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Towards a Generic Multi-Agent Engine for the Simulation of Spatial Behavioural Processes

MASQUE / SwarmCity

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Abstract: SwarmCity is being developed as a micro-simulation model, simulating the location-choice behaviour of a population of households, retailers, firms, developers, etc. reacting to an urban plan. The focus of SwarmCity lies –in a first phase- on the decision-making procedures of households, conceptualised as a series of three processes: awakening, search and choice. The methodology used to implement these processes makes use of life-time utility and decision-analysis trees. The final model should work as a scenario-analysis tool, allowing planners, developers, retailers and municipalities to test intervention-proposals, to evaluate legislations, to measure the attractiveness of services, to quantify residential mobility, etc.

This paper illustrates the state of the art in household location-choice modelling and introduces a first attempt in developing a conceptual framework.

1. INTRODUCTION

The design of an *urban plan* depends on, among other things, expected location-choice decisions of the future plan-population. The problem is that this population is, in most cases, unknown and if known, the possible reaction of this population to the plan is not. Each future resident, from households, over retail companies, to firms, developers, service-providers, etc., chooses locations based on particular preferences and constraints. This makes it very hard for the planner to argument his design decisions. Scholars now claim that location-choice behaviour displays regularities: for example: households changing location mostly stay within the same area (Clark, 2003), households in relatively large units are less mobile than households in smaller dwellings (Dieleman, 2001), rising income increases mobility rates of owner-occupiers, whereas it decreases mobility rates of renters (Van Der Vlist, 2001). These regularities make it possible *to model the location-choice behaviour* of the future plan-population and, in that way, provide the planner with a tool to test design decisions. It is the *ambition* of SwarmCity to develop such a model, simulating the reactions of a population to an urban plan.

Section 2 explores the state of the art in location-choice modelling. Section 3 defines the focus and relevance of the SwarmCity model. Section 4 & 5 introduce the underlying theory and research methodology. Section 6 proposes how to implement such a model and section 7 ends with some concluding remarks.

2. STATE OF THE ART

Location-choice models describe the behaviour of an individual (be it a household, firm, company, etc.) searching for a location to settle. Modelling urban phenomena, like location choice, originated somewhere in the end of the fifties in North America in reaction to the increased use of the car (Batty, 1976). A first type of models, for this reason, mainly focused on transportation: for example: calculating the number of trips between a set of destinations. Later, a second type of models focused on land-use allocation processes (Alonso, 1970): for example: predicting the spatial distribution of programs around a city-centre based on economical factors. Both type of models later integrated into land-use-transportation models. “The main engine of the generic land-use–transportation model has traditionally been the spatial interaction model or variants thereof” (Torrens, 2000). *Spatial interaction models* approach the city as a system of interacting aggregates in a continuous equilibrium condition. This (balanced) system can be represented by a set of mathematical equations: for example: predicting migration- and job-streams between different parts of a city, etc. This type of models is *static*, analysing the structure of an urban system at one moment in time.

In reality, equilibrium conditions do not exist; an urban system needs time to adjust to change, making a city inherently *dynamic* (Batty, 1976). Dynamic urban models therefore no longer approach the city as a collection of interacting aggregates but as interacting individuals. The focus shifts from analysing the structure of the total urban system to simulating the behaviour of single individuals. These individuals are driven by goals and desires and make decisions based on incomplete knowledge. From these micro-interactions, macro level behaviour emerges on the scale of the system (Torrens, 2000). Two modelling techniques were developed to incorporate these dynamics into land-use-transportation systems: Cellular Automata and Multi-Agent Models. "In *cellular automata*, space is represented as a uniform lattice of cells with local states, subject to a uniform set of rules, which drives the behaviour of the system. These rules compute the state of a particular cell as a function of the previous state and the states of the adjacent cells" (Dijkstra, Timmermans, 1999). *Multi-Agent systems* go a step further and link the rules directly to the individual (or cell), no longer to the system as a whole. Each modelled individual now interacts following a personal behaviour. This makes a multi-agent system an enormously powerful tool to model location-choice behaviour and, in turn, explains the boom, during the last 10 years, of agent-based land-use-transportation models: for example: UrbanSim (Waddell, 2002), OBEUS[1] (Aronovich, 2001), SprawlSim (Torrens, 2003), ILUTE[2] (Miller, Salvini, 2003), ILUMASS[3] (Wegener, 2002), etc. For a state-of-the-art overview on land-use-transportation models, see Berger (Berger, Manson and Parker, 2001).

