A MICROSIMULATION APPROACH TO THE MODELING OF URBAN POPULATION AND HOUSING MARKETS WITHIN AN OBJECT-ORIENTED FRAMEWORK

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ABSTRACT

Object-oriented methods represent some of the most promising ways of meeting the demands of the most advanced applications. That is why, in recent years, a growing number of demographic and urban microsimulation systems are being developed within an object-oriented framework. This paper presents a microsimulation model defined in an extension of the *Unified Modeling Language (UML)* that facilitates the modeling of household and housing markets. The Unified Modeling Language (UML) is extended with spatial and temporal semantics to allow the effective modeling of spatio-temporal software systems. Next, an intra-urban microsimulation model is defined using three UML modeling techniques, that is, *Use case*, *Class* and *Activity* diagrams to capture multiple perspectives of the system under development.

KEY WORD: spatial temporal UML modeling, UML extensions, microsimulation intra-urban models.

1. INTRODUCTION

The structure of a city constantly changes, in accordance to the population's *housing demand* and the city's *housing supply*. Housing demand depends on several factors, such as changes in household structure caused by *demographic events* (e.g. mortality, fertility, marriage/divorce etc), migration (in- or out- migration), *changes in income and employment* of the urban population, and *demand for specific housing services* (e.g. accessibility to employment location, structure type, neighborhood quality). Housing supply, on the other hand, develops on the long-term to satisfy housing demand. Urban housing markets are, thus, constantly adjusting to new demand/supply equilibrium.

Modeling household development and housing market changes may be used in applications such as forecasting housing demand, analyzing the impacts that shock events may have on urban populations, etc. These models result in complex behavioral systems whose development, management and exploitation require the use of *effective development tools*. Moreover, the use of effective *data analysis techniques* and powerful *computer science tools* are required, namely, tools that handle well the needs of complex systems.

Microsimulation was first introduced by Orcutt (1957) and is used for the development of models at the disaggregate level, that is, it aims at the modeling of micro-units such as individuals, households and firms, and the events they encounter. In other words, in a microsimulation model each entity of the modeled application forms a record within a database and the attributes of each entity are updated based on the assumed or observed behavior of the entity.

The field of computer science has defined several methodologies for the development of software systems. Most of them may be categorized as being one of the two kinds: function/data methods and object-oriented methods.

Object-oriented methods represent some of the most promising ways of meeting the demands of the most advanced applications. That is why, in recent years, a growing number of demographic and urban microsimulation systems are being developed within an object-oriented framework. Object-oriented analysis and design methods enable the modeling of a system as a collection of objects from the vocabulary of the problem domain. The *Unified Modeling Language (UML)* is defined by the Object Management Group (OMG), as *the standard object-oriented* modeling language for specifying, constructing, visualizing, and documenting the artifacts of a software-intensive system.

This paper presents a microsimulation model defined in an extension of UML that facilitates the modeling of household and housing markets.

2. UNIFIED MODELING LANGUAGE (UML)

The *Unified Modeling Language (UML)* is the standard object-oriented modeling language adopted by the Object Management Group (OMG) in 1997. It is a language for specifying, constructing, visualizing, and documenting the artifacts of a software-intensive system [2]. UML consists of a set of semantics and notation that addresses a wide variety of domains, life cycle stages and implementation technologies. Additionally, it provides a set of *extension mechanisms* that allows the core concepts of UML to be tailored to the needs of specific applications and domains. Moreover, UML focuses on a standard modeling language, not a standard process. It offers a set of concepts and a set of graphical notations for representing these concepts, which is process independent. As a result, UML may be used in conjunction with the processes defined in Booch, OMT, OOSE and many other methods.

UML defines a set of modeling techniques that provide multiple perspectives of the system under development: *Use case diagrams, Class diagrams, Object diagrams, Sequence diagrams, Collaboration diagrams, Statechart diagrams, Activity diagrams, Component diagrams, Deployment diagrams.* The technique used for the development of a database is the *class diagram. Class diagrams* show the static structure of the system, that is, the existence of *classes*, their *attributes*, *operations*, *relationships* with other classes, and the *constraints* that apply to classes and their properties.

Classes and the relationships among them may be grouped into *packages*. In addition, UML defines *three built-in extension mechanisms* that are common to all diagrams, and apply consistently throughout the language. These mechanisms include *tagged values*, *constraints* and *stereotypes*, and are defined to meet the needs of applications that require additional features and/or notations beyond those defined in UML [2].

