A Unified Framework of Urban Built-Space Evolution

Agents and Processes

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Abstract

In the modern age, human activities are predominantly concentrated within the urban built-spaces. Location of these activity-centres, especially home and work, strongly influences the short-term individual-level decisions (such as mode of transportation), and long-term household- and firm-level decisions (such as change in job and location). Thus, the spatio-temporal distribution of urban built-space plays a key role in shaping up the urban transportation system and patterns of travel, energy-usage, and greens-house-gas emissions, dispersions, and exposure. Similarly, the built-space is influenced by the changes in the transportation and other urban systems. Evolution of urban built-space itself, is a complex process that involves various agents (landowner, land developer, builder, subcontractor, household, firm, etc.) and their decision and interactions in a chain of various related markets (land market, housing market, commercial space market etc.). Decisions of these agents are influenced by the conditions in various markets and the decisions made by other agents. This paper presents an ongoing research effort to develop a dynamic agent-based framework that explicitly models the individual markets; the chain of land and built-space markets; agents' behaviour in various markets; and the bidirectional interactions that are going on among the markets within the chain. The supply-demand interactions in the markets are explicitly modeled. Agents' decision-making is modeled using random utility theory, where agents try to maximize their utility/profit. Individual market clearing processes are developed that beside agent interactions, accessibility, and regional economic conditions, also take into account the signals coming from other markets in the chain. The resulting framework is a realistic and more detailed representation of the evolution of urban built-space. Moreover, it also provides the opportunity to develop a truly integrated microsimulation framework of urban systems.

1. Introduction

To fulfill various recurring as well as non-recurring needs, human beings engage in a combination of different kind of activities (e.g. working on a job, to have a steady income, as a resource; eat dinner with friends to socialize; or look for a partner to spend life with). Timmermans (2003) pointed out that the diversity in labour in the modern society and the spatial features, encourage the uneven distribution of the activity locations over urban space. This results in the activity patterns that are spread across the spatio-temporal fiber of any urban area. Human beings thus require travelling between the activity locations as a mean to ensure the execution of episodes of activities that facilitates the fulfillment of their needs. *Travel is not the purpose, but one of an important facilitator of the goals humans want to achieve.*

