Heterogeneous real estate developers in an integrated land use transport simulation

Christof Zöllig Renner

Prof. Dr. Kay W. Axhausen

Institute for transport planning and systems

May 2014

STRC | 14th Swiss Transport Research Conference

Monte Verità / Ascona, May 14 – 16, 2014

Institute for transport planning and systems

Heterogeneous real estate developers in an integrated land use transport simulation

Christof Zöllig Renner
Institute for Transport Planning and Systems
ETH Zurich
Wolfgang-Pauli-Str. 15, CH-8093 Zurich
phone: +41-44-633 27 19
fax: +41-44-633 10 57
christof.zoellig@ivt.baug.ethz.ch

Prof. Dr. Kay W. Axhausen
Institute for Transport Planning and Systems
ETH Zurich
Wolfgang-Pauli-Str. 15, CH-8093 Zurich
phone: +41-44-633 39 43
axhausen@ivt.baug.ethz.ch

May 2014

Abstract

Managing urban areas is a concern which gains importance since more and more people live in cities. If we want to have better control of the urban system, we have to clarify the processes constituting to their evolution. Since real estate developers have a key role with respect to building stock evolution, we want to learn more about their behaviour. A better understanding of these actors' reaction to policies and market conditions should improve changes of political visions to be realised.

Thus, the aim of this paper is to show how developer type specific behaviour influences the development of urban areas. We investigate this issue by deploying a microsimulation of land use transport interaction which features a developer type specific real estate development model. The purpose of these models within the simulation is to provide real estate options for households and firms to locate their activities. The main tool to develop the simulation is *UrbanSim*.

The paper presents the results of a land use transport interaction simulation in the Canton of Zurich, Switzerland. The investigated scenarios assume different shares of real estate developer types to be active in the simulation area. The three discriminated types are self-owning developers with one project, self-owning developers with multiple projects and commercial developers which want to sell the project later on. For the reference scenario we take the shares observed in the period from 2000 till 2010. The planning scenario assumes a doubling of activity of commercial developers. The results will be analysed with respect to land consumption, densities of built space, population and job distribution as well as resulting travel indicators.

Keywords

Real estate development, location choice, taste heterogeneity, land use transport interaction simulation, Zurich

1 Introduction

The management of urban areas becomes more and more important to societies because most people live in such environments (Malik, 2013, p. 197). If we want to have better control of the urban system, we have to clarify the processes constituting to their evolution and how they can be influenced by policy measures. In the context of spatial planning the interest is in the reaction of decision makers to incentives or regulations. An example for a regulation is the fixation of a ceiling for the amount of land zoned for construction as demanded by a recent initiative (Staatskanzlei des Kantons Zürich, 2012). To assess the effects of such a regulation the planner needs to understand how affected stakeholders take their decisions facing the new situation.

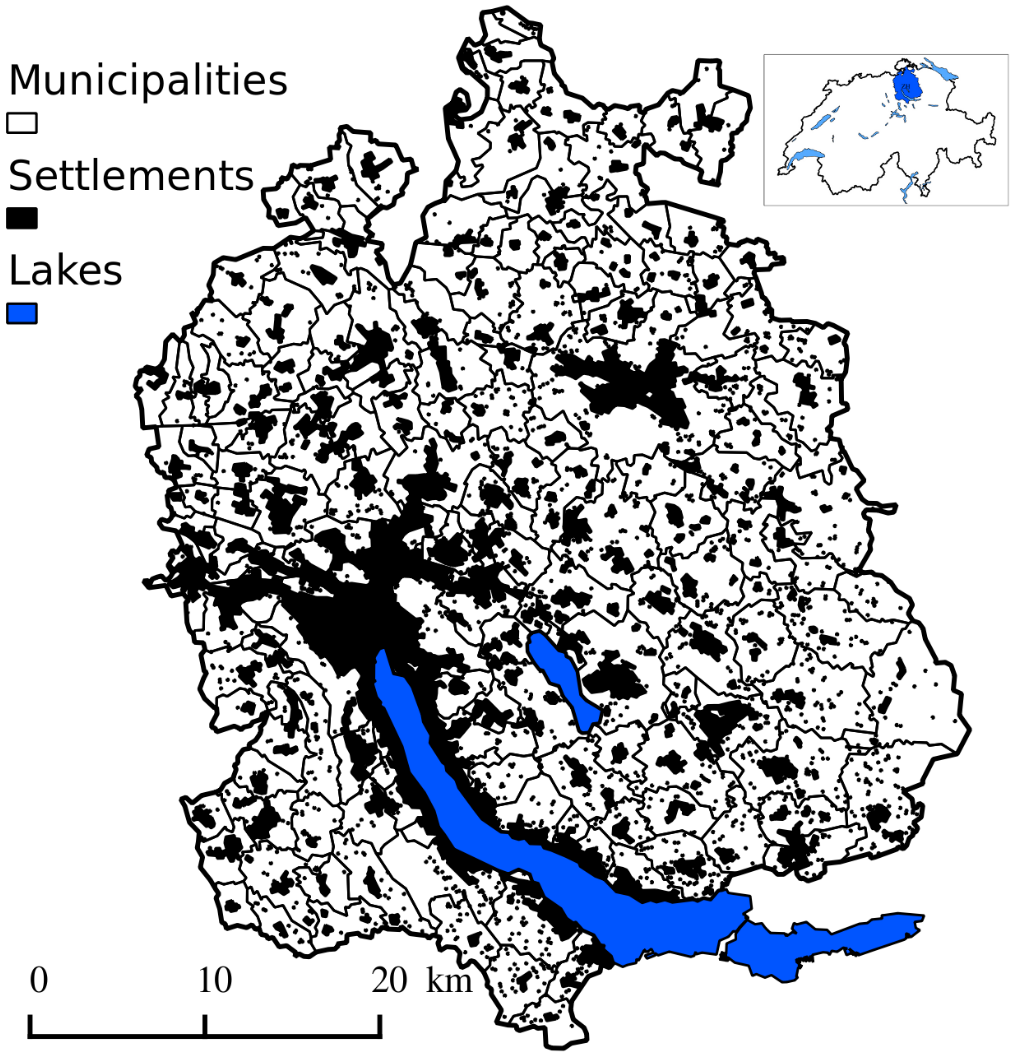
Important players for the evolution of the urban system are real estate developers since they provide customised built space. Here we focus on this population of decision makers since literature shows that real estate supply is scarcely researched in the context of land use transport interaction (LUTI) modelling (Hunt et al., 2005; Haider and Miller, 2004; DiPasquale, 1999). Further, qualitative (Zöllig and Axhausen, 2012; Schüssler and Thalmann, 2005) and quantitative (Haider and Miller, 2004; Dong and Gliebe, 2011) work has shown that differences among developers exist. Still most models of LUTI incorporate real estate supply by a representative agent. Therefore, this research investigates the following hypothesis:

- We need to consider different developer types to simulate the development process more accurately.
- The consolidation (more professional developers) of a real estate industry leads to more efficiency spatial development (*e.g.* in term of land consumption or energy use in the transport sector.).

