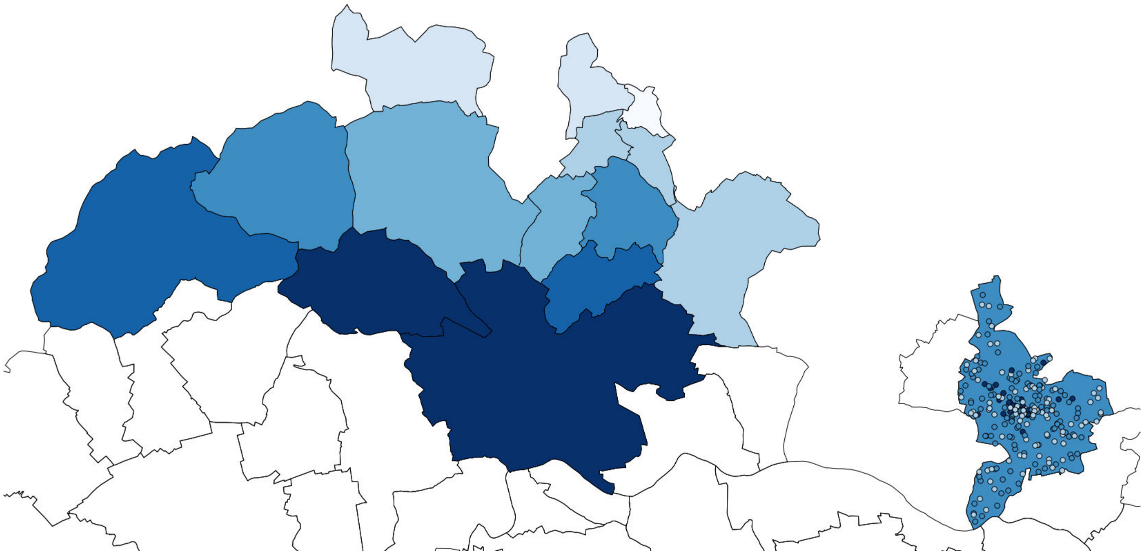

Market Clearing Models in FaLC

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Abstract

Decisions regarding the (re-) use of land is a negotiation between representatives of a broad group of stakeholders, bounded by the market prices of the land and its improvements and the regulations that shape further development. The costs resulting from transport and land use, such as greenhouse gas emissions, noise, and loss of habitat, are as important to these stakeholders as benefits like improved travel utility and synergistic relationships between collocated firms. The consequences of actions in this complex system are unclear and emergent, the information about the system often asymmetric across stakeholders. For a fair process, clear information and well-justified prognoses about the effects of land use and transport decisions need to be equally available to all interested and affected parties.

Models can illustrate possible outcomes of plausible scenarios. Currently available models of integrated transport and land use change (MTLUC) are complicated to run and require years of data collection in order to set up the scenarios, which means that they are employed only retroactively or on very large projects with long development horizons, and their results can only be accessed with certain technical expertise. "FaLC" (the Facility Location Choice Simulation Tool) is the working title for a simplified, user-friendly, open-source, agent-based simulation tool with lower data requirements which is being developed in a joint project between the Institute for Transport Planning and Systems (IVT) at ETH Zurich and the private firm, regioConcept. FaLC will support operational and research models of exogenous influences on regional development, with greatly reduced costs for scenario preparation and shorter run times.

FaLC synthesizes populations of individual Persons, Households, and Businesses within municipalities, and simulates their interdependent development in time. Property market simulations at different degrees of spatial aggregation were required for further refinement of these interdependencies, particularly with respect to the use and modification of geographic structure.

This paper reports on the architecture of the FaLC land market model and demonstrates two models for determining the market-clearing prices and spatial distributions of households at different spatial aggregations. A brief review of the state of the art in land market modelling provides the basis for the model architecture and the typeof simulation chosen for illustration. A conclusion indicates the priorities for further development of the FaLC land market model.

Keywords

FaLC – MTLUC – land use – transportation - integrated - market clearing - land price

1. Models of integrated land use and transportation

The study of the value of land and its improvements is fundamentally about understanding locations with respect to the characteristics of the locations in and of themselves, such as climate, geography and the built environment, the characteristics of the inhabitants, and the relationships to other locations with respect to accessibility and flows of different forms of capital: human-, knowledge-, ecosystem services, raw materials, manufactured goods, etc.