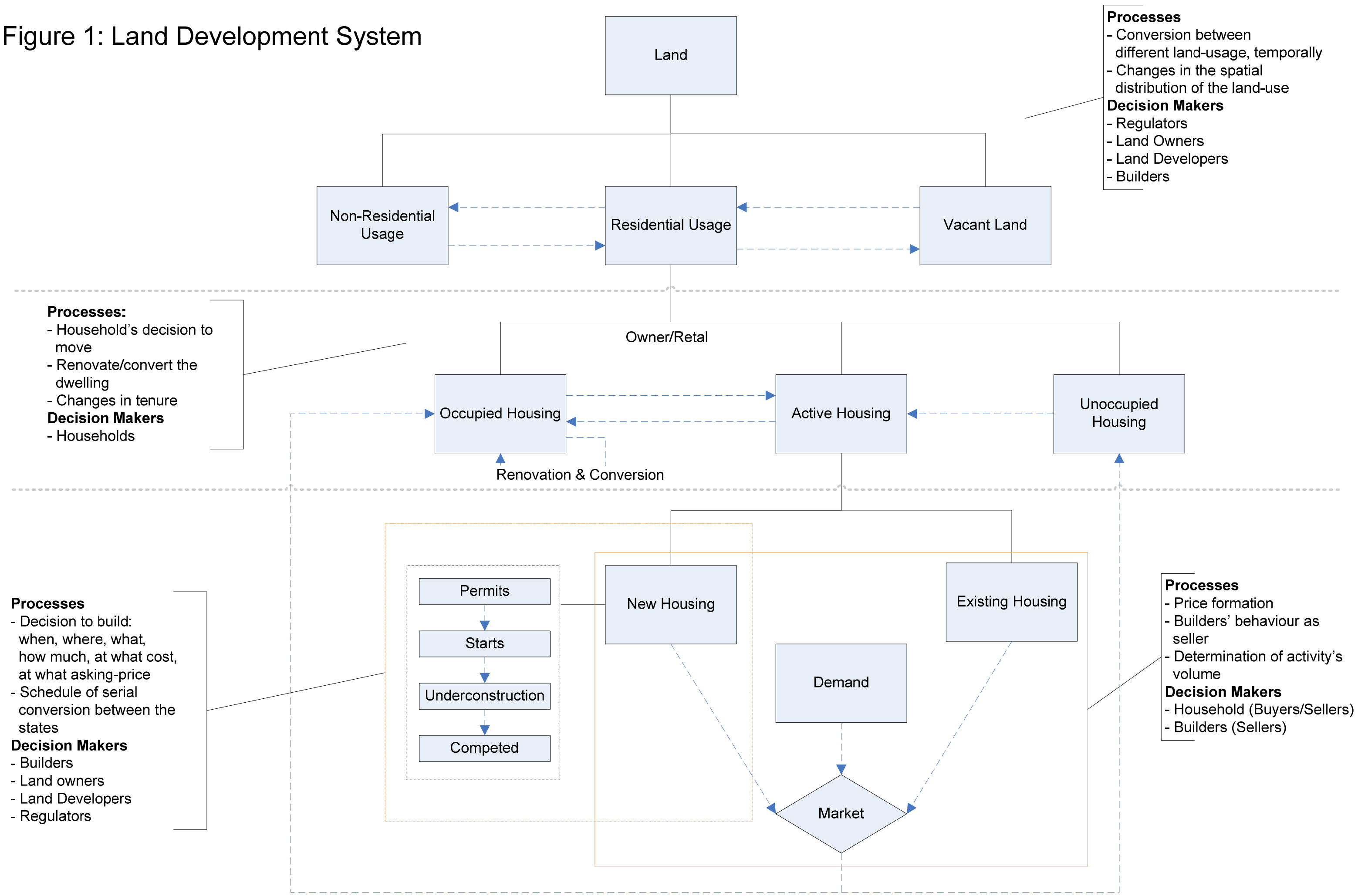
Urban built-space represents various types of spaces in an urban area that have a physical structure and associated monetary value; and can be identified as individual quasi-unique units (based on their attributes and location) (Farooq, 2010). Built-space provides opportunities and the physical infrastructure necessary for the centres of activities (e.g. office space provides the physical space, IT/communication infrastructure, energy, etc needed for a law firm to run the business, or dwelling serves a space to household to live and perform various family related activities). Accessibility characteristics, between built-spaces, play a key role in influencing the decision makers' (e.g. working person, households, firms) short- (e.g. whether to take the car to work or use public transit), medium- (e.g. buy a new car or not), and long-term (e.g. change housing location or not) decisions. In the same context, the spatio-temporal distribution of new built-spaces is influenced by the characteristics of accessibility provided by transportation. Various previous studies point out at the two-way interaction and influence that exists between urban built-space and transportation (Timmermans, 2003; Hunt et al., 2005; Miller, 2006 etc.). As a transportation researcher, we are interested in the coevolution of urban built-space and the transportation infrastructure system as a complex integrated urban engineering system.

The rest of the paper is organized as following: first we present the conceptual framework and describes its various features, we then discuss a case study in which the proposed framework is intended to be applied. We conclude the paper by discussing our conclusions and various dimensions in which this work can move forward.