3. ST-UML: EXTENDING UML WITH SPATIAL, TEMPORAL AND SPATIO-TEMPORAL CONCEPTS

Spatiotemporal information systems incorporate spatial and temporal concepts; moreover these concepts are combined to produce the spatiotemporal concepts [11], [12], [13], [14], [15], [16], [17], [5]. UML is extended with these concepts and a corresponding notation, using the *tagged value* and *stereotype* extension mechanisms.

Objects (Classes)

- *Spatial object (class)*: the object's position in space, i.e. spatial extent, is of interest (*«spatial obj»* stereotype).
- *Temporal object (class)*: the object associated with one or more timestamps, representing the object's valid and/or transaction time (*«temporal obj»* stereotype).
- *Spatiotemporal object (class)*: an object associated with a spatial extent and one or more timestamps representing the object's valid and/or transaction time (*«spatio-temporal obj»* stereotype).
- *Temporally dependent spatial object (class)*: an object with a spatial extent associated with one or more timestamps, representing the spatial extent's valid and/or transaction time («temporal att» tagged value attached to an attribute that represents the object's <u>position</u>).
- *Temporally dependent spatiotemporal object (class)*: an object associated with one or more timestamps, representing the object's valid and/or transaction time and a spatial extent associated with one or more timestamps, representing the spatial extent's valid and/or transaction time (*«temporal obj»* stereotype attached to the class and «temporal att» tagged value attached to an attribute that represents the object's <u>position</u>).

Attributes

- *Spatial attribute*: the attribute value is a spatial extent.
- *Spatially dependent thematic attribute*: the attribute has a set of thematic values, each associated with a spatial extent representing the location where that attribute value is valid, i.e. the attribute values may change over space and their changed values are retained («spatial att» tagged value).
- *Temporally dependent thematic attribute*: the attribute has a set of thematic values, each associated with one or more timestamps (the value's valid and/or transaction time), i.e. the attribute values may change over time and their changed values are retained («temporal att» tagged value).
- *Temporally dependent spatial attribute*: a spatial attribute whose value is associated with one or more timestamps representing the spatial extent's valid and/or transaction time («temporal att» tagged value attached to a spatial attribute).
- *Spatiotemporally dependent thematic attribute*: a spatially dependent thematic attribute that has a set of thematic values, each associated with a spatial extent and one or more timestamps («spatio-temporal att» tagged value).

Associations

- *Spatially dependent association*: each link of the association is associated with a spatial extent representing the location where the link is valid, i.e. the link may change over space and its changes are retained («spatial asc» stereotype).
- *Temporally dependent association*: the association has a set of links, each associated with one or more timestamps (the value's valid and/or transaction time), i.e. the links may change over time and their changes are retained («temporal asc» stereotype).
- *Spatiotemporally dependent association*: the association has a set of links, each associated with a spatial extent and one or more timestamps («spatio-temporal asc» stereotype).

4. INTRA-URBAN MICROSIMULATION MODEL

The microsimulation model presented in this paper is defined using three UML modelling techniques: *Use case*, *Class* and *Activity* diagrams to capture multiple perspectives of the system under development.

4.1. Use case diagrams

Use case diagrams show the behavior of the system under development without specifying its internal structure. It uses actors that are the roles played by users with respect to the system, and use cases where each one represents part of the system behavior that is performed during the interaction of an actor with the system

The *Housing Market System* may be decomposed into three *Packages* (components): *Housing Demand*, *Housing Supply*, and *Residential Search and Migration* that are quite independent from each other (Figure 1). There is a strong connectivity among the elements of a single package, and a weak connectivity between the packages. In other words, *housing demand* <u>determines</u> the number of households that search for a new house and *housing supply* <u>determines</u> the number of households that find a new dwelling (*Residential Search and Migration* package). On the other hand, the outcome of the *Residential Search and Migration* package <u>affects</u> the way housing demand and supply are modified.
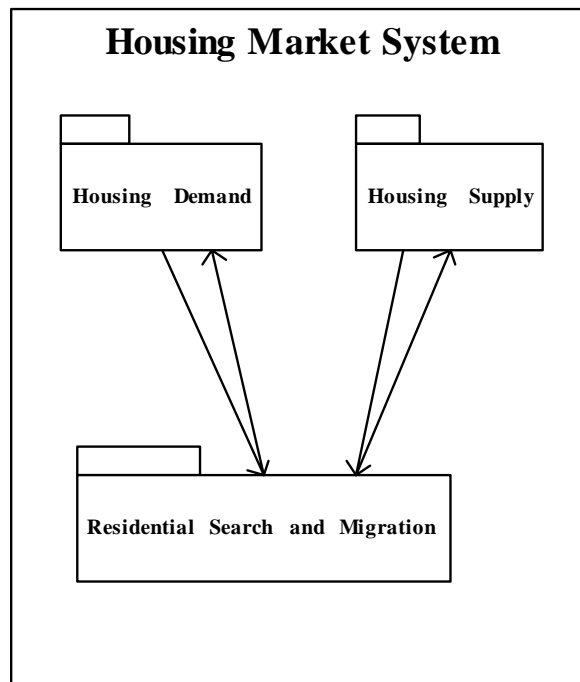
Figure 1