ILUTE, for example, is currently being developed by Miller & Salvini at the University of Toronto. Implemented, ILUTE should work as a tool to analyse "a broad range of transportation, housing and other urban policies" (Miller, 2003). ILUTE is a dynamic model: a series of mathematical equations and decision rules is applied sequentially through iteration. This sequence simulates, among others things, the migration behaviour of households and firms and daily travel behaviour.

Most of these land-use-transportation models are very ambitious in their intentions: combining market interactions, activity scheduling, (non)residential migration, etc. This ambition might explain why these models remain mainly *conceptual*. To date, implemented agent-based location-choice models do not exist. Analysing the conceptual framework of the different models reveals, for the same reason, that only rather crude behaviour is incorporated: for example: individuals will always choose for the alternative that guaranties them maximum profit or utility, given a set of constraints and decision rules. Plus, preferences and behaviour are assumed fixed over time, meaning that modelled individuals do not learn based on experience.

[1] OBEUS is the acronym of "Object-Based Environment for Urban Simulations".

[2] ILUTE is the acronym of "Integrated Land-Use, Transportation, Environment".

[3] ILUMASS is the acronym of "Integrated Land-Use Modeling and Transportation System Simulation".

The intention of SwarmCity should therefore be twofold: on the one hand to develop an implemented dynamic urban model and on the other hand to incorporate a more complex behaviour. This implies, for example, that decisions are no longer solely driven by immediate profit or utility but might anticipate future events, that individuals make decisions based on limited information, that individuals do not necessarily behave totally rational, that decisions depend on how people search for information, etc. Behaviour is not fixed, but can be adjusted by the individual, based on his experience. To allow for this *complexity*, the models driving the behaviour of individuals will not be based on mathematical equations but on heuristic *if-then-else* rules.

3. FOCUS OF SWARMCITY

Swarm refers to the phenomenon that objects, interacting without the intervention of a regulating super-object, nevertheless seem to –unconsciously- generate an ordering logic. *Swarm/City* takes as point of origin that a city can be interpreted as such a self-organizing object emerging out of the interactions of a population of individuals.

The aim of SwarmCity is to model the spatial behaviour of these individuals. The focus lies on defining and implementing a *generic model*, simulating the decision procedures underlying this behaviour. All assumptions are based on existing literature on location-choice behaviour of firms, households, retail, etc. It should nevertheless be possible in future research, to calibrate the generic model for specific cases.

“The urban system is presented as a mechanism for resolving conflict between various groups who require land for their various purposes” (Lowry, 1968 in Batty, 1976). Groups could be households, retailers, firms, service-providers, etc., all searching for the ideal place to live, to open a shop, to start a business, etc.

In the European context, service-providers like schools and hospitals are mostly planned by the government. Households, retailers and firms each follow a particular location-choice logic. For most firms and retail companies, this logic is mainly rational, market-driven, whereas for households this logic is much more *emotional*, reflecting the life-style of the household. This makes that households are more *flexible* and at the same time more *out-of-control*.

SwarmCity chooses to focus on the location-choice behaviour of *households*: where do they typically locate? (How) do they influence each-others choice? What factors do they take into consideration? The behaviour of all other groups, like retailers, firms, developers, etc. is limited to static decision-rules. The structure of the model will allow that their behaviour can be elaborated in future research.

The *input* of the model is an *urban plan*, defining the spatial allocation of housing types, neighbourhood character, density, amount of green, etc. The model then simulates the immigration, emigration and internal mobility of households. This process is known as *residential mobility* (Dieleman, Mulder, 2002). The *output* is a series of development scenarios, tables and graphs at different moments in time.

The *relevance* of the model lies in the possibility to implement changes in the urban plan and/or behaviour of the individuals while instantly being able to observe the reactions of a future plan-population to these changes. The user can in that way experiment with different spatial and behavioural scenarios. This might help the user to evaluate his decisions and/or convince others of these decisions. Spatial scenarios could, for example, be used to evaluate physical planning interventions, alternative legislations, plausible plan-layouts, etc. Whereas behavioural scenarios could, for example, help to test the robustness of the plan, the sensitivity of the population for certain elements of the plan, the appropriateness of concepts like target-groups and life-styles (Nio, 2002), etc. The model will be tested on *Meerhoven*, a new VINEX[4] location west of Eindhoven.