2. Framework of Urban Built-Space Evolution

At the core of urban built-space evolution, land remains as the primary resource that is regulated, processed, transformed, and traded continuously by various agents, so as to fulfill their goals (e.g. government trying to attracts more skilled labour, developers and builders trying to gain profit, while households trying to gain utility in various forms). In case of greenfield development, government, due to various social, political, and economic reasons, may decide on extending the urban boundaries and developing more built-space there. In the outer limits of urban areas, the landowners sell their land to the land developers. Developers, in anticipation, may buy cheap agricultural or developable land surrounding the city, many years ahead of the official extension of the boundaries and keep it until the local municipality designates it for the development. Based on the newly legislated zoning bylaws for the area, land developers then help shape the final zoning of the land and develop it into parcels, where the built-space can be built. These parcels are introduced to the market, where builders may buy them. Builders, based on general zoning guidelines and the expected demand, build different categories of built-space on these parcels. Builders then introduce these built-spaces to the market where firms and households are looking to lease or buy different-types of built-spaces. In case of brownfield development, existing built-space(s) may be demolished; parcels merged or split; and result in redevelopment of new built space(s). Here too, the government may be involved in the zoning bylaw changes. The resulting new space is then introduced to the market. Another source of built-space supply is the vacant space left by firms and households that moved out. This process remains very common in the modern day cities, but may deviate a bit, based on continent, country, culture, and socio-political scene. Figure 1 shows the involved sequence and interactions, processes, sub process, stages, and agents.

Figure 1: Land Development System



The most important to conclude at this point is that the complete evolution of urban built-space involves goods in three different states: two intermediate states (undeveloped land, and developed parcels) and one finished state (different types of built-space, including: office-space, housing, industrial-space, etc.). These goods are traded in various markets: undeveloped-land, developed-land parcel, and built space markets. Moreover, there are various agents that can influence the urban built-space evolution, including: government, land-developers, builders, subcontractors, firms, and households. Note that these agents may be supplied in one market, but the demander in another market. There decisions thus ripple through the markets, both horizontally and vertically in the types and chain of markets. The development process of new built-space, itself has many stages. The building project has various identifiable stages (Somerville, 2001) (figure 2). In the first stage, a builder applies for a permit to construct a certain quantity of built space, seeks any required zoning changes, and acquires financial backing. Once approved, the builder may start the construction of the entire or some quantity of the built space it is permitted to build. The time to start the construction may vary, depending on market and regional economic conditions, but the latest time to start is dictated by the terms and conditions of the loans. The completion time of the projects may also vary depending on these conditions. The introduction of space within the market may vary both in terms of time and quantity. Moreover, the whole project construction process may vary for different categories of built space.

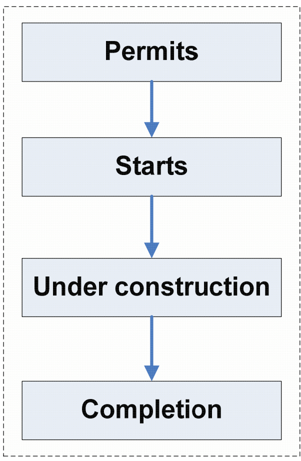


Figure 2
Various Stages of Construction

Despite the great importance in terms of policy evaluation and analysis, in the exiting integrated urban systems, most of the time, supply process of new built-space is overly simplified with effectively no behavioural representation. In UrbabSim, the built-space development is modelled as a discrete choice decision in which the landowner of a site (parcel/grid cell) decides on changing the state of site. This decision is modelled using a multinomial logit model. Landowners are faced with twenty-four choices that are a combination of built space type (residential, mixed use, commercial, industrial, government, vacant, developable, and undevelopable) and associated range of development intensity, in term of number of units or floor space (Waddell and Ulfarsson, 2003, 2004). In the simulation, these probabilities are used in combination with random draws to update the yearly built space stock. The simplicity of this approach makes it easier to operationalize in the urban simulation context, but at the same time, makes it very limited in terms of its ability to capture the underlying behaviour and structure of built-space evolution. Other similar examples in the literature are PECAS (Hunt and Abraham, 2003) and ILUTE (Miller *et al.*, 2010).

Martinez and Roy (2004) within the market-equilibrium based framework attempted to model the supply process for residential built-space, as a three-step production process. The three steps involved interactions between landowners, developers, and builders, thus dealing with the production of land, developed land, and residential space at each stage of the market, respectively. Using the demand- and supply-functions for all three types of agents, a clearing of market is formulated as an optimization problem in entropy maximization setup. Their modelling approach is a better representation of the various steps involved, finished products, and agents involved (only at aggregate level) in the built-space supply. But the strong equilibrium assumption fails to capture the complex interactions occurring among the various agents within these markets. Also this approach was limited to supply of new residential space only, thus ignoring the horizontal interaction/competition going on between the markets of different types of built-space, including: office-space, industrial-space, commercial-space, etc.

