Development project.

For the Citizen stakeholder, it was concluded that questioning only one citizen would be biased and questioning many citizens was unwarranted. During the unstructured interview, the Planner provided information on feedback he received through written and verbal communication with concerned citizens. In the public consultation for the Outline Plan and

Land-use Redesignation associated to the development, some motivated citizens provided written comments on the proposed development. These comments became part of the public documentation for the development and are summarized and addressed by the developer. Although this information may not represent the opinion of all citizens, it was the best available to represent the perspective of the Citizen stakeholder and was used in the Model.

Developer stakeholder: goals, decision and influence :

During the interview, the developer explained the general objectives that his company attempts to meet with all proposed land developments, including: profit, density, construction cost and timeline, and lot retail value. The developer discussed the general infrastructure issues that the Town of Strathmore needs to address prior to approving any development projects including: sweet gas well buffers, water sourcing and water treatment, sanitary sewer disposal, and storm water management. He also discussed specific details that pertain to the Strathbury development of which wetlands were the most controversial (Developer 2007).

The land developer wishes to maximize the number of market demanded lots by minimizing the lot size and increasing the density, to minimize costs - hence maximize profit, to provide building lots quickly, to provide the required Municipal Reserve (park space) rather than monetary compensation to the Town, to move wetlands when they interfere with the proposed design, and to follow the market demand for housing rather than the Municipal Development Plan. From this information, six properties were abstracted to become the Developer stakeholder goals: 1) profit, 2) increase residential density, 3) development timeline, 4) park dedication, 5) willingness to move wetlands, and 6) market demand to MDP ratio.

Many regulatory factors dictate the decisions of the land developer when planning a development including: the municipal development plan, the current and adjacent land use, the municipal land-use bylaw, the environmental regulations, and the law. Economic factors also influence the decisions of the land developer such as the housing market demand, the market value of developable lots, the construction cost, the cost of developable land, the distance to existing infrastructure, and the presence of wetlands within the land parcel.

When making the decisions on a proposed development, the developer looks at different development schemes, applies the regulations, assesses all the influencing factors, and then "calculates" the most suitable and profitable scheme. If the developer performs his/her "due-diligence", the proposed development plan on a parcel of land should be accepted.

Citizen stakeholder: goals, decision and influence :

Citizens are the source of values that define the community. They identify problems and provide feedback on solutions that are implemented. Typically the more involved citizens are in the community, the more influence they have on decisions affecting their community. The comments provided by the citizens proved to be very useful in developing their general concerns regarding the Town's growth.

The compiled information revealed these general desires of the citizens: they like the small town feel and they want to maintain it, they do not want the urban sprawl of Town, they like the network of walking trails within the town, and they feel the wetlands in their community are a great asset and want to maintain them as part of their park system. The Town planner verbally communicated a concern with the fire hazard associated with houses being excessively close. From this information, four properties were extracted to represent the Citizen goals in the model: 1) concern with wetland disturbance, 2) maintain Municipal Reserve (park space), 3) maintain density per the MDP, and 4) increase building side-yard Setback.

Planner stakeholder: goals, decision and influence :

During the interview, the Town planner described the Town's current zoning bylaws, the infrastructure issues, the trail network system, the municipal development plan, the density objectives, the future growth plans, and the wetland policy, which was recently updated following a public survey of the town's residents. He/she also talked about his/her role as a sounding board to residents' concerns and as an advisor to the Town Council.The town planner must interpret planning regulations for other municipal decision makers and be able to educate citizens about the benefit of community planning. He is the moderator between the land developer and the citizens over the issues while meeting the needs of the growing community. . From this information, seven properties were extracted to represent the planner goals in the model:

1) Development approvals per year
2) Weight of citizens' opinion
3) consistency with the town's municipal development plan
4) concern with wetland disturbance, and the increase/maintain/decrease of
5) Municipal Reserve (park space)
6) Density
7) Building side-yard setback.

The planner must evaluate the development proposal created by the developer in relation to the town's goals and the housing demand and the town's municipal development plan, and the right of land owner, represented by the land developer, to develop his/her property.

Chapter : 6

Implementation :

This section presents how the three types of information described in the previous section were implemented within the model.