The goal is thus to integrate developer type specific models into a land use transport interaction simulation to be able to assess effects due to consolidation of real estate supply industries.

The verification of the research hypotheses is approached by introducing previously developed real estate project location choice models (Zöllig, 2013) into an agent-based LUTI simulation of the Canton Zurich (Fig. 1) . *UrbanSim*, *multi-agent transport simulation (MATSim)* and Modgen are integrated and implemented using the same populations of microsimulated entities making the simulation consistent on a highly detailed level (Schirmer et al., ????). The usage of deterministically stratified location choice models according to three distinguished developer types allows to run and analyse scenarios about the composition of real estate suppliers. The particular scenario described in this paper assumes a higher share of professional developers. Scenario effects are calculated by comparison with a baseline scenario.

Figure 1: The overview of the simulation area shows the canton of Zurich with its settlements. The two major agglomerations are Zurich and Winterthur.



Source: Data © 2013 swisstopo (JD100042)

The next section reports on the set-up of the LUTI simulation and the baseline scenario. The description includes data preparation, estimated models, calibration and validation. Validation is done by comparing the baseline results to cantonal statistics. In Section 3 the reader can find the results of the consolidation scenario. After the scenario definition results are presented and discussed. The last section contains the conclusions and an outlook on further research.

2 The land use transport interaction simulation of the Canton of Zurich

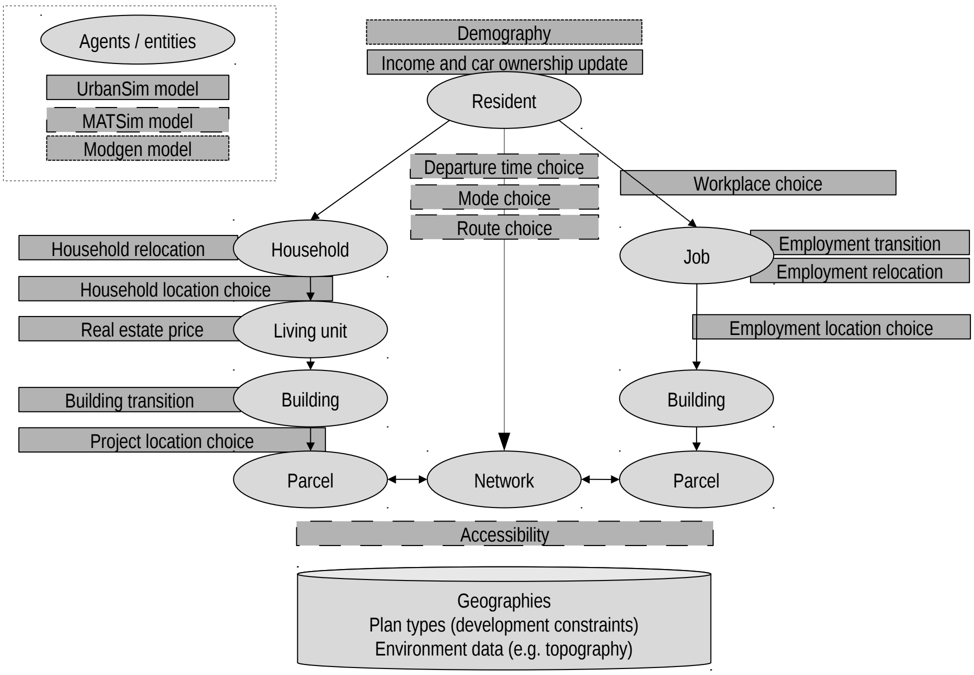
For the investigation of developer type specific scenarios we need a baseline scenario which represents the "business as usual" case. The baseline is the development path which is most likely to happen without any modifications to expected development. Its definition and set-up as a LUTI simulation with *UrbanSim* requires (i) the creation of the base year with all entities depicted in Fig. 2 as light grey ovals, (ii) assumptions about their evolution (either in terms of control totals or by defining appropriate transition models), (iii) selecting geographical units of analysis (GUA), (iv) estimation of choice models to define the entities behaviour, (v) estimation of a hedonic real estate price model, (vi) coupling with a transport model, (vii) implementing regulations, (viii) integration of relevant environmental data and (ix) a compilation of already approved projects and political measures becoming effective during the simulation period. The creation of the base year containing the integration of environmental data is quickly described in subsection 2.1. More emphasis to that process is given in Schirmer et al. (2011). An overview on the estimated models (dark grey rectangles in Fig. 2) follows below in subsection 2.2.

Parcels are chosen as most detailed GUA because the data is of high quality and it is the legal unit to which land use regulations apply. Further GUAs of interest are traffic analysis zone (TAZ), municipalities and the Canton of Zurich representing the study region. TAZs have been considered to be able to use traditional transport models and their output. Municipalities are important because a lot of data (*e.g.* tax level) is associated to this level of administration. It is also an appropriate geography to evaluate and communicate the results. Overall effects have to be calculated on the whole perimeter which is the Canton. It would have been ideal to use a functional region defined by commuting patterns (Killer, 2011; Gmünder et al., 2010). Due to time and budget constraints the simulation area is limited to the Canton of Zurich.

2.1 Data preparation

Data preparation is an important task for the set-up of a LUTI simulation and requires a fair amount of work. It consists of integrating relevant available information into the format required by the simulation software. The process consists of (i) obtaining the data, (ii) backing it up, (iii) sight the data, (iv) cleaning it, (v) combining / integrating various datasets and (vi) transforming it to the required format. To be able to repeat the process in case of necessary modifications, it is decided to automatise it as much as possible. The whole process is coded with a combination of scripts which can be evoked by a main shell script. However, it is also possible

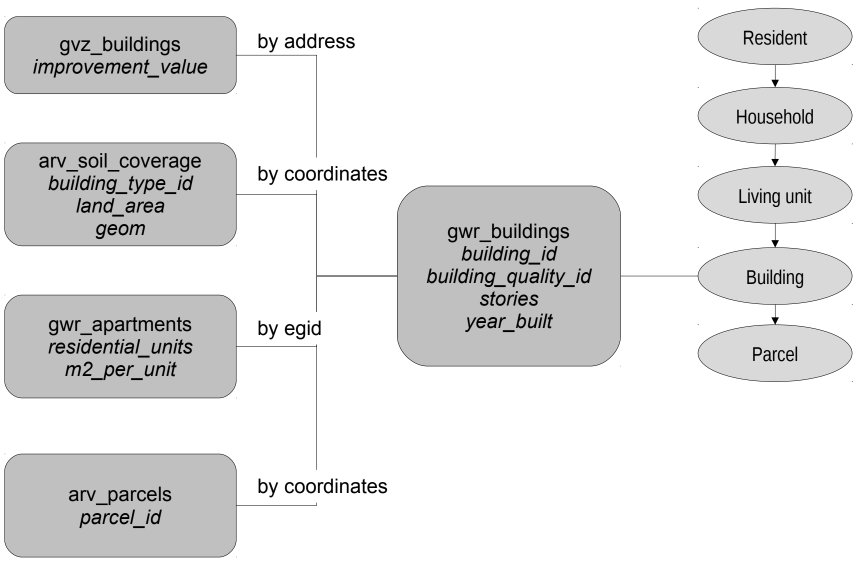
Figure 2: Entities and models of the LUTI model of the Canton of Zurich