Computer models of land use can range from digital experiments that attempt to identify the relevant system actors and interactions, to predictive systems that support investment decisions like transportation, sanitation, or safety improvements. Land use models seen generally all contain elements representing human activities, natural geography, and man-made modifications that cause locations to be interrelated and to develop interdependently.

1.1 Levels of detail

Different levels of detail may be appropriate depending on the availability of data and the needs of the modeller, in various dimensions:

- physical (scale of the smallest land unit, whether apartment, parcel, neighborhood, city, or larger);
- behavioral (scale of the decision maker, whether a person or a household, a municipality, property owner, or abstract representatives of these);
- network (the ability for interactions between the actors and between the locations);
- time (the way in which actions are scheduled, queues, time scales of different processes, simultaneity);
- dynamics (the degree to which change is exogenously dictated by the modeller or is emergent from within the model mechanics).
- econometrics (how fine of divisions of socioeconomic characteristics and choice set attributes are needed or desired?)

Iacono et al. (2008) chronicle generations of land-use models, summarizing them into the rough groupings: "Spatial interactions 1950s-60s"; "RUM and disaggregate decision makers" 1980s; and "Agent-based and Cellular Automata" since the 1990s, pointing out strengths and weaknesses of the various approaches. The increasingly disaggregate microsimulation representations were made possible by faster processors and more RAM, but the reasons that model development followed this path include the problem that earlier closed-form and statistically-based systems often introduce bias and were very poor at forecasting (Iacono et al. 2008). Interdependent agents reacting to one another can simulate emergent social behavior like the segregation of neighborhoods, agglomeration economies (economies of scope), or shifts in tastes.

Even among the microsimulation models there are many approaches to simulating land use and integrating it with transportatin. ILUTE (Salvini and Miller 2005) for example, enables long and short term decision models. Many modelling theories and techniques for the submodels can be integrated together in the system. Along with complicated transportation behavior like trip chaining and mode choice, there are varying time scales for sales, purchases, and construction of building stock. ILUMASS (Moeckel et al. 2003) includes firm development models and the integrated collection of daily activity diaries. Even rule-based models have attracted interest: RAMBLAS (Veldhuisen et al. 2005) is a rule-based microsimulation which includes road construction, and Devisch, et al. (2006) use 1:1 buyer-seller negotiation rules based on Bayesian belief updating to determine a market clearing price for apartments.

1.2 Falc

The range of existing modelling approaches is large, showing that there are still problems to solve and that the field is still evolving rapidly. FaLC (the Facility Location Choice Simulation Tool) is a new entry with a detailed firmographic model, agents representing Person, Business, and Household, and GIS-integrated land objects stored in a GIS database. Written in Java, the system is integrated with the Multi-Agent Transportation Simulation Toolkit (MatSim, TU Berlin and IVT), which simulates a day's travel of individual people. The interface between the two allows an origin-destination matrix of work trips to be assigned in the MatSim activity-based system, providing travel speeds on a loaded transportation network. With additional external data regarding other activities and location choices, entire daily activity patterns could be developed within MatSim based on the world that evolves in FaLC.

However a main application for FaLC will be fast desktop simulations of land use change over time for interactive decision-making games. These simulations will not run at the level of buildings, but at the level of municipalities. An external four-step transportation simulation is foreseen for this purpose.

1.3 Land market in FaLC

Modules in FaLC thus already exist at the Person, Household, and Firm level, whereby the main interactions take place at the spatial specificity of municipalities. Buildings, land use zones, or ways to deal with the associated developments had to be engineered to be compatible with the existing software core and with possible future applications of FaLC. The land market module is described here which can accomodate modellers' needs at the level of these decision-making agents, i.e. which building unit to use/buy/move into, as well as at the higher-speed level of municipal land use structures.

2. Examples of Land Market Models

Land market models generally have a supply of some kind of building or aggregate types of buildings; a relocation step which may also determine a willingness to pay or a price, and which converges in a buffered iterative process due to the relocating decision makers taking account of one another's actions; and some kind of resupply, or update to the supply of buildings.