The aim here is to develop a flexible microsimulation framework of urban built space evolution, which: a) models the behaviour of different types of agents on individually b) do not impose any stiff market level equilibrium assumptions c) explicitly models the various stages of markets and the horizontal and vertical interactions that are going on among different types of markets at different stages.

2.1. Agents and their Characteristics

There are various important agents whose interactions with other agents and individual decisions, directly or indirectly, influence the evolution of urban built-space. These agents may be involved at only certain stage(s) of the evolution and may play a different role in different stage of the evolution. As an analyst we are interested in understanding the behavior of these agents so as to incorporate it in our models and simulation for a more realistic, disaggregate, and enrich policy scenario analysis. Here we discuss the more important agents, their characteristics, and possible roles during the built-space evolution.

2.1.1. Landowner

In the context of greenfield development, the role of landowner may be important in determining the overall value of the finished built-space and type/quantity of the space within the zoning bylaws. The transaction of land in case of greenfield development is in bulk or very large sized blocks—as the land's existing use is agricultural. In most of the cases, land developers buy huge blocks of land in the outskirts of the existing urban boundaries, many years in advance, and own them in the anticipation that the area will be urbanized in the future. The role of landowner is this substituted by land developer at the time of greenfield development.

Incase of brownfield development, either an existing infrastructure(s) is/are demolished or an unused parcel(s) of land within the urban boundaries is/are used for redevelopment. In that case, the role of landowner is more prominent in determining the value and type of the finished space, as the specific location of the land may have influence and also the transaction of land is not in bulk as is the case in the greenfield development.

The major decision that a landowner is faced with is to determine the transaction price at which the land should be sold. This decision may be affected by: the market conditions, characteristics of the landowner, location and neighbourhood characteristics, and knowledge of the landowner about the market. Landowner is assumed to be profit maximize in the context of transaction price decision.

2.1.2. Regulators

The elected governmental body of the municipality, city, or region usually regulates the general use of the land in an urban area by developing master plan and periodically introducing zoning bylaws. The aim of the regulator behind these regulations may include: increasing the general welfare of the urban dwellers, encourage more economic activities in the region, political gains, etc. In most of the cases, we are not interested in modelling the behaviour of the regulators, as they are the one who makes the policies and use the modelling and simulation tools developed by the analysts to take well-informed decisions.

2.1.3. Land-Developer

In case of greenfield development, the land-developers according to the zoning bylaws, convert the land into developable parcels, build necessary infrastructure (e.g. systems like drainage, sewage, water, etc.) and introduce it in the developed-land market for sale. The goal of land-developer is to maximize profit from the sale of developed parcels by minimizing the cost related to buying the land and developing it and maximizing the revenue that is generated by the sale of the developed parcels to the builders. In case of brownfield development the role of land-developer may be limited to demolishing the existing buildings, clearing up the land, and merging or splitting the developed parcels.

Farooq (2010) reports that usually there are very few developers operating in an urban area, making it more like an oligopoly. They work with a small group of builders in long-term partnerships. In some case, the developers may also play the role of a builder. It can thus be expected that at least in the case of greenfield development, the developed-land parcel market has very less dynamics going on and is more like a market of well-cooperative agents.

2.1.4. Builders

While the regulations vaguely define the purpose of developed parcels and general mix of different types of built-space in the zones, it is the decisions of builders that determine at certain time, the type, quantity, and quality of the built-space that is built at a certain location (Farooq, 2010). Builders try to maximize their expected profit by forecasting the expected revenue and cost for a building project. A building project may have following stages (see figure 2): To start a project, builder first asks for a permit from the regulators.