to execute single scripts which are designed as tools for specific tasks. A first set of scripts import the original data from various file formats into a *PostgreSQL* database. It is decided to do so since a lot of information has to be related with respect to spatial attributes and a structured query language (SQL) definition of the data model for the simulation is made available by the *UrbanSim* developers. Further reasons to choose *PostgreSQL* were its licence, reliability and performance. A second set of scripts transforms the original data into the requested format of the data model. This step includes cleaning, completion and complementation techniques to achieve a consistent database as complete as possible. This step is no longer as modular as the previous one due to interdependencies. Most operations have been coded in SQL. An exception is the imputation of car ownership and income from the micro census of travel behaviour which is done in *R*. Computation is done in parallel for municipalities to improve performance. More details can be found in Schirmer et al. (2011).

Figure 3 shows the data integration example in case of buildings. Five data sets contribute to the finally used building entities used in *UrbanSim*. The `gwr_buildings` were used as reference data set since the entities are geocoded and records from the building insurance Canton of Zurich (Gebäudeversicherung Zürich) (GVZ) are not. The GVZ dataset contains however an estimation

Figure 3: Preparation of building data for the usage in *UrbanSim*



of the buildings replacement value which is added by matching the addresses. The soil coverage dataset of the Cantonal Office for Spatial Development (Amt für Raumentwicklung) (ARE) contains geometries (`geom`) of building footprints, consequently also its area and useful building categories. These data are joined to the federal building and housing register (Gebäude- und Wohnungsregister) (GWR) record whenever its coordinates lie on the respective polygon. The location of the building in terms of `parcel_id` is determined with the same mechanism. Joining the apartments is easy since the GWR data is already related via unique identifiers (`egid`).

Data preparation also includes determination of categories and categorisation of entities. This can be seen as a first modelling step since it defines possible market segments which can be considered later on. Relevant categorisations found here are (i) employment sectors, (ii) land use types, (iii) building types and (iv) plan types. A lot of categories are predefined in the data and impose difficulties when combining datasets whenever the categories are not identical. If possible, it has to be defined which categories correspond to each other.

Table 1: Overview on models in the LUTI model

Model	Abbrev.	Model type	Reference
Demography		Microsim., rate based	Turci et al. (2012)
Income update		Regression	Schirmer et al. (????)
Car availability update		Binary multinomial logit (MNL)	Schirmer et al. (????)
Building transition	building transition model (BTM)	Transition	Subsection 2.2.2
Project location choice	project location choice model (PLCM)	MNL	Subsection 2.2.2
Real estate price	real estate price model (REPM)	Regression	Schirmer et al. (????)
Employment transition	employment transition model (ETM)	Transition	Schirmer et al. (????)
Employment relocation	employment relocation model (ERM)	Rate based	Schirmer et al. (????)
Employment location choice	employment location choice model (ELCM)	MNL	Schirmer et al. (????)
Workplace location choice	workplace location choice model (WLCM)	MNL	Schirmer et al. (????)
Household relocation	household relocation model (HRM)	Rate based	Schirmer et al. (????)
Household location choice	household location choice model (HLCM)	MNL	Schirmer et al. (2013)
Transport	*MATSim*	Microsim., activity based	Balmer (2007)

2.2 Models

Three software packages are used for the entire simulation: Modgen for simulating demography, *MATSim* for simulating transport and *UrbanSim* for the simulation of land use in space. In the following we cover the integrated models briefly to give the reader a complete picture. For details on most models the reader is asked to consult the references as listed in Table 1.

2.2.1 Demography

The purpose of the demographic model is to update the population of persons over the course of the simulation. In fact, the demographic evolution is microscopically simulated in advance and then fed to *UrbanSim* for location choice. Most of the demographic models are rate based and require transition probabilities as input. The detail is considerable and requires a lot of population segment specific parameters (a total of 1’660’696) to be set. Simulated demographic events are ageing, migration, labour participation, household formation (marriage, union dissolution, leaving parent household) birth and death.

2.2.2 *UrbanSim*

UrbanSim distributes land uses in space. The considered main entities (households, employment and real estate projects) locate on parcels which are connected by transport networks.

Population update Before the core models can be applied it is necessary to update the population on characteristics used by further models. Income and car availability are two such cases in the current simulation. Income is imputed with a regression on the level of education, the number of cars in the household and the size of the household. Car availability is simulated with a binomial choice model where changes of not having a car decrease with education level and chances of having a car increase with household size, distance to the CBD of Zurich and income (Schirmer et al., ????).

BTM This model determines the amount of units per considered sub-markets. Nine non-residential sub-markets are considered besides the residential market. The sub-markets correspond to the employment categories in the ELCM. The number of units is calculated on the basis of market specific vacancy rates which enter the simulation as assumptions. Here we assume 0.66% vacancy for residential and 4.0% for non-residential markets based on cantonal statistics. The rate is low compared to other regions, also because it only includes units offered in the market (Thalmann, 2012). *I.e.* units currently under renovation or otherwise deliberately vacant are neglected. This is not considered in the simulation. Whenever the simulated vacancy in a market falls below the respective target vacancy, the necessary amount of projects – including buildings and eventually living units – is sampled from a pool of development projects to relax the constraint again.

PLCM The sampled projects are then located on parcels by the PLCM. Its specification and estimation is described in Zöllig (2013). 30 alternatives are sampled and evaluated for simulation which is the *UrbanSim* default. Due to computational constraints it is not possible to include all alternatives. The eligibility of a parcel is determined by plan type and associated density levels for discriminated uses. A project might fit into remaining capacity on an already built parcel and thus allows for densification. Extension, rebuilding, replacement or demolition are not simulated.

REPM A hedonic real estate price model determines the rent price for living units. The estimation results show the importance of living unit characteristics compared to location variables (Schirmer et al., ????). Price models for non-residential units are not available so far. Hence, it was not possible to implement a template based development model (UrbanSim Developers, 2013, p. 103).

ETM Employment transition is simulated based on assumed control totals per sector. The model creates or deletes the requested number of jobs each simulation year. Trend continuation as observed between 1996 and 2003 per sector is assumed for the simulation period.

ERM The number of relocating jobs is calculated based on exogenous relocation rates per sector. Sampled jobs are left to the ELCM to be newly located in a building with remaining capacity.

ELCM There is a ELCM for each discriminated sector. In a nutshell: Jobs tend to cluster in highly accessible places. Differences occur in respect of highway access and centrality. Unlike the other sectors jobs in hotels and restaurants (HR), service (Srv) and health (Hlt) tend to locate away from highway access points which is reasonable due to expected noise immissions. Srv and Hlt jobs tend to locate centrally whereas jobs of other sectors do not (Schirmer et al., ????).