Housing demand depends on several factors, such as changes in household structure caused by *demographic events* (e.g. mortality, fertility, marriage/divorce etc), *migration* (in- or out- migration), changes in *income and employment* of the urban population, and changes in *demand for specific housing services* (e.g. accessibility to employment location, structure type, neighborhood quality). As individuals and households pass through different life stages (fertility, marital, occupational, educational, household), their *housing preferences change*, triggering mobility [10]. For example, a change of job (occupational life stage) could lead to an increase in income, which makes an upward move in the housing market possible. If the new job is not within acceptable commuting distance, it could also imply that a move must be made. Figure 2 shows the *use case diagram* corresponding to the *Housing Demand* package. It contains the following elements:

- Two actors: *Individual* and *Household*.
- Three use cases: *Demographic change* (the demographic changes and the development of the population are determined), *Income change* (an individual of age 18 and above has its income changed due to its occupation) and *Demand change* (a household that has not experienced a demographic or income change event is subjected to the probability of searching for a new dwelling).
- The *Demographic change* use case is extended by nine use cases: *Death* (an individual is subjected to a probability of dying based on his/her age and sex), *Fertility* (a woman aged 15 to 45 is subjected to a probability of giving birth), *Union Dissolution* (a household having two heads is subjected to a probability of splitting), *Union Formation* (an individual finds a partner and decides to live in with her/him), *In-migration* (it is determined what kind of individuals/households are entering the housing market), *Flat Mate Formation* (an individual that lives on its own or flat-mates is subjected to the probability of flat-mating), *Flat Mate leave* (an individual who flat-mates is subjected to the probability of moving out), *Nest Leaving* (individual of age 18 and above, who still lives with his/her parents is subjected to a probability of moving out) and *Out-migration* (an individual/ household decides to migrate out of the housing market).
- The *Income change* use case is extended by three use cases: *Job change* (an individual, who already works, is subjected to a probability of searching for a job), *Job entry* (an individual of age 18 who is not a soldier/university student, or an individual who does not work (immigrant or currently unemployed worker)) and *Education* (an individual of age 15 and above has his/her education career determined).
- Both the *Job change* and *Job entry* use cases include the process of job search, so this functionality is factored out as a «uses» use case called *Job search* (an individual is simulated to search for a job).
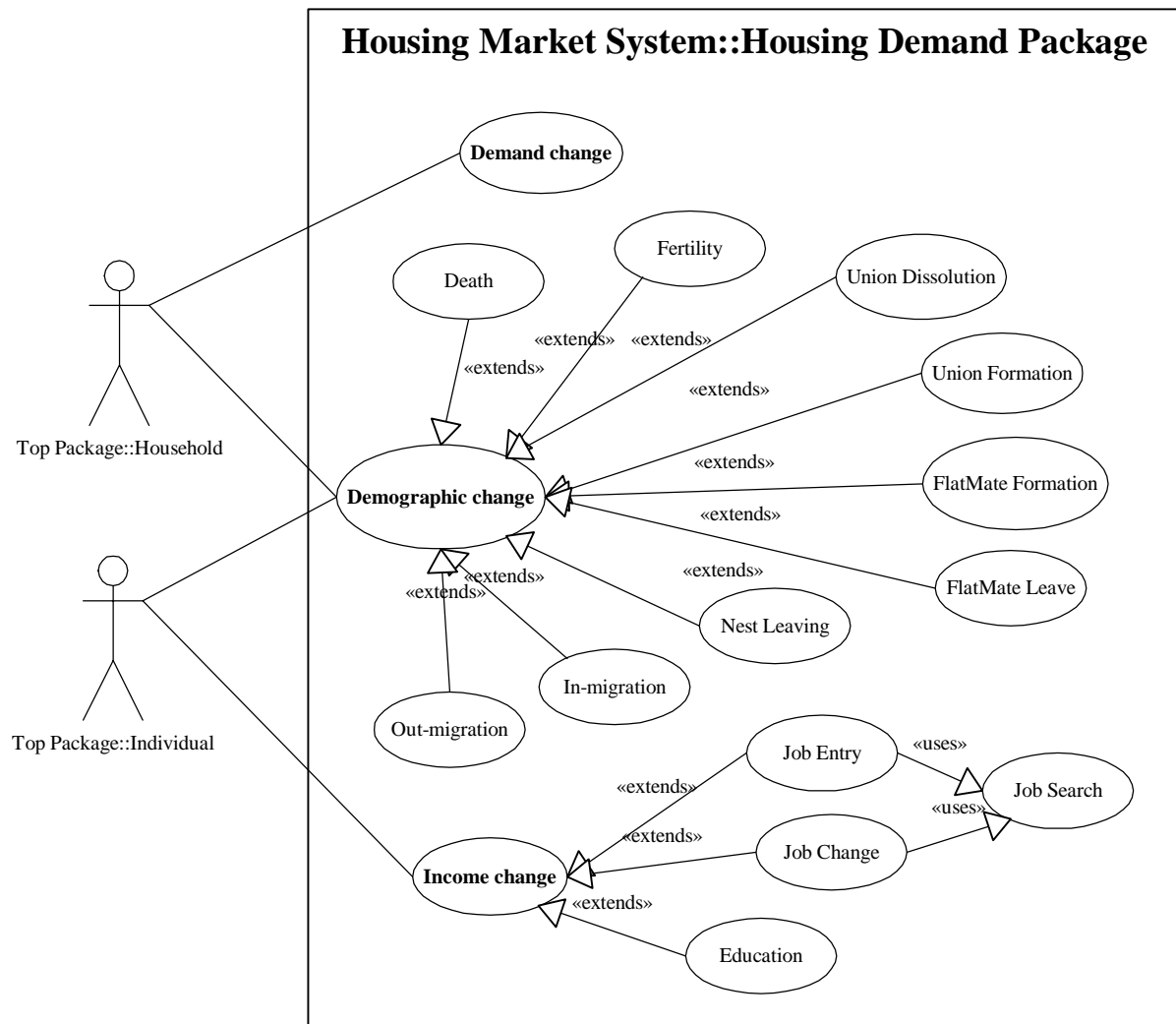
Figure 2