In case of brownfield development, this may require a request for change in zoning bylaw changes (for instance, if a residential building is demolished and a commercial building is to be built). In the permit application the builder specify the schedule and exact type, quality, and other characteristics of the built-space to be built. Once the permit is issued, builder has to start the construction process within certain imposed time lag. The construction of the project may start in phases. This is especially very common in the case of residential projects in the suburbs. For instance, the builder may ask for a permit to build 100 new detached-dwellings in next 2 years. It may build these dwellings in a bundle of 25 houses each 6 months. The time of construction may vary with the type of built-space and current market conditions as well. If the market it performing very good, then the builder may speedup the building process or slow it down in the case of slower market trends. In terms of finances for the project, the builder arrange for the capital by pre-booking of the space by the demanders (households and firms) and through bank loans.

Builders are usually localized in terms of their operations (Buzzelli and Harris, 2003). Moreover, builders and their associated contractors/sub-contractors typically specialize in building specific types of space. The builder that builds detached dwellings is more likely to build semi-detached and attached dwellings than high rise apartments. The location case is similar: A zone (business node) that primarily has Type-A office space will unlikely to get built an inferior, Type-C office space. Farooq (2010) reported that in 2005 there were about 500 builders in the Greater Toronto Area. The sales volume of 13% of the builders was less than 1 million dollars, 70% of the builders had sales between 1 and 10 million, and 17% of them had sales more than 10 million dollars. The building industry, thus is dominated numerically by small- to medium-sized builders, but at the same time there is a significant presence of heavy-weight players in the industry. Buzzelli and Harris (2003) similarly report that the building industry in Ontario has a high number of small- to medium-sized builders. The total volume of the sales by the building industry in 2006 was approximately 5 billion dollars, with small to medium builders contributing 800 million dollars of this total. The large-sized builders contributed 4.2 billion dollars, which is more than five times of what was contributed by the small- and medium-sized (83% numerically) builders. This shows that the large-sized builders play a dominating role in the building industry. Another interesting fact about the building industry is that the number of employees for about 95% of the builders is less than 25. This is because builders do not perform the construction job in-house. Instead, they heavily rely on contractors and sub-contractors to actually do the job for them and their employees are usually only managing the project. Buzzelli and Harris (2003) reported that this relation between the builders and contractors is spatially localized and long-term.

2.1.5. Sub-Contractors

Sub-contractors play an important, but not very well understood role in the evolution of urban built-space. As stated above, the builders heavily rely on the sub-contractors who are specialized in specific aspect of construction (electric work, welding, etc.) for the completion of the project. In fact, builders seem to only conduct the project management activities and the employed sub-contractors do the actual construction work. The sub-contractors are profit maximizes and their decisions on bidding for a particular work in the project will depend upon availability of specialized labour, wage rates, market conditions, cost of raw material, and availability of the required machinery.

2.1.6. Households and Firms

The mobility, location and relocation decisions of the households and firms generate the demand for the built-space in the market and thus drive the construction of new built-space. The decision making of household and firms have been studied extensively by: Elgar et al., 2009; Habib 2009, etc. As an analyst we are interested in their behaviour in the actual selection of the built-space in the market and the transaction prices that are generated due to their decisions. Note that this determines the market activity, which then influences the builders' decisions to built new space.

2.2. Decisions Modelling

From the discussion above, it can be concluded that there are two important decision dimensions that are important in the evolution of urban built space: *valuation* and *supply*. In terms of valuation decisions, landowners have to decide what price to ask from land-developers for the land; land-developer have to decide on what price to ask from builders for the developed land-parcels; and builders and existing owners' decisions on what price/rent to ask for the built-space from the households and firms. In terms of supply decisions, land-developers have to decide within the zoning restrictions, on when, where, what sized, and how much developed land parcels to supply; builders have to decide on when, what type, quantity, location, and quality of built-space to provide.