WLCM Employed persons are linked with a job by the WLCM. We denominate it as WLCM because the job is already located when the person gets to choose it. The choice is currently only depending on the distance between the worker's residence and the job location. Chances to take a job decrease exponentially with distance between the two locations. The model has been fitted against 2000 population census data (Schirmer et al., ????).

HRM Since population development is already simulated no transition model is needed for households. To determine relocating households, relocation rates distinguished by income and age of household head are applied. Analogue to the ERM selected households are located by the HLCM.

HLCM The HLCM locates households and associated persons in an available living unit. The MNL model features non-linear interaction terms in the utility function for distances to workplace and previous residential location[1]. Strongest effects come from these two variables and the rent-income ratio (Schirmer et al., ????). An increase in all the three variables decreases chances of a household to get the considered living unit.

MATSim *MATSim* is dynamic, activity and agent-based microsimulation of transport. This means that daily plans for activities of an initial population are simulated on provided networks resulting in dynamic network loads and travel times. An iterative evolutionary algorithm

[1]Therefore, the model had to be estimated in *biogeme*.

calculates a relaxed state of the system such that agents can no more significantly improve the score of their plans. It is implemented as follows.

As part of their improvement strategies the agent can make choices regarding mode of transport (public transport (PT) or car), departure time and route. Destination choice is not included since only activity chains of type home-work-home are considered. Origin and destination of the trips are thus given by the travellers residence and workplace location. Due to performance reasons[2] only 10% of the population are actually simulated and the transport simulation is only run every fifth year of simulation. The resulting travel indicators are attached to parcels (workplace accessibilities) and persons (mode, travel time, travelled distance) which are fed back to *UrbanSim* influencing land use choices. Departure and arrival times at activity locations are not exchanged with *UrbanSim* since there is no use of this information at this point.

2.3 Calibration

In the context of urban modelling Batty (2009, p. 51) defines calibration as

> "The process of dimensioning a model in terms of finding a set of parameter values that enable the model to reproduce characteristics of the data in the most appropriate way. Calibration is not the same as validation [better estimation] which seeks to optimize a model's goodness of fit to data, but often, these processes are equivalent."

Description of calibration steps A first step of calibration is model estimation itself. But model estimation does not concerns the whole system. Therefore, a second step is needed to calibrate the overall system to observed development as good as possible. It is basically the comparison and manual adjustment to match the statistics of interest better. For some parts of that problem methods have been proposed to automate this huge task[3] (Flötteröd et al., 2012, 2011; Flötteröd, 2009). The author is not aware of a similar approach to LUTI models.

Calibration has been done manually and to a minimum in this work. In the following calibration for the demography model and the travel model are briefly described.

Demography model calibration The simulation is calibrated against the overall population size of the cantonal statistics with the following steps:

- Multiply emigration probabilities by 1.3

[2] A 10% *MATSim* run takes approx. 4 hours.
[3] Hundreds of parameters can be modified.

- Multiply immigration numbers by 1.5
- Multiply mortality by 1.8

The individual sub-processes of the overall population dynamics like fertility, mortality or migration are not fitted. Ageing of the population is however visible in the results which would ideally be reflected in travel models as well. Ageing has an effect in HRM and HLCM since they include the age of the head of household as independent variable.

Calibration of MATSim Travel model calibration is done against travel times of the cantonal travel model (Vrtic et al., 2005) and previously calculated workplace accessibilities (Löchl, 2010). The travel times are approximately reproduced with the initial parameter set and thus left as they are. The parameter of the distance decay function for accessibility calculation is set to 0.2 (Schilling, 1973).

2.3.1 Validation

Validation is the assessment of model performance after calibration. In a dynamic simulation a validation period has to be defined, here it is from 2000 – 2010. According to Gilbert and Terna (2000, p. 66) validation can be done at 4 levels which depends on simulation performance and detail of validation data.

- Level 0: Behaviour of simulated agents mimics the one of observed object
- Level 1: Qualitative agreement of simulation with empirical macro structures
- Level 2: Quantitative agreement of simulation with empirical macro structures
- Level 3: Quantitative agreement of simulation with empirical micro structures

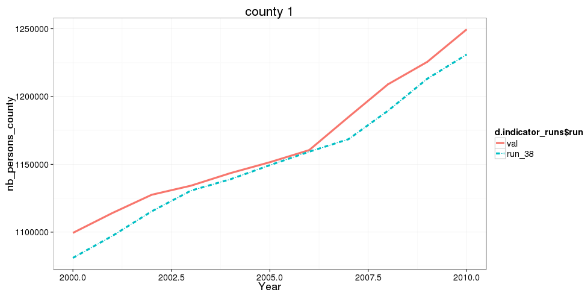
We can validate the base line up to level 3. Different data should be used for validation than for estimation and calibration, therefore we deploy statistics of the cantonal office of statistics (Statistisches Amt Kanton Zürich) (SAKZ). Complicating issues are different categories and irregular times series of the SAKZ-data. It is also a disadvantage to be limited to officially published statistics since they eventually do not include the aspect of interest.

Quantities of interest Validation has to cover the three main dimensions of time, space and content. This means that we have to do a longitudinal analysis (time series) to assess the dynamics and cross-sectional analysis (spatial patterns) to assess distribution in space for each quantity of interest (*e.g.* number of new buildings). For all three aspects we have two options for analysis: Calculate statistic or visualisation for better context related interpretation.

Table 2: Error in main entities 2008

	[%]	Abs. Deviation
nb_persons_county	-1.61	-19501
nb_jobs_county	0.89	6776
nb_living_units_county	4.80	28996
nb_buildings_county	2.16	4906
buildings_volume_sum	6.70	37025.056

(a) Persons



(b) Jobs

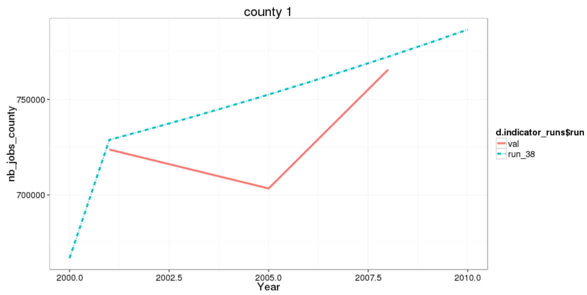


Figure 4: Person and job dynamics in study area

In the following we are looking at the main entities simulated (persons, jobs and projects). Firstly, we look at the simulation errors after 8 years of simulation, secondly we analyse the simulated data longitudinally, and thirdly we look at spatial metrics.

Deviation after validation period Of first interest is the error after simulation of the whole validation period. Table 2 shows the errors regarding the main entities after 8 years of simulation. The year of comparison is chosen because validation statistics for jobs are only available for 2008. The totals show underestimation for persons and overestimation for all other quantities. The simulation overstates especially built space production (6.7% in volume and 4.8% in living units).