Housing supply, on the other hand, develops on the long-term to satisfy housing demand. Changes on housing supply arise from the construction of *new dwellings*, the *demolition* and *conversion* of existing dwellings (e.g. splitting, combining and renovation) and the *changes in the housing expenditures* of dwellings. Figure 3 shows the *use case diagram* corresponding to the *Housing Supply* package. It contains the following elements:

- An actor: *Dwelling*.
- Four use cases: *New construction* (the number of new dwellings to be added to the housing supply set is determined based on the market's mobility and housing shortage), *Structure conversion* (The structure of a dwelling is converted according to some possible way), *Demolition (*a dwelling in poor condition is subjected to the probability of being demolished and *Housing expenditures change* (The housing expenditures (maintenance capital, heat, electricity etc) of the dwelling is determined based on the dwelling's type, size, age and construction quality).
- The *Structure conversion* use case is extended by three use cases: *Renovation (*A dwelling in medium or poor condition is subjected to the probability of being renovated)*, Split* (a vacant, large dwelling is subjected to the probability of splitting to two or more smaller dwellings) and *Combination* (two or more vacant, small and neighboring dwellings are subjected to the probability of being combined to a larger dwelling)*.
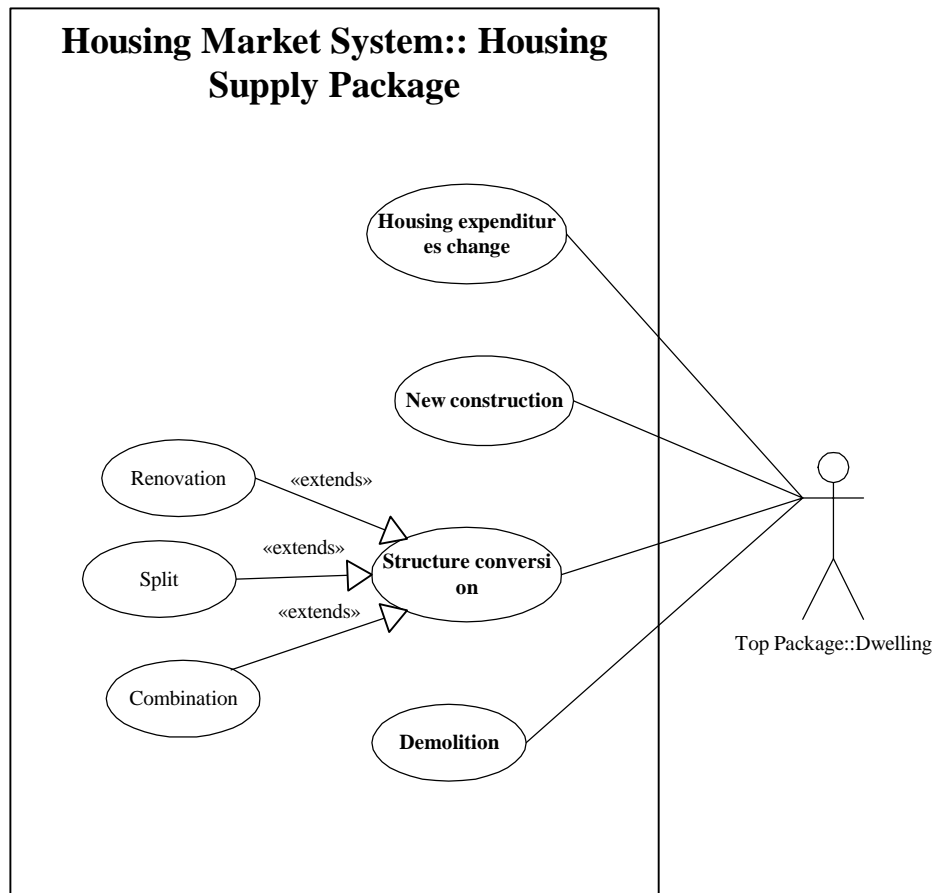
Figure 3