In all these decision-making processes, given the level of available information, the agents are trying to maximize their profits, buy speculating about the demand and developing the good (developed parcel or built-space). This speculation is necessary because of the lag-time involved in the development and construction of the parcels and built-space. Within the active market, the agents also have to decide the transaction price, based on the existing demand, market conditions, and trends. Given all the necessary information, these agents will take rational decisions. As an analysts though, it is very hard for us to completely model the behaviour of these agents. To over come this shortcoming, a profit-based theory that is analogous to random utility theory has been developed. One such example is developed in Farooq (2010), where a generic multidimensional decision-modeling framework for built-space supply was proposed. The framework, formulates the expected profit of a builder at the time of decisions as the function of expected revenue and expected cost.

$$\Pi = \sum_{i=1}^{N} \frac{\gamma_i}{\alpha_i} \left\{ (f^r(X_i^r) - f^c(X_i^c))^{\vartheta} \left(\left(\frac{q_i}{\gamma_i} + 1 \right)^{\alpha_i} - 1 \right) \right\} + f^z(z)$$

Where:

$f^r(X_i^r)$ represents the expected unit revenue from selling product *i*

X_i^r is a vector of variables related to product attributes, location features, and built space market conditions that influence the revenue

$f^c(X_i^c)$ represents the expected unit cost in building product *i*

X_i^c is a vector of variables related to product attributes, location, state of regional economy, and conditions in various associated markets (labour, material *etc.*) that influence the cost

q_i is the quantity of product *i* that is decided to be built

Note that this is behaviourally richer approach than simply calibrating a certain type of profit function and making assumptions about the supply and demand curves. Moreover the same model can be extended to model the decisions of the builders in terms of supply of new developed-land parcels.

In terms of modelling the valuation decisions, the predominant method that can be found in the literature is hedonic price/rent models. The examples of such models are: Farooq et al. (2009), Habib (2009), and Mun and Hutchison (1995).

2.3. Markets Modelling

All the decisions described above, are not independently taken by the agents, but instead are highly tied up to each other through the supply and demand interactions within various markets. It is thus equally important to model the markets in a disaggregate fashion; the horizontal and vertical interactions for different markets; and the interactions among the individual agents in these markets. In the microsimulation framework, a built-space market can be conceptualized as following:

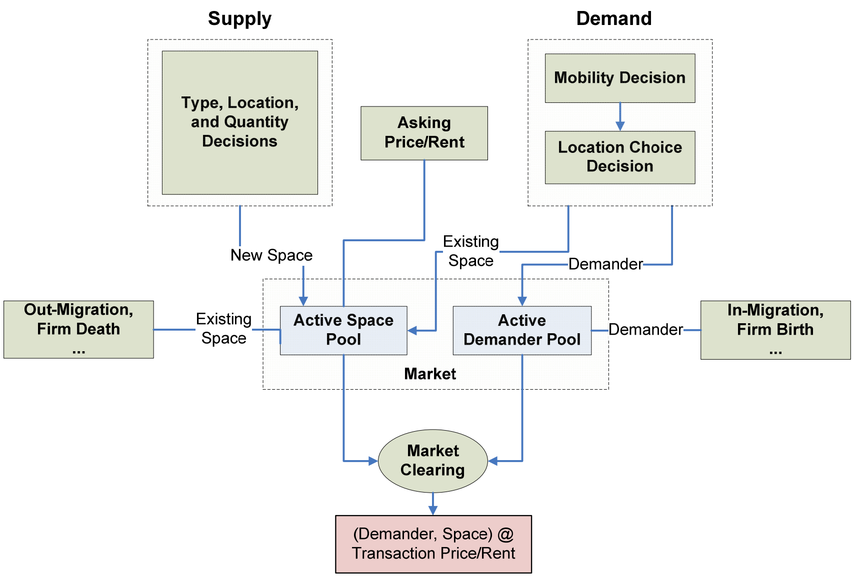


Figure 3: A general representation of the decision and markets in the built-space evolution

The demand sub-module encapsulates the decision-making behaviour of the demanders. Existing demanders in the urban area decide on becoming active in the market. A mobility decision model can be used to evaluate this decision. Once the demanders are active in the market, they start looking for the available built space options. This behaviour of choice formation is captured using a separate choice set generation mechanism. Based on the available choice set, demanders determine their preferences. The preferences are represented by a location choice preferences model. New demanders of built space are created by various other modules (e.g. in-migration sub-module, firmography module, etc.) within urban microsimulation system. These demanders also go through the choice set generation and location choice preferences models. The existing demanders may also act as suppliers, by bringing in the built-space they currently own for resale or rental in the market.