Assessment of dynamics Figure 4(a) shows the main result of the demography model which is total population over time. Demographic development is reproduced with high accuracy (coefficient of variation (CV) smaller than 0.0125) which is also a consequence of calibration. The jobs side is less interesting since the numbers show the assumed control totals. The kinks in the validation data are due to limited employment censuses availability (2001, 2005 and 2008).

(a) Number of living units (b) Building volume

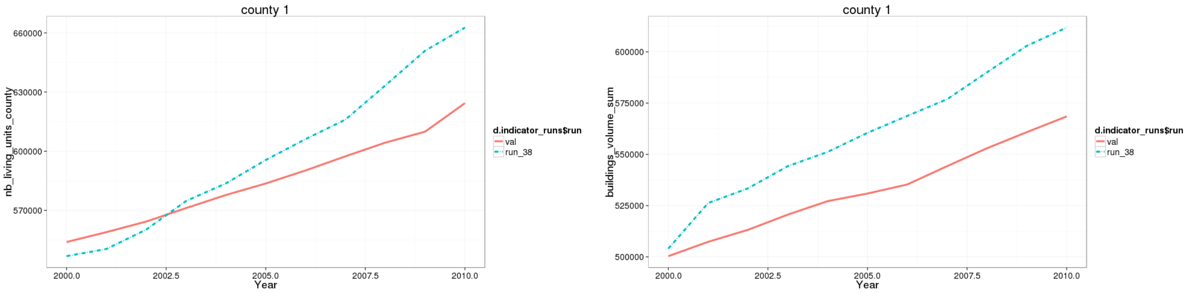
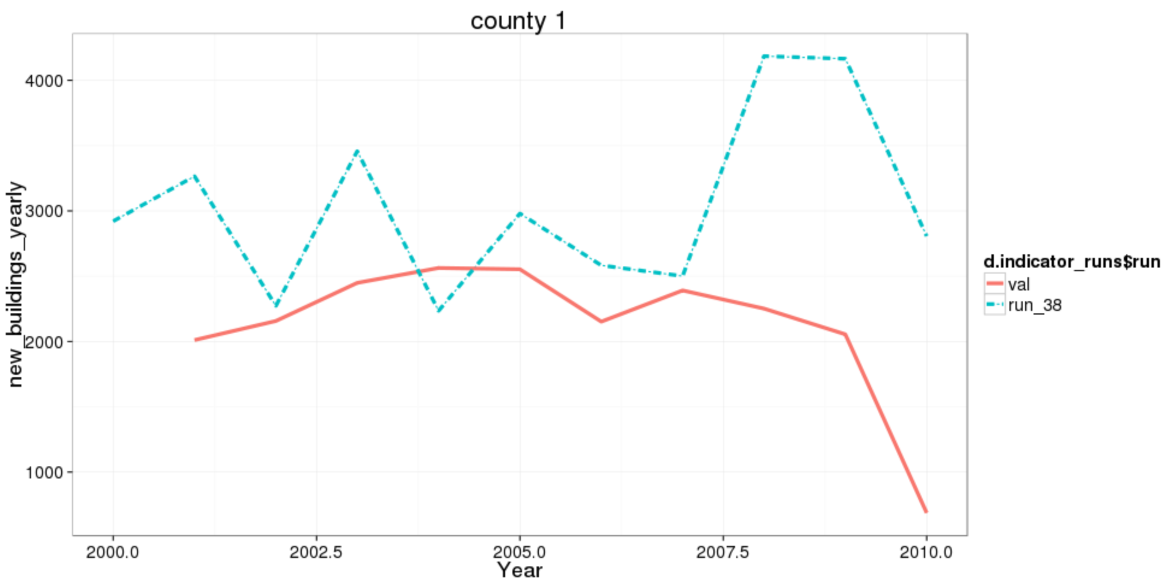


Figure 5: Built-space dynamics in study area

Figure 6: Validation of new buildings added to the building stock per year



Source: Data GWR

More interesting are the totals of living units and building volume. They show overall production determined by the building and living units transition model. Simulated surpasses actual production during the simulation (Fig. 5). Figure 6 shows the comparison of simulated new construction in terms of buildings to the validation statistics. *I.e.* we are looking at the first derivative of building stock development. The increase in terms of buildings is pretty constant over the validation period. The CV ranges between 0.05 and 0.5 over the years not considering values in 2010. This shows that accuracy is variable over time and way lower compared to metrics of the overall stock where CV varies between 0.005 and 0.05. It also reflects relatively little dynamics in the building stock in relation to the total mass.

Table 3: Validation statistics over municipalities for selected indicators with respect to construction in 2008

variable	Min	Q1	Mean	Median	Q3	Max	Sd
nb_persons_city	−23.58	−7.30	−0.42	−3.44	4.97	37.63	10.85
jobs_city	−46.38	−22.60	−2.64	−10.00	8.59	177.23	31.94
nb_living_units_city	−18.54	−1.00	6.24	4.02	12.69	42.96	10.74
nb_buildings_city	−16.17	−2.35	2.00	1.42	5.03	23.43	6.49
buildings_volume_sum	−42.17	−6.82	3.53	1.63	13.45	52.10	15.56

Spatial assessment The distribution metrics in Table 3 show that buildings are regionally (per municipality) most accurately predicted (6.5%). Living units follow with 10.7% which is almost equivalent accuracy as in case of persons (10.8%). The two entities are strongly related since households choose living units to locate. It is therefore not possible that persons are better distributed than living units. Larger standard deviation (sd) for building volumes suggest that the projects are not sufficiently modelled in terms of volume. Employment shows largest sd which suggest that these location choice models might be improved first.

3 Scenario

After having calibrated and validated the simulation one can start with scenario simulation. Here we simulate only one scenario as proof of concept because quality of the simulation is not yet on a satisfactory level. Simulation and their evaluation are further very time consuming which did not allow to run multiple experiments which is actually desirable.

3.1 Scenario definition

Since we only do an exemplary scenario we rely on the approach of changing one factor at a time. This factor is the developer type shares in the developer population. In the current implementation this means to change the number of projects with a certain developer type. For the scenario we set the share of projects developed by *Smc* developers to 60% in the development project pool. Developer types are derived from observations on real estate projects as shown in Table 4.

Table 4: Definition of developer types in DOCUMEDIA data

Developer type code	Developer type name	Purpose	Number of projects
O1	Self-owning without portfolio strategy	Own use or letting	1
Om	Self-owning with portfolio strategy	Own use and or letting	Several
Smc	Commercial developer / Promoter	Sale	Several or 1

3.2 Results of scenario run

The scenario results are assessed similar to the validation of the baseline. However, it seems better to go topic wise about the results. Within each topic the following order is obeyed. Firstly, we are looking at the effects after the whole simulation period. Secondly, we investigate the dynamics which led to the outcome by analysing the simulated data longitudinally. Thirdly, we add the spatial component which finally reveals the spatio-temporal dynamics of the simulation. Simulation data from the baseline is now the reference to which the scenario is compared to.