This paper is concerned with the mechanism for the determination of prices. The "choice" approach uses random utility to allocate households and firms to the locations in a choice set offering them the highest utility. The "bid", "auction", or "bid auction" approach allocates locations to the firm or household with the highest willingness to pay for the location. Random utility-based hedonic models using discrete choice methods are more prevalent than auction-based market-clearing mechanisms for determining price. Market-clearing denotes the condition at which all demand is satisfied and is often used loosely to mean the price at which agents realize their maximum utility. This can yield the same location and price distributions for certain hedonic price functions, but consistency is not guaranteed.

2.1 Hedonic versus Bid Auction

Hurtubia et al. (2010) summarize the choice and bid approaches and compare their ability to determine the market clearing price. Choice assumes that decision makers choose the location that maximizes utility, where price or rent can be one of the location attributes. Hedonic models assume the decision maker is a price-taker and that the individual attributes of the location determine its desirability. Hedonic models can be quite complex, including externalities like agglomeration externalities, accessibility (a network measure), and population densities that rely on decisions of other households and firms.

In bid auctions, consumers maximize their surplus = income - rent (willingness to pay). Rents result from the expected maximum bid across households. In a sense, it is the location that is choosing the most likely household. By accounting for the desire of all the decision makers in the population to determine rents, a bid model is thus able to adjust prices to changes in willingness-to-pay (for example, a new income distribution or a shift in household budgeting that might accompany an energy shock, which affects different income groups differently) that a hedonic model will not respond to. Thus the bid-auction model lends itself better to models which emphasize emergent pricing distributions in an adaptive population.

If prices are determined in an auction, the location where the agent is the highest bidder is also the location with the highest utility, and the bid model and the choice model give the same clearing price. Hurtubia et al. (2010) explain that the hedonic model is an approximation of the maximum expected bid for a household because it gives a weighted average of the household preferences across the population. This means that the choice of individual (household) utility function determines the corresponding hedonic rent function that will yield the same clearing prices; i.e., not all hedonic models will yield the auction clearing price.

So using hedonic models for determining rent requires some care in specifying the model if the willingness-to-pay is to be derived from the resulting utilities.

2.2 What other models use

MUSSA (Martinez and Henriquez, 2003) simulates zone-averaged willingness-to-pay with zone-aggregated characteristics of the households and the building stock, with endogenous effects in the hedonic utility function. According to the authors, it is an assumption that the hedonic price is the equilibrium market-clearing price that gives the maximum utility for the consumers, and thus is the bid-auction price, as well. As in Hurtubia et al. (2010), Martinez and Henriquez (2003) require the identification of a market correction (heterogeneity) term that relates the auction rents to the hedonic rents. This is a fixed-point problem solved in iteration.

UrbanSim (UrbanSim.org, accessed 03/2013) uses hedonic rent functions in two different scales: parcel and zone-based models. The location choice occurs in two steps: to move or not; then the location choice based on the hedonic model. The hedonic model estimates the logarithm of price in a linear regression, using endogenous attributes of the building stock and an accessibility measure at the zone-zone level.

Zhou and Kockelman (2011) introduce a "bid-choice" microsimulation to simultaneously relocate households and firms and to determine the market-clearing prices for different groups of consumers and different types of buildings. The microscopic model simulates rental as well as purchasing prices for individual housing units (apartments or houses). It simulates firm relocations and bids for different business types, different location characteristics, and different building attributes.

The portion of agents relocating in a time step are assigned a choice set from the available buildings: half of the choice set is chosen strategically based on the agents' own characteristics, and half the choice set is random.

The utility of each building/unit for each agent is calculated in a linear function of accessibility measures and hedonic attributes of the spaces, with a term weighting the building rent negatively, so that the hedonic function also represents a willingness to pay.

In the bid-choice approach, if more than one bidder bids on a property, its price is raised. If there are no bidders, its price is lowered. With this mechanism, iteratively applied over the relocating population and its choice set, the demand will redistribute such that the households choose their highest utility locations and the locations are chosen by the households with the highest willingess to pay for them. The prices are not bids for the building units that are formulated by the agents; they are variables entering into hedonic utility functions, adjusted by an auctioneer. The prices are adjusted in a buffer until the market-clearing condition is reached: each consumer has a location. The auction winner is allocated to each location as soon as a single winner can be determined.