SwarmCity is a component of a planning support system called MASQUE[5]. MASQUE is currently being developed as a tool supporting urban planners to generate *and* evaluate local plans. The intention of MASQUE is to model the negotiation process of the different experts involved in the making of a local plan in order to generate a multitude of alternative plans, approved by these experts. SwarmCity can then be used to evaluate these plans by simulating the reaction of the future population.

4. CONCEPTS & THEORY

As mentioned in the previous section, SwarmCity will, in a first phase, only focus on the location-choice behaviour of households. This behaviour can be summarized as a series of 3 processes: (1) a household decides it is willing to move, (2) searches for available properties and (3) chooses a property. This series can be conceptualised as: *awakening*, *search*, and *choice* (Bettman, 1979 in Goetgeluk, 1997). Each of the 3 processes involves

[4] VINEX is the acronym of "Vierde Nota Ruimtelijke Ordening Extra". This are plans for new urban expansions, approved by the Dutch Government.

[5] MASQUE is the acronym of "Multi-Agent System supporting the Quest for Urban Excellence".

making decisions, choosing strategies and is subject to more or less *regular* behaviour (see figure 1).

(1) AWAKENING

Each household *demands* a number of things from a property: for example: a minimum size, a level of comfort, a particular location, etc. Over time, certain *events* might change these demands: for example: a house might become too small because of an extra child.

As a result the household is no longer satisfied and decides something has to change. It is *woken up*.

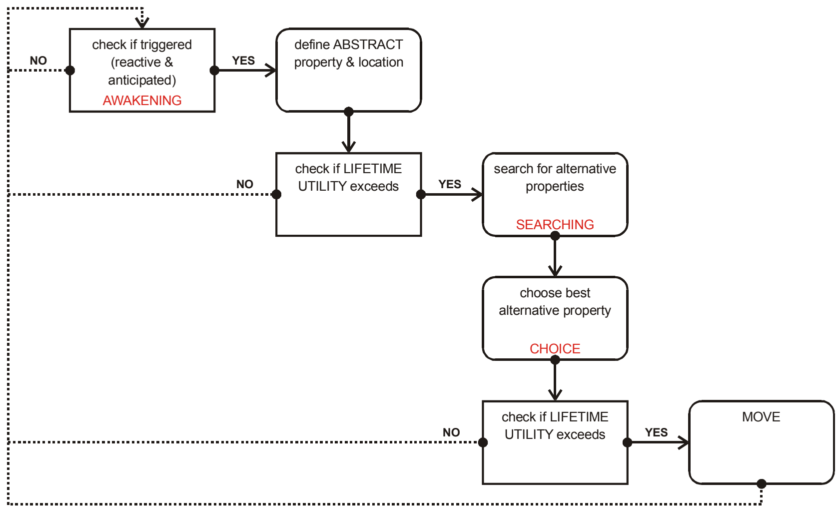

Figure 1: Conceptual framework illustrating awakening, search and choice

Events are not the only awakening-triggers; a household might also start to feel uneasy out of *uncertainty* concerning the appropriateness of his current situation: for example: the household wants to know if there exist properties that better suit its demands. Events might trigger the household to move, whereas uncertainty might trigger the household to look for information.

Once triggered the household has to decide which strategy to follow: will it move to another property, will it extend the current property or will it adjust its requirements? If it decides to move, what will it then move to: a villa with a big garden in a villa quarter or a bigger apartment in the same block?

The answer depends, among other things, on the type of trigger. A first distinction can be made between *actual* versus *anticipated* triggers: a household might wake up because something changed at that moment: for example: one of the household members gets fired, or because it expects something to happen in the future: for example: a child. Secondly, a trigger can be *voluntary* or *involuntary*: for example: because it would like to try something new or because the renting contract ends. Thirdly, a trigger can be a *sudden* event or a *gradual* process: for example: a household might stumble across their dream-house without even having the intention to move, or, the household might decide to move in 5 years out of old-age. Fourthly, a trigger can be related to the current property or to another property. These triggers are known as *push-motives* and *pull-factors*: push-motives push a household out of their current property: for example: a house that becomes too big, whereas pull-factors attract a household to a new property: for example: a cheaper rent. A final distinction is related to *scale*: triggers can be related to the micro, the metropolitan, the national and the international level (Dieleman, 2001): for example: age, tenure, household composition, etc. belong to the micro scale, turnover rate of housing stock, total number of housing, level of urbanization, etc. belong to the metropolitan level, rates of inflation, mortgage interest, etc. belong to the national level and housing policies, variations in wealth, etc. belong to the international level (Dieleman, 2001).