Agent implementation: properties and decision functions :

The goals of each stakeholder type and the factors influencing their decision were abstracted to become the properties of the agents, and the decision making was abstracted into decision functions with property variables. The properties and results of decisions from each agent type were quantified as numerical values, stored as arrays of numbers, or tuples. In the implementation, each agent type was given an *opinion* property that ranges from -1 to 1 (negative opinion to positive opinion) and a *happiness* property that ranges from 0 to 10 (unhappy to happy). At different steps throughout the model, an agent evaluates the results of a decision and develops an *opinion*. A comparison is done between values contained in the decision tuple and values contained in each of the agent's properties tuple. If the result of a decision is contrary to an agent particular property, it will have a negative (-1) impact on his opinion regarding that property; if the result of a decision is similar to an agent property it will have a positive (+1) impact regarding that property. The average opinion is calculated and is weighted by 10 less the happiness and is stored as the agent *opinion* property; therefore the *opinion* of an unhappy agent will be stronger. The *happiness* property of an agent fluctuates according to how his *opinion* is accepted. If his *opinion* is ignored in the following development decision, it will lower his *happiness* and if it is well received, it will increase his *happiness*. Fig. 4 provides an example of the calculation. Provision was also made for weighing each agent property allowing for different properties to be given more or less importance when developing an *opinion*. This was implemented in a Multicriteria Decision Analysis fashion using an Analytic Hierarchy Process (AHP) method called the pairwise comparison . Each pair of criteria, or properties, is evaluated separately; one property is given an intensity of importance value over another property. The values range from 1 to 9 (equal importance to extreme importance) and they are entered into a matrix form. The values in pairwise comparison matrix are then checked \

or consistency by normalizing the eigenvector by the eigenvalue of the reciprocal matrix. If the consistency ratio is less than a certain value, then the values are said to be consistent; if the consistency ratio is greater than the value, the importance values are not consistent and they must be re-evaluated. A weight for each property is also derived, the sum of which equals 1. The weights are then normalized with the smallest weight being equal to 1. The normalized weight is applied to each opinion (+1/0/-1) before the agent *opinion* is developed, as previously discussed.

The benefits of using this method over a straight rank weighting are twofold. First, the resultant weights are not only relative to one another, but they also have absolute values; second, the user only compares two goals at a time rather than subjectively weighting all goals at the same time (Malczewski 1999). The pairwise comparison method was used by Malczewski et al. (1997) in a multicriteria group decision-making model to analyze environmental conflict. In the model, stakeholders in planning or resource management positions evaluate the suitability of land for different socio-economic activities. The research of Malczewski et al. (1997) showed that the pairwise comparison method allowed the stakeholders to objectively derive weights for the various land uses, rather than subjectively assigning them.

Developer agent properties and decision functions :

The properties of the Developer agent are stored in the developer tuple and were implemented as follows:

1) Profit: the goal on the return on the capital investment put into the land parcel: 5 to 20%;
2) Density enhancement: the goal to increase the allowable density: 0 to 2 units/acre;
3) Development timeline

The goal on the start and expected completion of The following is a description of how the eight decision functions of the Developer were implemented: (1) Wetland assessment function: The Developer calculates the size of wetlands impacting the development and determines if any wetlands are below their maximum Size of wetland moved property (5.a.). If wetlands are to be moved, their total area is multiplied by the Moving wetlands multiplier and the area is added to the existing wetland area; (2) Gross developable area function: The Developer determines the amount of developable area, which is the gross area less the Environmental Reserve (ER) or wetlands from the wetland map; (3) Municipal Reserve (MR) function: The Developer determines the amount of land to be dedicated as MR (park) from the developable area based on the Percent MR dedication parameter; (4) Net developable area function: The Developer determines the area of developable area that will be residential and that will be road based on the Percentage of road dedication parameter; (5) Housing allocation function: The Developer uses the Market demand to MDP ratio property and weights the market demand for residential lot types: R1-detached, and R2(X)-semi-detached(attached), with the allocation in the Municipal Development Plan (MDP); (6) Lotting function: The Developer determines the number of lots based on the Minimum lot area and Minimum lot width for each residential lot type, the Density regulation parameters, and its Density enhancement property; the lot depth is optimized to use all the developable area; (7) Profit determination function: The Developer determines the profit in the proposed development as the market value for sold lots, comparing the Developed land value to the construction cost, which is a function of the land value, Construction cost per metre of frontage, the amount of lot frontage, and the Construction to retail value multiplier; and (8) Opinion function

Citizen agent properties and decision functions :

The properties of the Citizen agent are stored in the citizen tuple and were implemented as follows:

(1) Concern with wetland disturbance: The Citizen's view on the displacement of wetlands to accommodate the proposed development: Concerned = 1, Not concerned = 0

(1.1) Size of wetland moved: The maximum size of a wetland the Citizen is willing to see moved: 1000 m2 to 40000 m2

(2) Density target: The Citizen's goal regarding the density in proposed developments: increase the density = +1, maintain the current level in the by laws = 0, decrease the density = -1

(3) Building side-yard setback: The Citizen's goal regarding the distance between residential buildings as a fire protection measure: increase the current building setback = +1, maintain the current building setback = 0, decrease the current building setback = -1. The opinion function of the Citizen was implemented through a comparison of the appropriate values in the development tuple with the values in the citizen tuple.