The decision also occurs in a nested manner (independent decisions) like in UrbanSim: first the decision to move is taken, and then what kind of building to seek (rent apartment/buy a house), and finally the choice sets are allocated. The model for Firms is similar but includes decisions to expand or contract and whether to develop new land.

The prices are kept in check by upper and lower bounds set on what price the seller would accept. There are also tiebreak conditions in which it is necessary to randomly allocate tied bidders.

After the prices are determined, as in the other models summarized here, a supply model evaluates the profits that could be made by altering the building stock or the unbuilt land in the various locations, based on the rents or sales prices realized in the current time step, and proposes the changes, which are realized in another timestep of the model.

3. Data Structures for FaLC

As an open-source resource developed in cooperation at ETH, FaLC may be used at some point for research and should be extendable for experimental purposes, rather than having a fixed land market model from the outset. A data structure based only on Locations, i.e. municipalities, would require later core changes in order to study, for example, building-specific policies, or for more geographically focused studies of land use like a simulation of a single city. An economical data structure is proposed which can enable a range of land market models for different purposes. Users who intend to contribute alternative land market models may find the structure sufficient as-is, or may add fields to the objects by extending the FaLC I/O routines in Java.

3.1 Spatial object hierarchy

Building on UrbanSim, the following hierarchy is proposed, representing a Many:1 relationship from left to right:

Person< Household/Business < Unit < Building < Parcel< Zone < Location

Person< Household/Business < Unit<Building < Parcel <Zone Location

Person< Household/Business < Unit<Building<Zone < Location

Person< Household/Business < Location

The final hierarchy is the existing core definition of the FaLC objects, without the proposed Land Market model. It is important that all of these relational chains may be realized; i.e. not to require only the uppermost one, otherwise the generality and flexibility of FaLC would be compromised. The data structure ensures that land use models at all the above levels of aggregation are possible.

A building "unit" is a subdivision of a building which contains specific characteristics. It may appear at first to be an exceedingly detailed step to take for a large-scale land use model. But if a building has a single unit, then the unit's characteristics are the building's characteristics. A "Building" becomes merely a pointer to the building unit. For a fast, bird's eye-view model, a single abstract building may be defined for each municipality, which is large enough for everyone in the municipality, without an attached land parcel or zone. The price of the building is then the average price of buildings (sharing its characteristics) in the municipality. Or this single, large building may contain several large "units", each of which is an abstraction for different types of buildings found in the municipality, for example "large", "medium" and "small", or "high/med/low luxury".

Alternatively, a fully defined and highly disaggregate model might use the same data structure to represent an individual apartment unit for each household, resulting in millions of objects for a region the size of the Kanton Zürich. These units exist in buildings, which are located on parcels of land which have their own characteristics, which are within zones that have rules for how the land is used.

Each of these objects corresponds to a data table in the PostGres database.

3.2 Buildings Table

The Building is a central storage unit for ID keys that link the Location to the land market, which is regulated by the building attributes ("units"), the parcel (if used), and the zones (if used). Because there is a 1:Many hierarchy of Location > Zone > Parcel, it is redundant to store the ID keys of all these entitites in the Building. But doing so allows the freedom of not requiring all these entitites to be present in each model. Thus models without Parcels or Zones can have Buildings because the Building has a key direct to the Location (the other fields would be empty in this case).

The "build date" enables building projects to be valued hedonically (by age, for example), but also to be queued up for realization (modification of the Building Stock) at the corresponding year in the simulation, if it is set in the future. Thus the result of a building supply model is a modification to the Building list and associated "date."

Building ID
Parcel ID
Zone ID
Location ID
X
Y
Build Date (latest renovation to outer structure)
Price/Value (of Improvements, excluding land if desired)
Number of floo**rs**

The keys and the date are the important fields in the database. Other building characteristics like the number of floors are easier to modify by future users and aren't set in stone. Likewise, any additional fields can be added to the database by the code developer and the Java I/O modified accordingly.

3.3 BuildingAttributes Table

The units, or "BuildingAttributes" inside the buildings have their own characteristics, or, if the building has only one unit, these characteristics can be used to describe the building. For example, if a very large building has many nearly identical units in it, it may be desirable to model the building as having one unit with a very large capactiy (N Units).