On the supply side, builder agents decide on maintaining a certain level of new supply to the already existing stock of the built-space. They are faced with decisions of when, where, what type, and how much of the built-space to build. These decisions are modelled using a multidimensional decision model that can maintain the interplay between all these dimensions of decision-making. Another decision that suppliers have to make when listing the built space in the market is the setting up of asking price/rent for the built-space. Asking price/rent represents the expectation of the suppliers regarding how much profit they can get from selling or renting the built-space in the market. A separate model is needed to capture the behaviour of suppliers in term of setting asking price/rent for the built space they own. Other sources of the suppliers may come from out-migration, death of a firm/household, etc.

The built-space market is the place where suppliers and demanders interact with each other so as to transact a built-space at certain monetary value. In the microsimulation context, the interactions for each built-space are individually managed. The demanders show their level of interest in the built space and the supplier decides which demander to sell/rent the space to. It is very important that the behaviour of the agents in the models of this interaction is properly represented. Based on the behaviour of the demanders in terms of price/rent, the market can be classified as *price-taker* or *price-formation* markets. In price-taker markets, the demanders accept the asking price as non-negotiable, while in price-formation markets, demanders negotiate the price in a bidding process, thus the transaction price may be different than asking price.

It should be noted that conditions in different kind of built-space markets might affect each other horizontally, as well as have an effect vertically in the chain of markets. Figure 4 elaborates these kind of horizontal and vertical effects in detail.