The sensitivity for a certain trigger depends on the profile and preferences of the household. Change in household composition is for example a trigger that makes most young households move from rental to owning (Clark, 2003), whereas a good housing-market might stimulate owners to move to bigger and better located properties (Clark, 2003).

(2) SEARCHING

Searching implies collecting information. A household can be more or less sure of the content of that information. This can be formalized by drawing a probability distribution of all the messages the piece of information could hold. The probability assigned to each message indicates how convinced the household is that this message fits to that piece of information. The more horizontal this distribution, the more uncertain the household is. The *entropy* of this distribution is a measure for this uncertainty. Searching then implies reducing the number of possible outcomes or minimizing the information-entropy. The point where this uncertainty becomes acceptable depends on the particular household.

Searching can be done in different ways. The household, for example, has to decide where to search, how to search, how long it will search, which selection criteria it will take into consideration, etc. Searching costs time and money. The search-radius, -mode, -demands, etc. therefore mostly depend on the *budget* of the household, the *urgency* of the search and the *expected* *information gain*: for example: a household that urgently needs to move will have a different searching behaviour than a household that is just curious about what the market has to offer.

Collected information is stored in a *choice-set*, a list of options meeting the criteria set by the household. The size of this choice-set depends firstly, on the budget and urgency, secondly, on the available information and thirdly, on the capabilities of the household to store information. This last factor is known as *mental effort*. Research, for example, indicates that most households mainly search in their immediate environment and within their current housing market (Clark, 2003) and that households without children have lower demands concerning housing than households with children (Dieleman, 2003).

This can be translated in two types of searching: *querying* versus *exploring*. Querying implies that the searcher has a clear objective, while exploring is used when this objective is not so clear: the more urgent the search, the less explorative. Independent of the objective, a household can search in three ways: (1) through *interaction* with his environment: for example: reading newspapers or driving around, (2) through *communication*: for example: using social networks or consulting estate agents, and (3) through relying on *experience*: for example: a household might only recognize something as an opportunity if it saw it before.

(3) CHOICE

Choice implies evaluating and selecting. The household has to decide upon the type and number of evaluation criteria and the relative importance of these criteria. This might require negotiation and/or group decisions.

What the household does is comparing the utility he expects to derive from each alternative in the choice-set. The alternative with the highest level *wins*. This is not necessarily the best alternative available at that moment in time because the household might have searched in the *wrong* areas or might have misinterpreted important pieces of information. This is known as *limited information condition*: each individual only has access to a limited amount of information.

The final choice depends on the size of the choice-set, the urgency of the choice and the preferences of the household. A household might for example be *risk-aversive* (familiarity seeking) or *risk seeking* (novelty seeking). The result of a choice is a loss or gain in utility or information. A risk-aversive household assigns a bigger weight to expected loss than to expected gain. A risk-seeking household does the opposite.

In reality, search and choice are sometimes part of one and the same process: a household finding a property matching its preferences, might immediately decide to buy this property, because if it waits too long, someone else might buy the property. In this case, there is no choice-phase.

The opposite also occurs: searching without choosing. This might happen when the household is unsatisfied with the search result. It might then decide to *adjust* its demands, preferences and/or search-mode and start searching again. In this case, the household goes more than once through the awakening / search / choice series.

5. METHODOLOGY

In each of the awakening / search / choice processes the household has to make decisions: whether it will move or stay, where and how it will search, which alternative to choose, etc. This requires a standard against which the household can weigh choice-options. This standard is *utility*. In many cases this can be expressed in terms of money (Arentze & Borgers, 2002). A person using an object derives an amount of utility from that object. The more suited this object is to the demands of the user, the higher that amount. Utility thus depends on the preferences of the user. Another implication is that utility can change over time because the demands of the user regarding the object can change over time. The utility derived from using an object thus has to be measured over a period of time, related to a particular user. This is known as *lifetime utility*.