Building Attribute ID
Building ID
Unit ID
Building or Unit Type
Size
Size measure (m2, num Units, etc)
N Units
Price/Value (same measure as size) of improvement or including land, as desired
Build date
Occupancy (same measure as size)
Quality1
Quality2

The Households and the Businesses contain pointers to the Building Units, not to Buildings:

Household> HouseholdParameters>BuildingUnitID
Business>BusinessParameters>BuildingUnitID

The Building that they are assigned to is obtained via the field in the BuildingAttribute (or unit). As with Buildings, the date in the BuildingAttributes table can be used for determing the time elapsed since the last renovation (for example) and also as a trigger for loading the Building (BuildingAttributes) into the model in the future, when the model iteration arrives at the date in which a modification to the status or attributes of the BuildingAttribute or Building will be realized.

Like the case with Buildings, it is this relationship that is important; the specific fields describing BuildingAttributes will likely be changed by future code developers.

3.4 Parcels Table

Land market models may or may not require zones, so this table is linked into the database with two upstream keys: one to the Location and one to the Zone. This is in case the zone isn't used but parcels are. If zones are used however, then parcels must be used (see Zones):

Parcel ID Location ID Zone ID Parcel Value (land only) TheGeom

The Parcel represents the land underneath the development. It can have a separate monetary value if desired. It is also the object affected by the zoning rule.

The field called "TheGeom" is a GIS shape object (boundary) that modellers can make use of if desired.

3.5 Zones Table

The Zones table frames the zoning rule, which is applied to parcels (and thus buildings). The Zoning Rule is a text string for looking up a set of coefficients from FaLC's general Coefficients table. These coefficients are available for many functions within FaLC. In this case, they would be used in equations governing the zoning requirements. For integrated transportation planning applications of FaLC, the Zone could be a transportation planning zone.

Zone ID Location Zoning Rule forumulation ID TheGeom

Again, the zone contains a GIS boundary that can be used if it is available or desired in the user's dataset.

The coefficients table, and thus the zoning rules, contain the following parameters for each Zoning rule:

```
id integer
type character varying ("rule name")
int_value_1 integer
num_value_1 numeric
legend text
subtype text
min numeric
max numeric
```

3.6 Conspicuous absences

This data structure does not allow for specific owner agents of the land parcels or the buildings or their units, nor for land developers. Cases of multiple owners who are difficult to negotiate with, of power brokerage between owners of multiple properties who wish to acquire a bridging property to develop a megalot, and other microscopic market behavior is beyond the scope of this proposal. Models of developers (sellers) is a proven area of difficulty because of the few examples avilable to study. A developer is hard to represent as an agent because it is often a composite of many stakeholders held together only for the duration of a project, and little evidence is left of the decision processes (Zöllig 2011). A supply model, though it would not have explicit agents represented in the FaLC data structure, could however have exogenous simulations of supplier/developer behavior.

4. Structure of the Land Market Model

FaLCs core algorithm executes the modules: "synthesis" (generate the world, or "universe" containing Persons, Households, Locations, and Firms), "visualization", "universe" (which runs the steps through time, altering the land structure as people and firms age, move, and otherwise change, as well as a series of standalone utilities that facilitate pre- and postprocessing. The modules affecting the state of the "universe" during the simulation are called, "service" modules.)

The land market model involves the stages, "synthesis" and "universe" ("Service" module). Producing the Buildings and their Attributes is a "synthesis" module, and calculating the land/building prices and the corresponding relocation is a "service" module. The "universe" is automatically loaded by the Service SuperClass and then saved at the end of the service iteration. So the land market model, as a Service implementation, only has to concern itself with running the market dynamics.

The price model's interface contains constructors for the general logical flow of iterative building stock and relocation (pricing) decisions based on the literature of land market models:

1. Run the Construction model (modify the building stock acccording to a queue of planned projects). This is most easily modelled by storing Buildings and BuildingAttributes in the database with a "build date". The building will be read in during the year of the simulation in which it is scheduled to be built.

2. Load/choose the Households and Firms who will move. If a quasi-equilibrium market-clearing simulation is being run, in which demand may not be completely served by supply each time step, this list of "re-locators" can include those who may have attempted to relocate in the past but were unable to for price barriers or other reasons. Since the "universe" is read into the service module each new timestep of the simulation, it is easy to store a value in a field each timestep indicating whether the Household (Firm, etc.) satisfied its needs in a particular timestep, or whether it should be reconsidered in the marketplace in the next one.