The following topics are treated in order of appearance:

- Main entities
- Supply by developer type
- Centrality of developments by developer type
- Density of development
- Land consumption
- Compactness
- Price

Validation of the scenarios cannot be done against measured data since we cannot replace the developer population and observe what happens in the next decades. Therefore, the scenario can only be validated up to level 0 since we do not have any data on the hypothesised development. Results on the system level can however be examined for plausibility (subsection 3.2).

Main entities Table 5 shows the relative and absolute deviation of the scenario to the baseline. There are more persons in the scenario than in the baseline, which is surprising since the demography data is the same. The difference comes from the fact that not all households, and consequently persons, can be located. Persons in a household without a living unit ID are not counted in this indicator. One can thus conclude that there are more homeless people in the baseline. The same happens with jobs, but there are only 9 unplaced jobs. Sort of the same as

Table 5: Scenario effects 2029 regarding totals of main entities

	[%]	Abs. Deviation
nb_persons_county	3.52	50424
nb_jobs_county	0.00	9
nb_living_units_county	3.01	23011
nb_buildings_county	0.38	1015
buildings_volume_sum	-1.38	-10525.8790000001

well happens in case of buildings and living units which cannot find a suitable parcel. These buildings remain unplaced. Again, there are more buildings unplaced in the baseline. The available parcels are more efficiently used in the scenario.

Dynamics Fig. 7 shows the evolution of population sizes during the simulation. Households and persons show the predicted linear increase as simulated by the demographic model. The exponential increase of jobs is the assumption implemented via control totals. The close match of living unit and household curves is the consequence of the vacancy mechanism that controls the amount of new living units provided. Building volumes have been summed over the whole set of buildings regardless of whether or not they could have been located. Therefore, there is no kink visible. The only difference between the scenarios concerns the number of buildings which is smaller assuming consolidation in the developer population.

Spatial variation There is a tendency in the scenario for household to locate more in peripheral municipalities. The comparison with living units shows that they follow their housing options. Jobs move from peripheral municipalities to more central ones. Buildings are increasingly located in the Glatttal region (Fig. 8).

Supply by developer type The results in Table 7 show that an assumed consolidation of real estate industry leads to less projects which is explained by the bigger size of the projects. Developments and living units provided by *Smc* developers increase. This is a direct consequence of the scenario definition.

Dynamics The dynamics of real estate production (Fig. 9) is steadily following the vacancy. This is not very realistic and has to be improved in further modelling work. Divergence of developments realised by the respective developer types is also steadily increasing. Measuring supply in terms of living units gives the same insights. Resulting end effects have been discussed before.

Table 6: Descriptives of distributions of deviations [%] of considered indicators over municipalities

Indicator	Min	Q1	Mean	Median	Q3	Max	Sd
Main entities							
nb_persons_city	-20.00	0.02	5.64	4.35	9.31	102.07	11.83
nb_hh_city	-22.47	-0.48	5.87	3.92	8.93	114.41	13.01
jobs_city	-82.84	-9.91	10.48	3.76	18.52	314.65	46.47
nb_living_units_city	-22.33	-0.48	5.88	3.80	9.03	122.11	13.45
nb_buildings_city	-19.49	-1.09	0.52	0.24	1.49	53.15	5.46
buildings_volume_sum	-26.04	-3.05	3.77	2.34	7.67	98.91	12.45
Supply by developer type							
developments	-46.06	-5.19	4.79	1.07	8.88	99.61	19.49
developments_o1	-100.00	-35.20	-5.96	-23.76	-8.54	380.00	73.27
developments_om	-71.43	-41.27	-24.33	-29.06	-16.00	100.00	25.53
developments_smc	-20.00	38.03	89.22	58.04	95.33	1400.00	135.36
living_units_developed	-58.17	-1.30	49.24	13.66	30.93	3900.00	319.93
living_units_o1	-100.00	-50.00	-28.05	-33.05	-13.47	300.00	39.83
living_units_om	-89.07	-37.98	11.68	-18.61	9.51	2300.00	199.71
living_units_smc	-83.33	27.65	222.75	64.92	105.05	9000.00	981.38
Central development by type							
developments_high_car_acc_o1	-100.00	0.00	16.51	0.00	0.00	380.00	72.08
developments_high_car_acc_om	-100.00	-29.92	-8.58	0.00	0.00	300.00	41.19
developments_high_car_acc_smc	-100.00	0.00	23.44	0.00	25.00	444.44	69.54
developments_high_pt_acc_o1	-71.43	0.00	9.15	0.00	0.00	411.76	55.16
developments_high_pt_acc_om	-100.00	0.00	-8.35	0.00	0.00	19.16	19.63
developments_high_pt_acc_smc	-100.00	0.00	8.10	0.00	0.00	209.66	28.18
Density							
pers_km2	-20.00	0.00	5.67	4.37	9.39	102.05	11.83
hh_km2	-22.42	0.00	5.97	3.98	9.14	114.21	13.03
jobs_km2	-82.83	-11.00	10.48	3.59	18.47	316.44	46.87
lu_km2	-22.22	0.00	5.96	3.85	9.09	122.28	13.49
bldg_km2	-19.57	-1.16	0.52	0.00	1.61	53.43	5.52
far_over_residential_zones	-30.99	-4.08	2.68	0.81	6.49	140.44	15.12
Land consumption							
floor_capacity_residential_city	-19.68	-3.20	1.95	0.96	5.11	33.63	8.44
floor_capacity_non_residential_city	-16.16	-1.71	1.31	0.64	4.06	23.93	5.98
Compactness							
person_meter_traveled_car	-94.75	-22.51	33.45	0.67	45.76	699.18	110.10
person_meter_traveled_pt	-91.64	0.00	22.09	0.00	0.00	672.81	104.06
person_minutes_traveled_car	-91.35	-20.14	28.83	4.15	37.42	707.84	99.96
person_minutes_traveled_pt	-70.40	0.00	11.50	0.00	0.00	408.26	58.19
Price							
rent_price_mean	-21.77	-3.43	-1.96	-1.73	-0.10	37.31	5.21

Figure 7: Development of main entity populations in the simulation area over the simulation period