Applied to residential mobility, lifetime utility can be used as a *measurement tool* indicating whether it is better to move or to stay. What the household basically does is continuously comparing the utility derived from staying in his current property with the utility he expects to derive from moving to another property. In SwarmCity, this *other* property is referred to as *abstract property* representing the property the household thinks of moving to if possible/necessary. Abstract refers to the fact that this property only exists in the mind of the household and is thus not a physical property. Besides an abstract property, the household also has an *abstract location* in mind, representing the location where the abstract property should preferably be situated. Depending on the household, the abstract property and location can be more or less detailed: from a Mediterranean villa with two bathrooms and a big garden located in a particular neighbourhood to, just a villa somewhere in the suburbs. The move from current to abstract property can be seen as a step in the *housing career* of the household. “A housing career is the way people change their housing as they progress through the life course” (Abramsson, 2000). Such a step could be upwards: for example: from renting to owning, or downwards: for example: from a house with a garden to a house without a garden. The abstract property can change over time parallel with the household, without necessarily always becoming real.

A household derives utility, on the one hand, from living in the current property, and, on the other hand, from performing activities: for example: going on vacation, meeting friends, doing sports, etc. The *property-utility* depends on the budget of the household, the household composition, the value of the property, the condition of the property and the satisfaction with the neighbourhood. For the current property the utility can be calculated on the basis of direct experience, whereas for the abstract property this is calculated on the basis of the *beliefs* the household has of these factors. The *activity-utility* depends on the budget of the household and on the value of the property. A decreasing budget, for example, has no direct influence on the property-utility but limits the money left for travelling, recreation, shopping, etc. The decrease might be so dramatic that the total utility derived from the current property goes under the utility the household expects to derive from the abstract property. The household then decides it is willing to move and starts searching.

Some of the location-choice decisions are interdependent: for example: the decision to search in a certain area depends on the housing type the household is looking for. These interdependencies can be represented in *decision-analysis trees*. Such a tree consists of nodes and branches; *nodes* call for a decision, whereas *branches* point at the alternatives to choose from. The simplest tree has only one node and two branches, representing a decision with two options: for example: a household having to choose between two properties. The household assigns a utility and a probability value to each of these options. The utility indicates the amount of utility the household expects to derive from that property and the probability value indicates how sure the household is about these expectations. A lower probability results in a lower utility. The option with the highest utility is selected.

In most cases, a decision tree has more than one node. For example, in the case of a household changing location, there are *three nodes* (see figure 2) implying three decisions: first the household has to decide whether to move or to stay. Secondly, if the outcome is to move, it has to search for locations and thirdly, it has to search for properties. The first decision now depends on the second, which in turn depends on the third: a household will only decide to move when the utility he expects to derive from the abstract location and property exceeds the utility derived from the current property. Once this is the case, the household starts searching, building up the decision tree. First, locations are chosen, then properties for each location. Once the searching is over, the household has to choose. He starts by calculating the utility he expects to derive from each property. Then, he selects, for each location, the property with the highest utility. In the next step he has to calculate the utility he expects to derive from each location, each time adding the utility of the selected property. The combination of location and property with the highest total expected utility results in the final choice. A consequence of this interdependency might, for example, be that a household prefers an average villa in a super neighbourhood to a super villa in a bad neighbourhood.

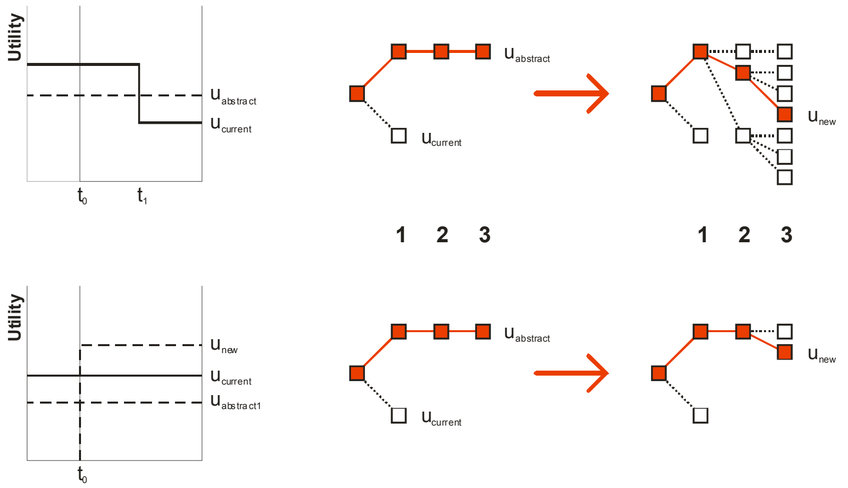

Figure 2: Lifetime utility & decision-analysis trees are used as a tool to visualize scenarios: for example: a household anticipating a change in family composition (top), or a household suddenly stumbling across the ideal property without having the intention to move (bottom). $U_{current}$ represents the utility derived from the current property, $U_{abstract}$ represents the utility the household expects to derive from the abstract property, U_{new} represents the utility derived from the new property, t_0 represents the present and t_1 represents the future.