3. Get the list of vacancies available for relocating agents.

4. Read in or calculate the initial (current) price of each vacancy.

5. Select choice sets. Random or based on a model. (Note that choice sets are not used in some models).

6. Test whether there are enough vacancies for the demand wishing to relocate.

7. Simulate the market exchange: bid auction, discrete choice, rule-based, etc. to arrive at market clearing prices

8. Plan new supply (building stock changes) based on the demand information, zoning rules, and the prices.

9. Queue up the supply plans. This is a new Building Object, with a date in it when it will be realized.

Each time step, the market model is called up anew, with the "universe" (Locations, Households, Firms, Persons, Buildings, etc.) re-loaded from the PostGres tables. Changes to the object attributes are saved again to the PostGres tables as the market model runs, so that the objects in the tables are in a state "t" ready for state "t+1" in the next step.

5. Example Implementation: Bid-Choice

Two simplified versions of the Zhou and Kockelman (2011) price-clearing model were implemented in the FaLC architecture to illustrate the scalability afforded by the data structure. The model treats only household relocation. The total number of households equals the total number of available capacity, and the model is constrained to calculating an equilibrium clearing price, i.e. all households will have a building unit at the end of the time step. There is a fixed building stock.

The point of the simulation is to begin the model with non-market-clearing prices, and to observe the new distributions as prices converge to a market-clearing price while the agents relocate.

The implementation has the same basic mechanism as its predecessor. Households are generated with income, size, and location distributions according to Swiss statistical aggregate figures. They are initially allocated to building units with an uniform price of 1000 Franks. A portion of the households (say 10%) is chosen to relocate. In the equilibrium model, where there are no vacancies to start with, the households open up vacancies in their building units when they intend to move. The households all receive a choice set from these available units. They then compete for these vacancies, which alters the price of the units.

The willingness to pay function for each household for each Building Unit is:

$$V(d,I,P) = 0.5 * \left[\left(1 - e^{(-0.01*(0.25*I-P))}\right) + e^{(-0.2*d)}\right] \qquad (1)$$

where d is the distance from the Building to a central point of interest, say a Central Business District, and the exponential weighting represents an accessibility. I is the household income, and P is the price of the unit. When the V are calculated, the households each rank their choice of building unit by the value of V and issue an intent to bid on the unit giving the highest V value. If there are more bidders for the unit than vacancies in the unit, the price is increased by 5%. If there are no bidders at all for a unit, its price is decreased 5%. After the price changes, the households recalculate their willingness to pay for each unit and offer their bids again. Households are committed to a unit if the number of bids is less than or equal to the number of vacancies in the unit. This is the market clearing price and market clearing distribution of households.

Note that if a unit has a capacity of more than one household, the resulting price is valid for all the households choosing that unit.