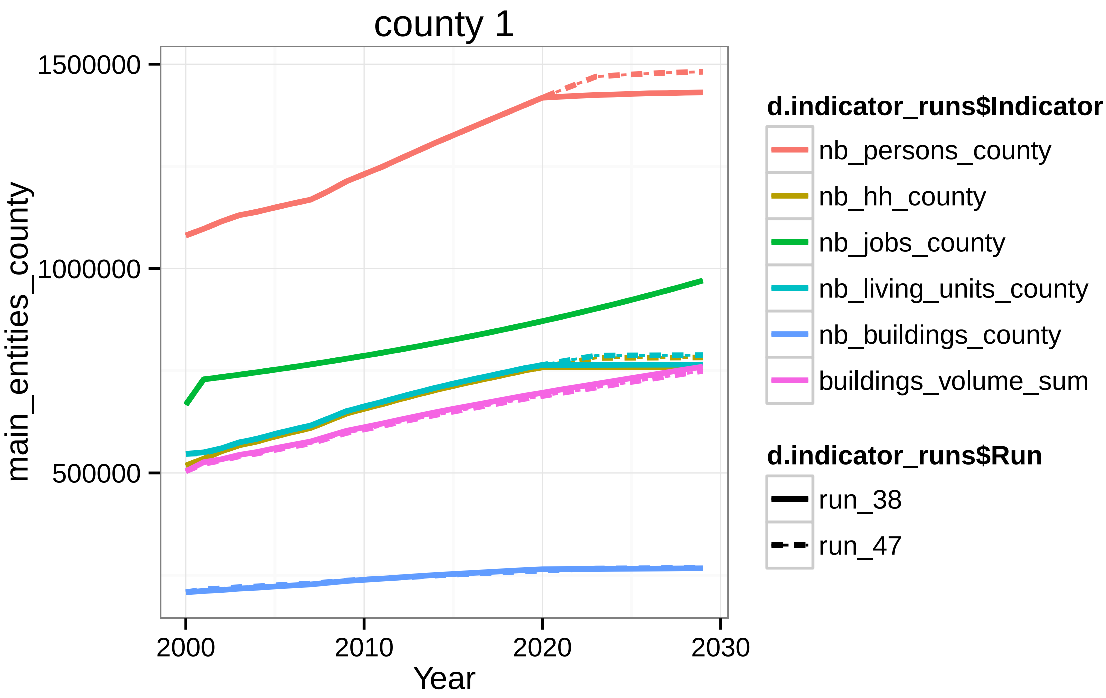


Table 7: Scenario effects 2029 developer type activity

	[%]	Abs. Deviation
developments	-8.07	-5987
developments_o1	-29.40	-6614
developments_om	-38.89	-9075
developments_smc	34.18	9702
living_units_developed	-0.02	-110
living_units_o1	-41.36	-14438
living_units_om	-27.48	-26905
living_units_smc	27.61	41233

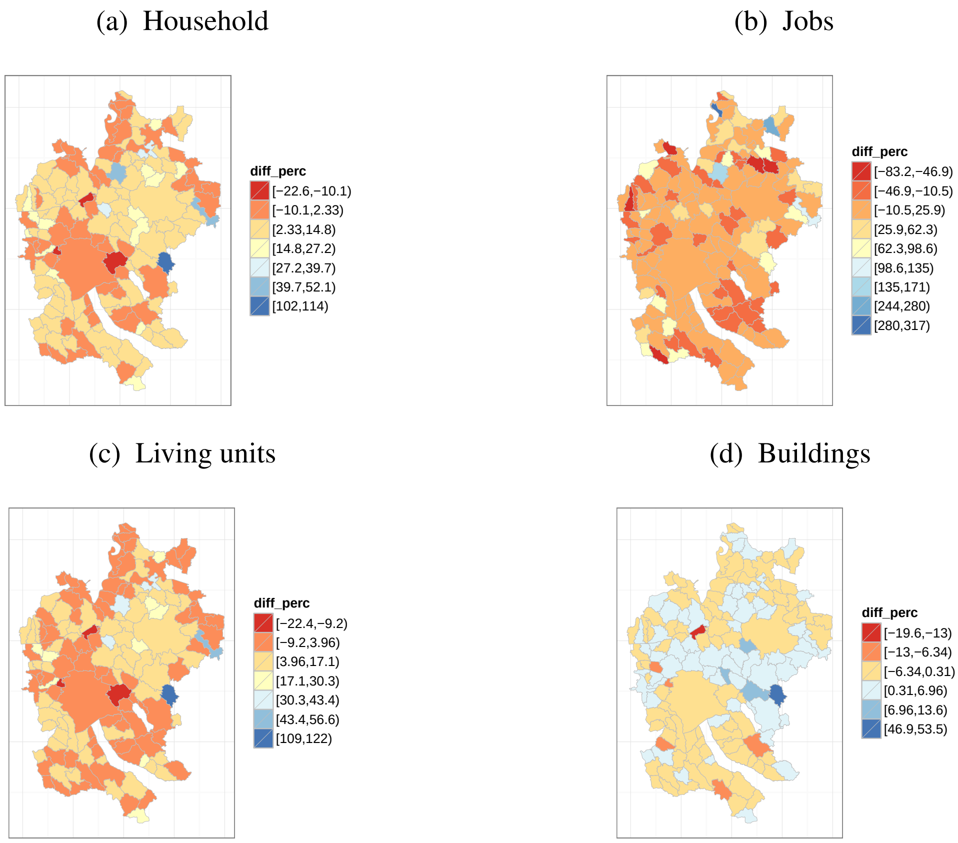


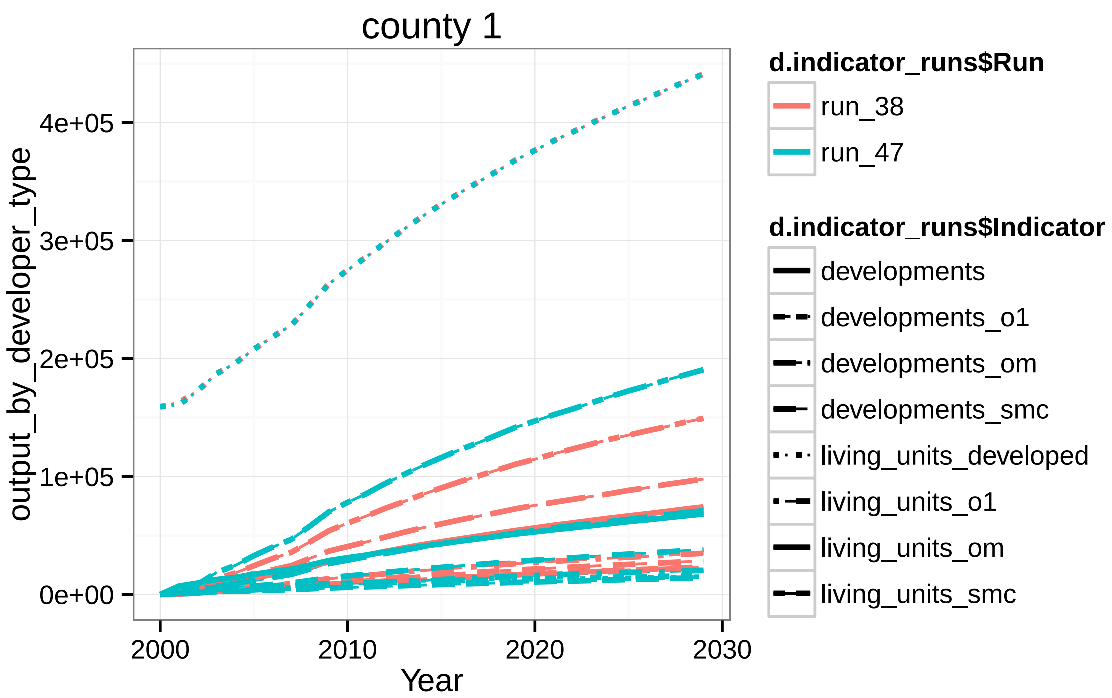
Figure 8: Spatial variation in densities of main entities.