To conclude, the combination of lifetime utility and decision-analysis trees makes it possible to model both *reactive and anticipating behaviour* and offers a powerful tool to *visualize different scenarios* of awaking, search and choice: for example: a household suddenly stumbling over its dream-property or a household expecting a child (see figure 2). The methodology is generic enough to also apply for location-choice behaviour of retailers, firms, etc.

6. THE MICRO SIMULATION SYSTEM

As mentioned in section 2, the SwarmCity model is a *micro-simulation* of households searching for the ideal place to live. “Micro-simulation models aim at reproducing human behaviour at the individual level, i.e. how individuals choose between options following their perceptions, preferences and habits subject to constraints, such as uncertainty, lack of information and limits in disposable time and money" (Moeckel, 2002).

Multi-agent technology is used as the tool to implement this micro-simulation model. A multi-agent system "consists of a set of agents which together achieve a set of tasks or goals in a largely undetermined environment" (Timmermans, 1999). In SwarmCity, agents represent both persons and objects: for example: households, individuals, properties, neighbourhoods, etc. Each agent has *attributes* representing the characteristic features of this agent: for example: the attributes of a household might be budget, composition, number of children, etc. (see figure 3). The agents representing persons also have *methods*, representing the behaviour of this person: for example: behaviour might be driven by family-motives, profit, etc.

As mentioned in section 4, all these agents demand certain things from their current property. Once these demands no longer hold or are no longer satisfied, they might decide to move. On their search for alternative properties, the agents might interact with other agents. The model consists of three *basic agents*: actors, institutions and an environment. *Actors* can be individuals, households, retailers, firms, service providers and developers. *Institutions* can impose regulations, award subsidies, define average prices and indexes, etc. As mentioned in section 3, the study area considered as a case is Meerhoven, a new VINEX location west of Eindhoven. This study area makes up the *environment* and is represented by 4 *layers*: a zone-, a neighbourhood-, a cell- and a property-layer (see figure 3). The *zones* and *neighbourhoods* are defined by the planner. Each zone has a certain land-use and density. Each neighbourhood has a certain character, building-type, amount of green, etc. Neighbourhoods can vary widely in scale. Therefore, a cell-layer is added. Each *cell* counts 50 by 50 meters and is mainly used to calculate distances.

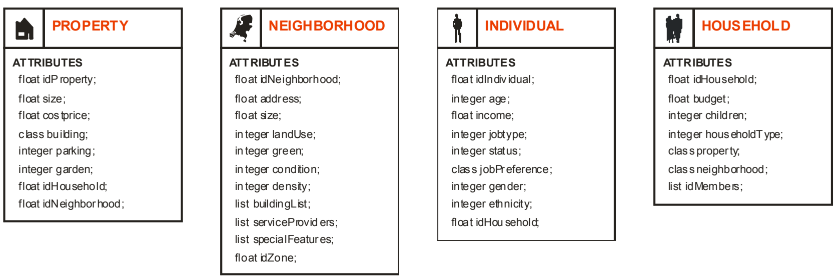

Figure 3. Agent attributes

The properties represent the plots the households can buy. Each *property* has a certain building-type and size. The zone- and neighbourhood-layer are vector-based, whereas the cell layer is grid-based. The property layer is a non-physical layer.

The simulation starts with a planner making an *urban plan*. This plan defines the future neighbourhoods of a given city-part. The finished plan is then inserted as a GIS-file in the SwarmCity model. Now the simulation can start. Each time-step (representing one month), new households enter the plan searching for a property to settle.

Searching starts with selecting neighbourhoods. For each selected neighbourhood, the households then read newspapers and cut out housing-ads that meet their demands. Once a household decides it collected enough information, it contacts the developers selling the selected properties. If the property is not sold yet and if the household decides that the price of the property is acceptable, it will buy the property and put its current property for-sale, if not, it keeps on searching. The price is defined by the developer, based on a general market analysis. Whether or not a household will accept the property depends, among other things, on the budget, the expected utility, the urgency of the move, etc.