The following is a description of how the decision functions of the Planner were implemented:

(1) Opinion function: the Planner compares the appropriate values in the development tuple with the land-use allocation in the Municipal Development Plan (MDP), the housing demand and the development potential of the town, the land-use bylaws (density, minimum lot area, and minimum lot width), and the first four values in the planner tuple

(2) Decision function: The Planner weights the Citizen opinion based on the power sharing property. The sum of the opinions of the agents is calculated. If the sum is positive the decision is an approval; if the sum is negative, the Planner requests revisions. A
decision of rejection occurs after four revisions

(3) Revision function: A request for revisions includes simple recommendations to the Developer regarding the proposed development. These recommendations are based on the opinions of the Citizen and the Planner: "(Increase/Decrease) density", "(Increase/Decrease) lot width", "(Increase/Decrease) development time", "(Increase/Decrease) MR dedication", "Follow MDP more closely".

(4) Development potential function: The Planner evaluates the development potential on a yearly basis based on the development potential of the previous year, less the housing market demand for that year, plus the development potential of approved residential land development projects whose construction timeline contributes to the development potential for that year. As an example, if in the current year a development containing 200 units is approved having a start and finish construction timeline of one and five years respectively, the development will contribute 50 units per year to the development potential for the following four years.

Social and economic factors and governmental regulations Implementation :

The social factors, the economic factors, and the governmental regulations were abstracted into model parameters. The following describes how each of the parameters is stored :

(1) Population growth: variable calculated yearly
(2) Housing market demand: variable calculated yearly
(3) Development potential: variable calculated yearly
(4) Housing type market demand: stored as a constant for each residential housing type
(5) Land value: stored as a two dimensional array with the unique parcel identifier
(6) Construction cost per metre of frontage: stored as a constant
(7) Percentage of road dedication: stored as a constant
(8) Developed land value: stored as a constant for each residential housing type
(9) Construction to retail value multiplier: stored as a constant;
(10) Cost of moving wetlands: stored as a constant
(11) Density: stored as a constant
(12) Minimum lot area: stored as a constant
(13) Minimum lot width: stored as a constant
(14) Percent MR dedication and MR compensation: stored as constants;
(15) Moving wetlands multiplier: stored as a constant
(16) Wetland compensation: stored asa constant.