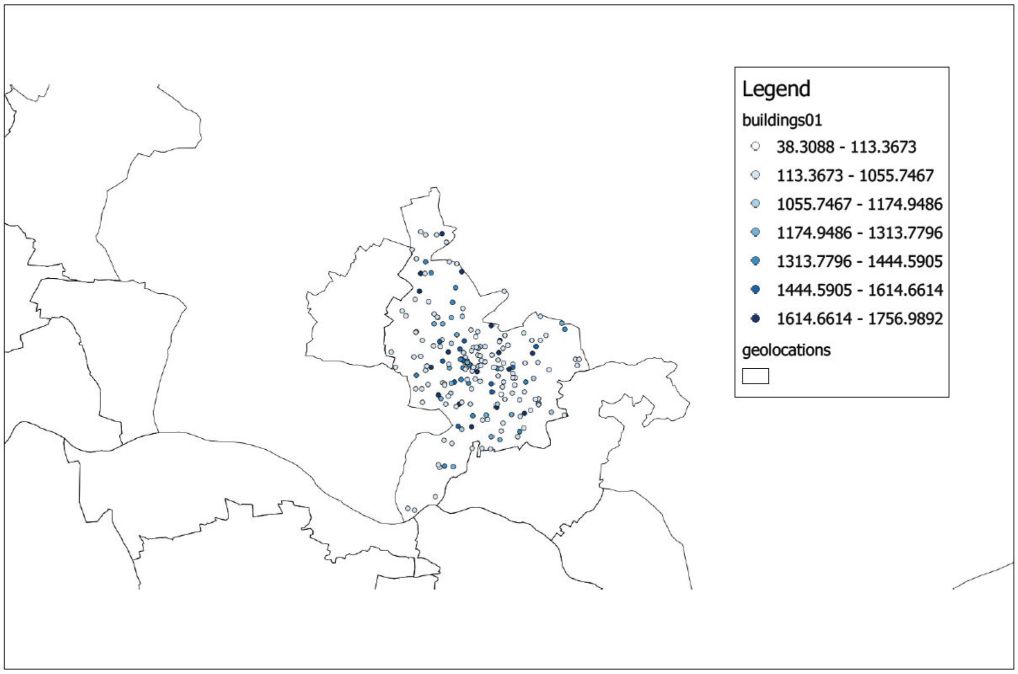
This FaLC implementation is changed from the original implementation in several ways. There are no limitations on the bids that sellers will accept, nor are their any limits placed on prices. No households are committed to a unit until the number of bids for all units is less than or equal to the number of vacancies in the unit.

The only exogenous intervention in the market-clearing process is a tiebreak which is enforced because, if left to itself, the demand will eventually enter a mode in which there are only a handful of units with very similar utilities: all the demand shifts to the higher-utility location, far more demand than its capacity, which causes its price to rise, while the price of the location for which all the households just retracted bids declines, because it has no bids, after which all the demand switches back, resulting in an interminable flip-flop of demand and price that has to be interrupted. The difference in utility at this point between the contested locations for most agents is generally one part in 10e6; it is a flat portion of the utility surface in which convergence is difficult (especially in the aggregate case, as in model 2, where large clumps of agents switch their preferred location at once). Thus a small error in the determination of market clearing prices is accepted as a consequence. The tiebreak functions as follows: at the point of interruption, households bidding over the capacity at a location are chosen randomly to be relocated there, until its capacity is filled. The location and those agents are removed from further auctions, and the bidding proceeds for the remaining units until the number of bids for all units is less than or equal to the units' capacity.

In the first model, a population of 491 Households was generated in a single municipality. The land market building generator randomly generated 197 buildings in random locations within the municipality, each with a single unit with capacity 3. Thus there was an oversupply of housing (591 units). The distance field d was calculated in a straight line to the centroid of the municipality. The choice sets were randomly assigned.

To test convergence, the auctions were simulated with relocation portions of 5%-100% and choice set sizes of up to all the building units. The simulation converges poorly with large choice sets, but the choice sets must be large enough to provide sufficient overlap, or else there is no competition. This is an area of future investigation and has something to do with the similarity of the building units and the bidding agents (i.e. the simplicity of the willigness-to-pay function). A sample converged price distribution for a single time step is illustrated by the legend in Figure 1.