Households that are dissatisfied with their current housing, *search* the *housing market* for a vacant dwelling that meets their needs. If a household finds a dwelling that complies with its preferences, then the household *moves* into the new dwelling. If household search fails, then the household either *remains* to its current dwelling or migrates to another housing market (*out-migration*). Housing demand and supply determine the rent and market value of the dwellings (*housing prices*). Figure 4 shows the *use case diagram* corresponding to the *Residential Search and Migration* package. It contains the following elements:

- Two actors: *Household* and *Dwelling*.
- Two use cases: *Housing prices (*the rent and market value of the dwellings are updated based on housing demand and supply) and *Residential Search and Migration* (a household that intends to move to another dwelling, searches the list of vacant dwellings).
- The *Residential Search and Migration* use case is extended by three use cases: the *Tenure* (the household decides whether to search for a house to own or rent) and *Dwelling Search* use cases and the *Out-migration* Housing Demand Package use case.

5

**Housing Market System:: Residential Search
and Migration Package**

Housing
Prices

Residential
Search
and Migration

«extends
»

«extends
»

Dwelling
Search

Housing Demand::Out-
migration
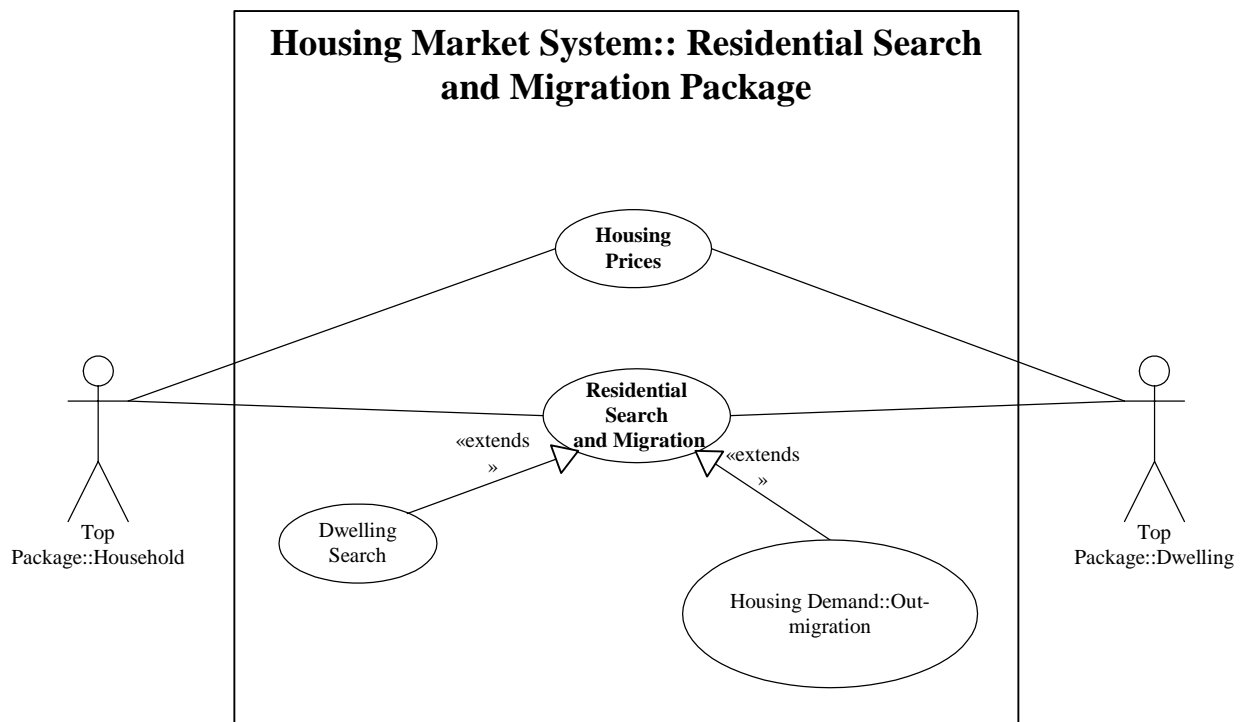
Top
Package::Household