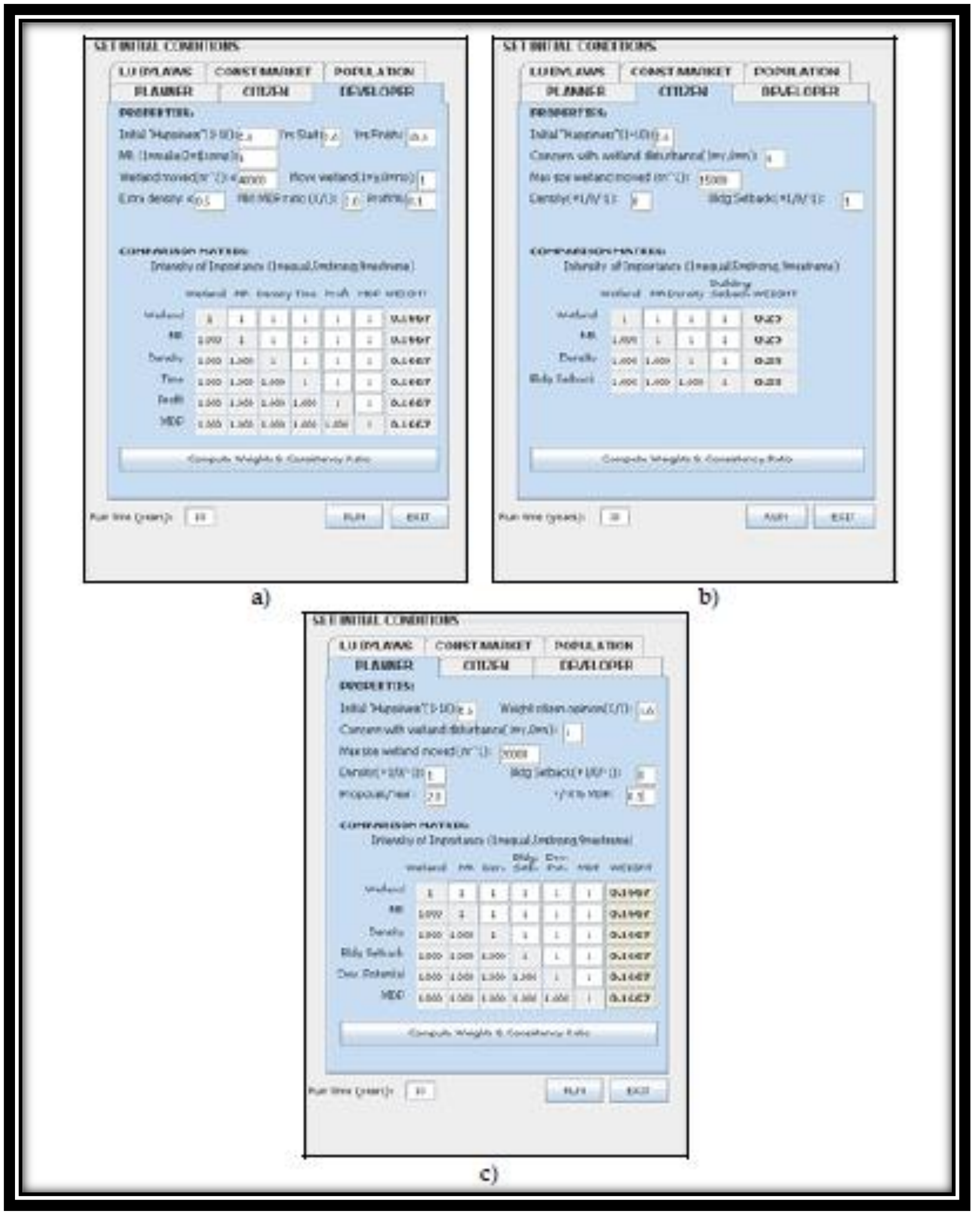
SET INITIAL CONDITIONS
LU BYLAWS
CONST MARKET
POPULATION
PLANNER
CITIZEN
DEVELOPER
PROPERTIES:
COMPARISON MATRIX:
RUN
EXIT
a)
b)
c)

Fig. 4

Agent-Agent interaction :

Developer - Planner: A development proposed by the Developer as a *development tuple* is submitted to the Planner and is circulated to the Citizen

Citizen - Planner: The Citizen shares its *opinion* regarding the proposed development with the Planner

Planner - Citizen and Planner – Developer: The decision of the Planner on a proposed development is shared with the Citizen and the Developer.

A request for revisions includes the recommendations from the Planner *revision function*.

Agent-environment interaction :

Agent-environment interaction occurs on several occasions within the model as environment observations and environment transformations:

Observation by the Developer: the Developer observes the wetlands within the land parcel of the proposed development and evaluates them through the Developers *wetland assessment function*

Observation by the Citizen: the Citizen observes the wetlands within the proposed development and generates an *opinion* based on how they are impacted

Observation by the Planner: the Planner observes the wetlands within the proposed development and generates an *opinion* based on how they are impacted

Transformation by the Planner: a decision by the Planner to approve a proposed development generates an immediate transformation of the *land-use map*.
The transformation does not physically change the environment but it allows the Developer to begin construction.

<u>Conclusion And Future Scope</u>

The process was formalized into a simple agent-based model that accounts for social, economic, regulatory, and environmental factors. The results of the model and the comments provided by the experts show that this model has the potential to provide insight into the impact of municipal planning policies and stakeholders' goals in residential land development planning.

This research was primarily focused on the decision-making process during the " ***land development planning process"*** of the Strathbury residential land development case study. The creation of this model from an engineering aspect gave a very quantitative approach to the interview process and conceptual model development, establishing stakeholder goals as numerical figures, quantifying those factors impacting the decision-making process, and deriving formulas to mimic the decision-making process. The model allows stakeholders to test different goals and policies, providing the opportunity to quickly analyze possible future impacts before their implementation.

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