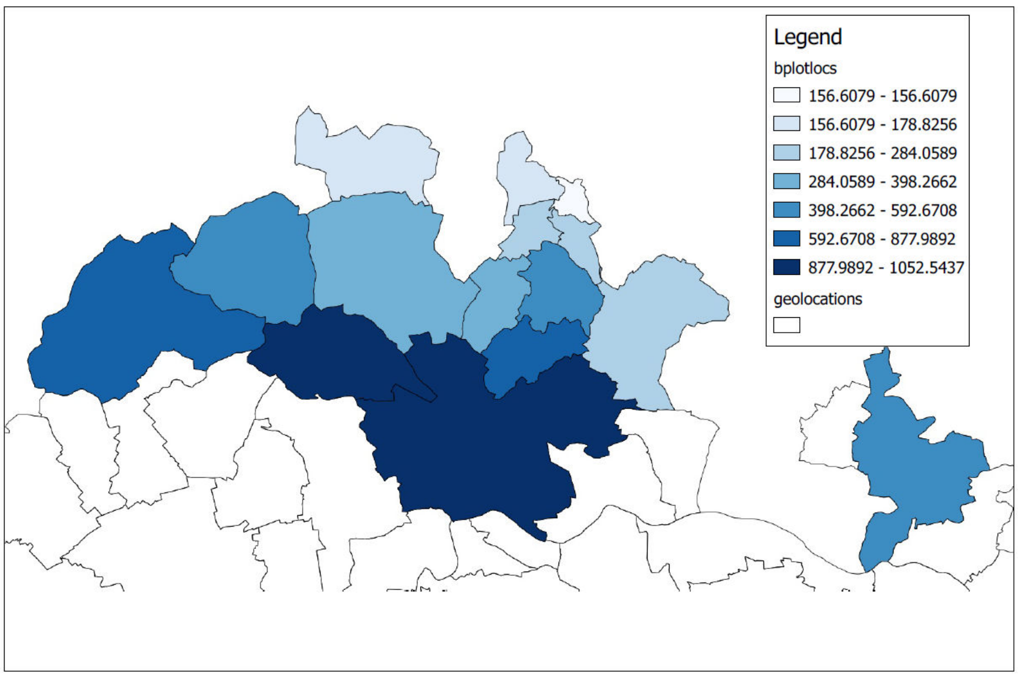
Figure 1 Distribution of buildings in a single municipality and illustration of their market-clearing prices, 491 Households, attractor at centroid of the boundary.



A general increase in rents toward the central attractor in the municipality is obvious, indicating qualitatively that the converged algorithm produces the expected result. Approximately half of the building rents were altered from the initial value of 1000 in this example; the rest weren't in the choice sets. Substantial refinement in the prices would be obtained by iterating over more "timesteps", thus involving more of the population and more of the building units in the auctions.

The second model uses a "universe" of 15 municipalities and 17890 Households, likewise generated with parameters so that they represent residents of Switzerland. This time, a fast model at "municipality resolution" was desired. To effect this, a single building with a single large unit was generated for each location and placed in the data table. The same utility function was used, but this time the distance, *d* was the distance to a random point in the City of Zurich, many kilometers away from the municipalities in the simulation. In this model, each building unit is large enough to house all the households that live in that municipality at the initialization of the model. The number of available units equals the number of households at the level of municipalities. This need not be a condition of equilibrium but it is the approach used in this particular simulation. 10% of the households were chosen at random to relocate, and each received a choice set of all 15 locations. The simulation was run for 10 time steps to give a high chance that roughly all households were recruited to relocate. Each iteration was calculated in 20-21 seconds (220 seconds total). In a complete FaLC simulation, this market simulation would begin in an equilibrium state and only run on those households (and firms) wanting to relocate that timestep, i.e. only one iteration.

Figure 2 Illustration of market-clearing prices at the municipality level, 17890 Households, attractor is south of the map.



Again, the distribution of prices follows the expected pattern of increasing price nearer the attractor point. Other GIS plots could be made of the resulting sociodemographic makeup of the relocated populations which are affected by this market-clearing algorithm.

A more detailed quantitative or microeconomic analysis of the results has not been carried out.

6. Summary

The land market model in FaLC consists of a carefully considered database architecture and an algorithmic logic that is based on the study of published land market simulations. It sets an accent on scalability and reusability in the hands of moderately skilled Java programmers. The implemented tests show that the concept can be useful as planned, thus market-clearing conditions can be simulated with the structure. Not just the illustrated bid-choice, but also hedonic or rule-based models may be programmed, as well as much more involved utility functions and more variegated building types.

The aggregate model at municipality level could have been achieved in the core FaLC architecture by using location parameters, a list of special fields for each location. But hardly any efficiency is lost by attaching these attributes instead to single building objects which have a capacity equal to the population of the municipality. And the increased flexibility and the clarity of the modelling concept afforded by this structure is a worthwhile modification.

The mechanism illustrated in the implementations is not restricted to households or to renting versus buying. It is a generic algorithm for finding the market equilibrium that can be recycled, as could other algorithms for finding a clearing price.

The next steps before estimating bid function or utility parameters are to gain experience with different types of markets by attempting to value different types of land use and different household and firm intentions, and to implement and control a quasi-equilibrium in which demand may go unmet for a timestep. The implementations to experiment with include: buildings of different types, a buying as well as a renting market, valuations of undeveloped land, separate land and building prices, tests with the zoning rules, and finally a supply model.

7. References

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