Top
Package::Dwelling

Figure 4

4.2. Class Diagram

The population of a city consists of *households*. A household has one or more members. Each household member is an *individual* with a specific position in the household (couple member, child or single). An individual may have an *occupation* (and therefore, a salary) or not. The occupation belongs to a *residence zone*. A household lives at a *dwelling* that owns or rents. In addition, a household may own one or more dwellings. A dwelling may have one or more ancestors (the dwelling is the outcome of a split or combination) or one or more descendants (the dwelling takes part in a combination or split process). A dwelling belongs to a *building*, which in turn belongs to a *building block*, which in turn, belongs to a *residence zone*. The residence zone has one or more neighbors.

An *individual* has the following characteristics:

- Personal characteristics
  - *Sex.*
  - *Date of birth.*
  - *Marital status* (never married, married, divorced etc).
  - *Date of in-migration*
  - *Date of out-migration*
  - *Date of death*[1].
- Occupational characteristics
  - The *education* group to which the individual belongs (none, primary or less, lower secondary, upper secondary, post secondary, tertiary).
  - The *employment* status of the individual (employee, employer, self-employed, family worker, unemployed, student, engaged in family duties, engaged in the army service, retired, other inactive).
  - The *search intensity* with which the individual searches for a new job (none, low, high).
  - The *income* of the individual which is calculated as the sum of the individual' *occupational income*, that is:
    - *Salary* if the individual is a worker
    - *Unemployment allowance* if the individual is unemployed
    - *Pension* if the individual is retired
    and the individual's *non-occupational income* (e.g. rent of a house owned by the individual etc).

An *occupation* has the following characteristics:

- *Occupation branch* (professional, technician and associate professional, clerk, service worker and shop and market sales worker, etc)
- The *industry branch,* that is, the branch of economic activity to which the occupation belongs (construction, wholesale and retail trade, hotels and restaurants, public administration and defence, education, etc).

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[1] Individuals who die are not deleted from the database in order to store the past of the housing market system.

- *Working time* (full-time, part-time)

A *household* has the following characteristics:

- The *household size* that is, the number of individuals that constitute the household.
- The *event* that the household currently experiences.
- The *search intensity* with which the individual searches for a new house (none, low, medium, high).
- The household's *income*, which is calculated as the sum of the household members' income.

A *dwelling* has the following characteristics:

- *Dwelling Size.*
- *Number of rooms* (1, 2, 3, 4, 5, more).
- The dwelling's *structure quality* (quality of interior and exterior finishing, the architectural distinction of the unit, and the unit's spaciousness or average room size).
- *Renovation year.*
- *Renovation type* of the dwelling if any (room add/change, structure renovation, building renovation)
- *Market value* of the dwelling.
- *Rent value* of the dwelling.
- *Housing expenditures* of the dwelling.
- *Available*, that is an indicator to denote whether the dwelling is available to searching households or not.

A *building* has the following characteristics:

- *Building type* (single-family, small multi-family or large multi-family).
- The *size of the lot* to which the building belongs.
- *Number of floors*
- *Number of dwellings*
- *Parking,* that is, an indicator to denote whether the building offers parking place or not.
- *Garden*, that is, an indicator to denote whether the building has a garden or not.
- The *construction year* of the building (age of the building).
- *Demolition year[2]*.

A *building block* has the following characteristics:

- The level of *shopping access* of the neighborhood.
- The level of *school access* of the neighborhood.
- The level of *transportation access* of the neighborhood.

A *residence zone* has the following characteristics:

- *Zone name.*
- *Zone type.*
- *Zone quality.*
- *Population type.*

Figure 5 shows the *Class diagram* corresponding to the Housing Market System. This diagram shows the database structure of the system (static structure of the system), that is, the *classes*, their *attributes*, *operations*, and *relationships* with other classes that will be implemented and maintained in the database of the Housing Market System to be developed.