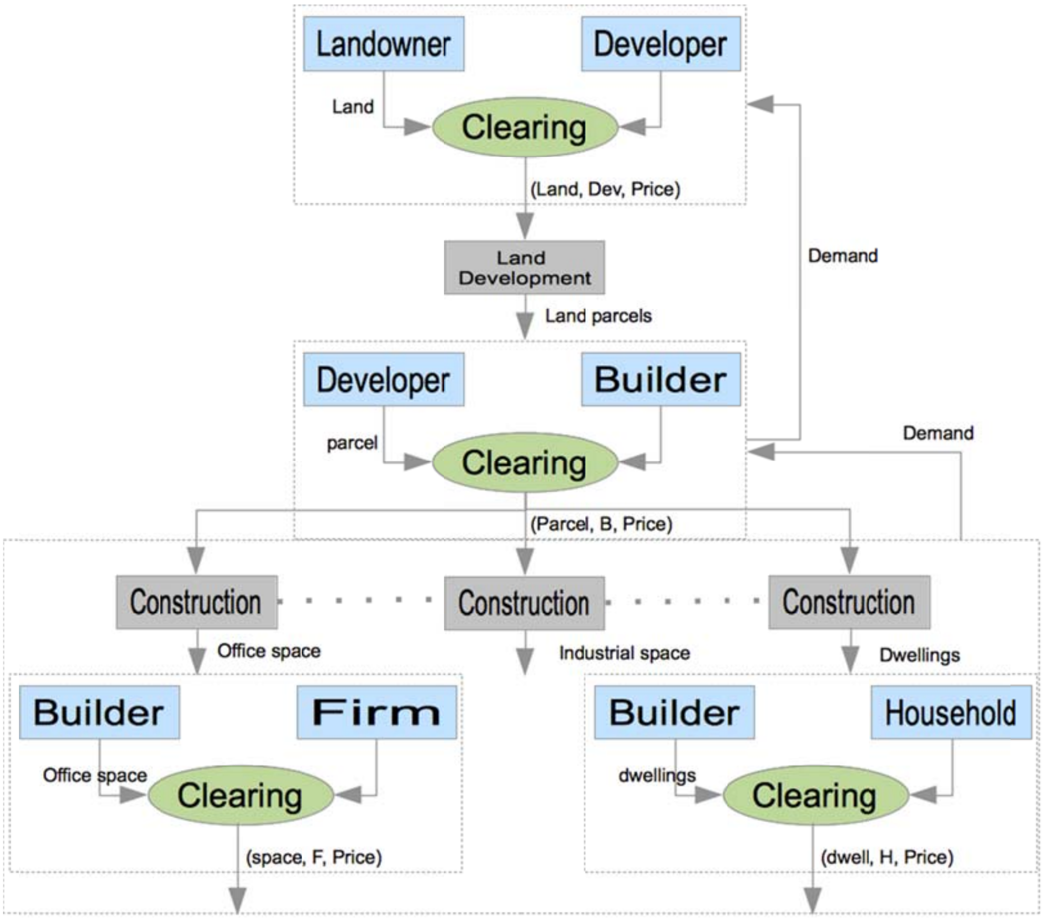


Figure 4: Urban Built-Space markets and their interactions

The higher demand for new dwellings in the housing market of a region may attract housing-builders to pay more for the parcels and compete with the builders who are specialized in building office or commercial space. In addition to this horizontal interaction, if the regional economy is performing very well, this will result in demand for all kinds of built-spaces, which will induce more demand for developed-land parcels. This will result in the vertical interactions. The Developers will reply to such a situation by buying more land and developing it. A price adjustment mechanism based on existing supply levels and the demand both horizontally and vertically, will also take place at each market level.

Note that this framework is also capable of incorporating markets with completely different characteristics. A high-rise office-space market, which may have a monopoly, can coexist with the housing market where there may be oligopoly or a free market, depending on the number of builders and their power of influencing the market.

3. Case Study and Descriptive Analysis

As a small case study example for the proposed framework, the urban evolution of City of Brussels will be modelled. The dataset that is constructed from the land registry data, consists of the all the new building development projects that started from 1990 to 2000. The dataset has limited information on the price and sizes of the developed, but the information on undeveloped land transactions is missing. Moreover, any information on the landowners, developers, builders, and subcontractors is also missing. It is therefore decided that a more stylized version of the proposed framework will be modelled for the Brussels case study.

The built-space types are created arbitrarily to match the commonly used names. Table 1, shows the names of the built-space types and their description. The spatial resolution of the available data is at sector level, which is the smallest census resolution that is readily available. In the study area, which contains the greater Brussels area, there are 4945 sectors. The temporal resolution of the data is 1 year time step.

Name	Description
Houses	Detached, semi-detached, and attached single family houses
Apartment	Apartment multi-family buildings
Private Office	Office building (private sector, inc. bank)
Industry	Industrial buildings
Shops	Shops and retail
Horeca	Hotels, Bars, Restaurant
Public Admin.	Office building (public sector)
Health	Hospital and other medical buildings
Education	School (including university)
Leisures	Land and building for leisures activities (inc. sport and museum)

Table 1: Types of Built-Space

In the first phase, using this dataset, we are in the process of modelling the supply decisions by the builders only. The spatial and temporal resolution of the dataset will be maintained in the models (i.e. sector level and yearly time-step). As currently, we do not have any information available on the characteristics of the builders who built the projects in the dataset, we will have to make certain simplifying assumptions about the builders (e.g. homogenous behaviour of the builders).

4. Concluding Remarks

The framework proposed here is an important step forward in terms of making the integrated Transportation, Land Use, Energy, and Environment modelling, behaviourally richer and providing in-depth tools for the sustainable policy analysis. The microsimulation nature of the framework ensures that it seamlessly hooks up with the activity based travel demand modelling and microsimulation energy and environment modelling. Currently, due to the unavailability of the data on the characteristics of important agents like landowners, developers, and builders, we have to make some simplifying assumptions in the framework. It is however intended that special surveys will be designed in near future to capture the behaviour of these agents.

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