From the moment a household buys a property it will each time-step evaluate if that property still meets its demands: for example: the neighbourhood features might change over time because of new developments. If the demands are no longer met, the household will start searching again. What the user sees of this scenario is a change in residential-mobility-density, continuously visualizing the amount of households moving in and out of a cell.

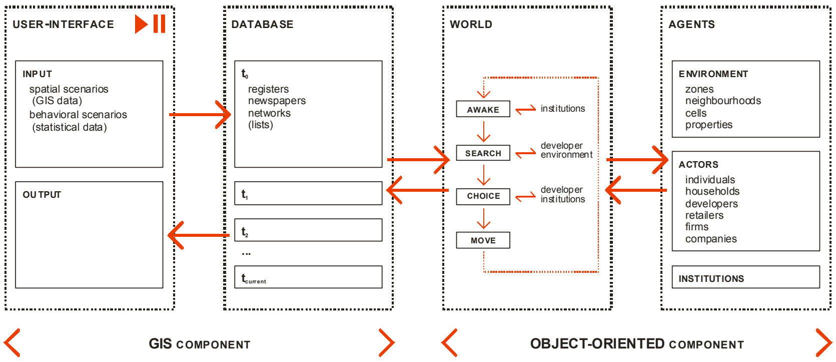

Figure 4. Structure of the implemented model

At this moment, only a limited test-model is implemented. There are, for example, only three actors: individuals, households and developers, and there are no institutions yet. All these actors are randomly generated. In a future version, they will be synthesized through a *Monte Carlo* micro-simulation of a sample of representative households derived from existing surveys and statistical databases like WBO[6], CBS[7], the database of the research group, etc. The test-model is written in the *object-oriented language* C++ Builder with MapObjects as an integrated *GIS-component* (see figure 4).

7. CONCLUSIONS

A review of the current modelling literature learns, firstly, that implemented micro-simulations of location-choice behaviour do not exist yet and, secondly, that the conceptual frameworks underlying existing models only incorporate very simple choice-behaviour. SwarmCity will address both points and can therefore be considered *innovative* for two reasons: firstly, it will be an implemented micro-simulation model and secondly, it will incorporate flexible and dynamic behaviour. The implementation will make use of multi-agent technology. This technology makes it possible to assign a unique behaviour to each household, adjustable over time.

The final model should work as a planning support tool allowing the user to evaluate urban plans. The focus lies on *scenario analysis*, not on prediction. The user will be able to change both spatial and agent settings and can in that way experiment with both *planning- and behaviour-scenarios*. The user could, for example, be a planner trying out different plan-layouts, plan-compositions and/or plan-implementation-strategies; a retailer evaluating if it is suitable to open a new outlet given this type of neighbourhood or checking out what the population composition distribution would be over 10 years; a municipality testing the effect of a new legislation or trying out alternative locations for a particular service; or, a developer trying to get an insight in the willingness of households to adjust their residential-behaviour.

At this moment the model is only partly implemented. *Future development* will, in a first phase, elaborate on the location-choice behaviour of households. In a second phase, the location-choice behaviour of retail will be incorporated. And finally, SwarmCity will be extended with an existing activity-based model AURORA[8] (Joh, 2004), a model simulating the daily

[6] WBO is the acronym of "Woningbehoefte Onderzoek" or "Housing Demand Survey".

[7] CBS is the acronym of "Centraal Bureau voor Statistiek" or "Central Bureau of Statistics".

[8] AURORA is the acronym of "Agent for Utility-driven Rescheduling Of Routinized Activities".

activities of households. This extension might be in the form of a parallel research.

The final model will be *validated*, firstly, by comparing observed model-phenomena with existing *location-choice literature*, secondly, by *simulating historical events* and thirdly, by performing *robustness-tests*. Location-choice literature provides an extensive amount of data on, for example, length of property occupation related to household types, residential movement patterns, choice-behaviour of households, etc. These data will be used to synthesize the model population. Historical events refer, for example, to the developments of VINEX locations. These locations are quite recent and the underlying developments are therefore very well documented. This makes it possible to test if a simulation based on a particular VINEX-plan would evolve parallel with the documented developments. One way to test the robustness is by confronting the model population with 'strange' phenomena and registering if their reactions are 'normal': for example: would households still move to a villa if this villa is surrounded by apartment buildings. With each of these evaluations, the model will grow more valid.

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