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[2] Demolished dwellings are not deleted from the database in order to store the past of the housing market system.
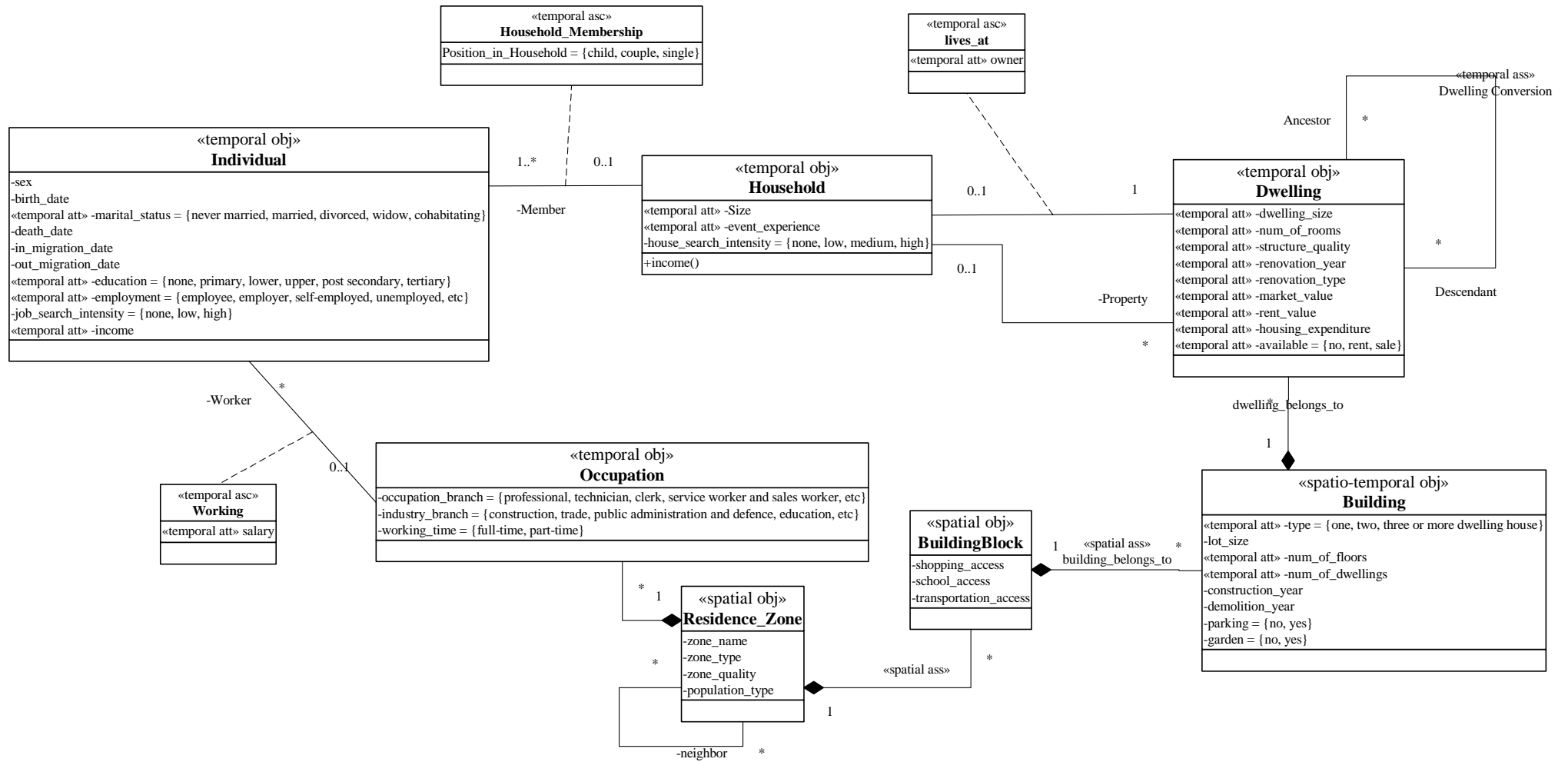
Figure 5

4.3. Activity Diagram

Figure 6 shows the *Activity Diagram* corresponding to the Housing Market System under development. This diagram shows the *workflow* of the Housing Market System to be developed, that is, the steps the system goes through, in order to execute the system processes and explores how various processes interact in the system.
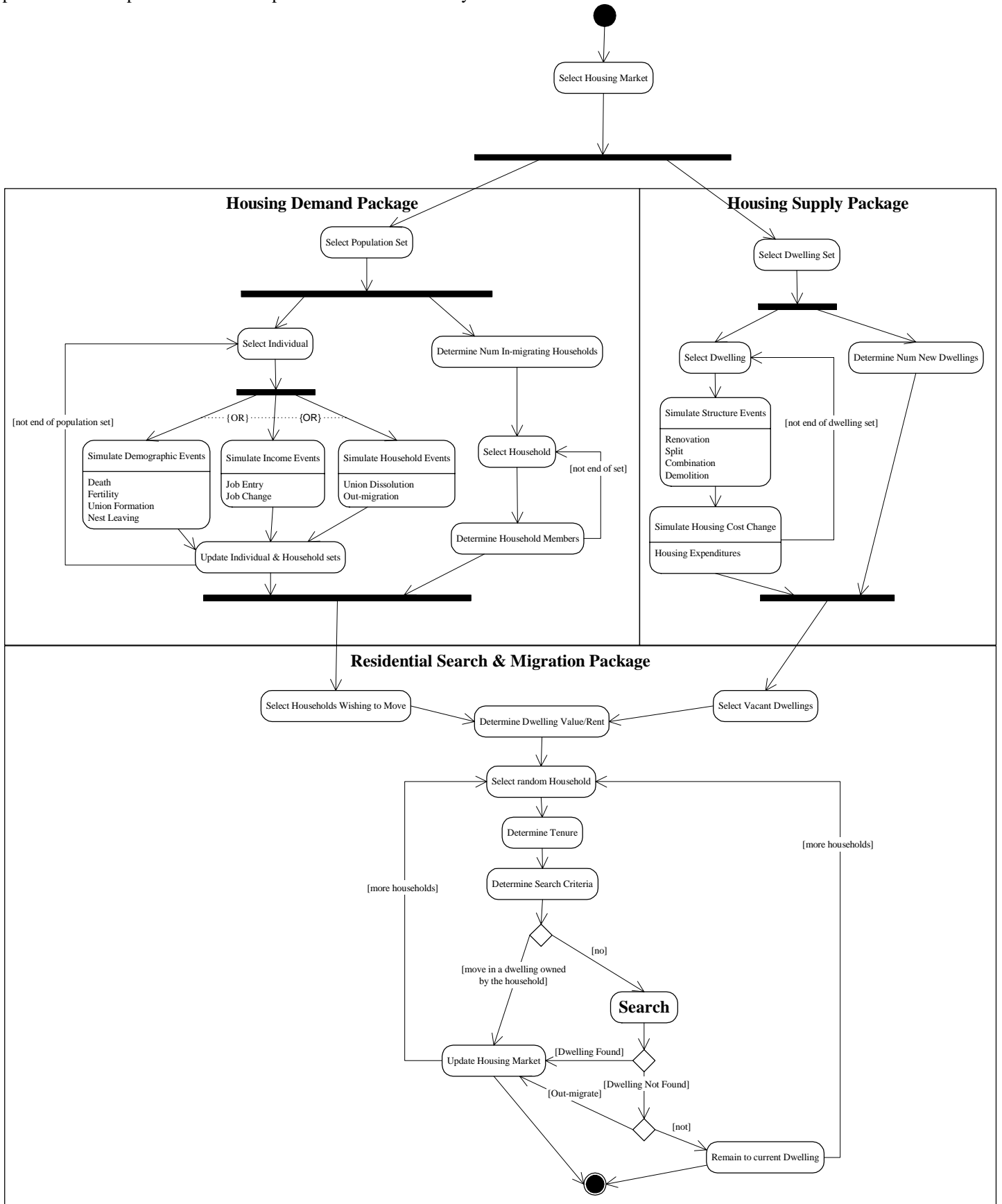

Figure 6

5. CONCLUSIONS AND FUTURE WORK

Object-oriented methods represent some of the most promising ways of meeting the demands of the most advanced applications. That is why, in recent years, a growing number of demographic and urban microsimulation systems are being developed within an object-oriented framework. This paper presents a microsimulation model defined in an extension of the *Unified Modeling Language (UML)* that facilitates the modeling of household and housing markets. The Unified Modeling Language (UML) is extended with spatial and temporal semantics to allow the effective modeling of spatio-temporal software systems. An intra-urban microsimulation model is defined using three UML modelling techniques: *Use case*, *Class* and *Activity* diagrams capture multiple perspectives of the system under development.

The next step of this work would be the implementation of the microsimulation model for the town of Mytilene, Lesvos, Greece, using a GIS system as the implementation platform.

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