Spatial variation The maps in Fig. 10 show that developer types to not build in the same areas. While *O1* developers largely build in the Glattal, *Om* developers develop very dispersedly over the canton. Developers of type *Smc* largely build in the eastern municipalities. Higher presence of *Smc* developers concentrates development activity of each developer type to a few municipalities (Fig. 11).

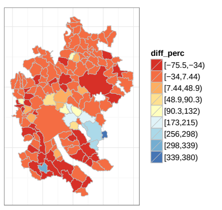
The descriptive statistics in Table 6 show positively skewed distributions for the developer specific supply indicators. This means that there are some municipalities which get a lot more construction or a lot less construction. Most (interquartile) municipalities experience variations between -50% and 100%. Skewness is higher for development projects. The tail of the distributions is however fatter for living units where the maximum deviation is 3900% compared to the third quartile being 31% only.

Centrality of developments On the next pages we assess the "centrality" of development. We define *centrality* as parcels with higher than average accessibility. We have two centrality structures related to the considered modes (car, PT). Also, centrality is defined in respect of job locations, *i.e.* large replacements of jobs would have an effect on "centrality" of locations.

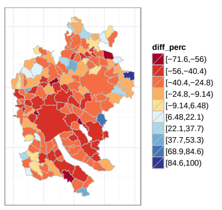
Figure 9: Developments by developer type over time



(a) O1



(b) Om



(c) Smc

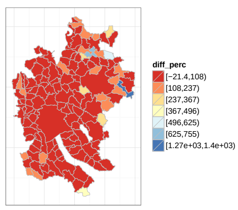


Figure 10: Spatial variation in supply by developer type [Projects].

Development happens more central in the scenario. This is the general message from Table 8. With respect to car 11.2% more developments are on parcels with high accessibility, with respect to PT it is 2.95%. The increase happens due to *O1* and *Smc* developers. In case of *Smc* developers it is arguably as well due to overall increase which is not the case for *O1* developers. Developments of *Om* developers decrease at central parcels by 36.8% in respect of car mode and 41.24% regarding PT. The situation is similar for single family housing (SFH) and multi family housing (MFH) developments. The second hypothesis is thus confirmed by the simulation.

Dynamics In Fig. 12 we find the hypothesised effect that *Smc* developers would dominate at "central" places over time. This is evidence for the theoretical reasoning that more professional developers find better options there.

(a) O1 (b) Om (c) Smc

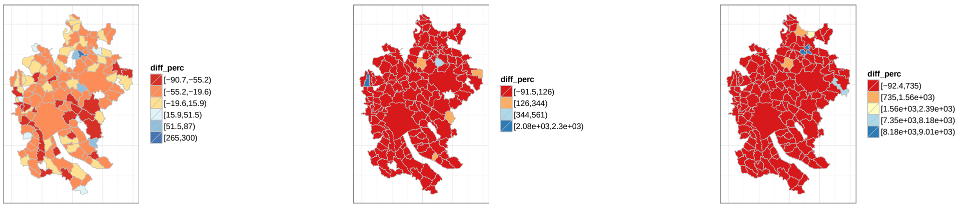


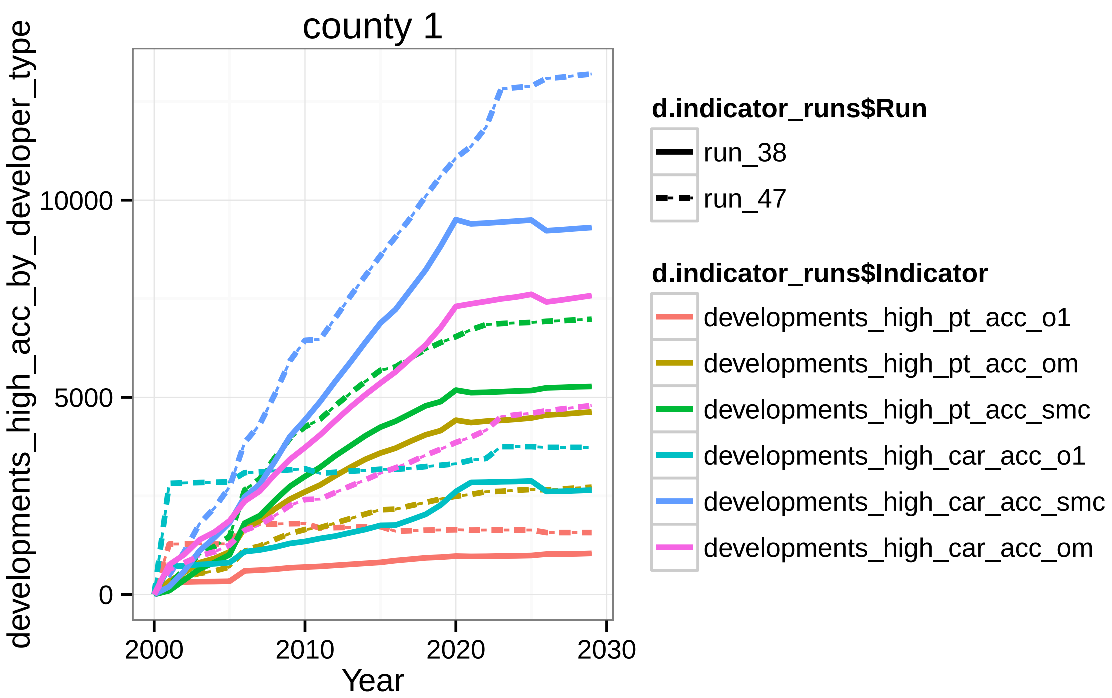
Figure 11: Spatial variation in supply by developer type [Living units].

Table 8: Effect on high accessibility developments in 2029 by developer type

	[%]	Abs. Deviation
developments_high_pt_acc	2.95	323
developments_high_pt_acc_o1	50.67	528
developments_high_pt_acc_om	-41.24	-1909
developments_high_pt_acc_smc	32.30	1704
developments_high_car_acc	11.20	2187
developments_high_car_acc_o1	40.91	1083
developments_high_car_acc_smc	41.84	3894
developments_high_car_acc_om	-36.80	-2790
sfh_developments_high_car_acc_o1	-37.24	-308
sfh_developments_high_car_acc_om	-48.69	-463
sfh_developments_high_car_acc_smc	25.88	301
mfh_developments_high_pt_acc_o1	-68.97	-40
mfh_developments_high_pt_acc_om	-46.95	-1314
mfh_developments_high_pt_acc_smc	27.52	1202
living_units_high_car_acc	4.20	16042
living_units_high_car_acc_o1	-36.18	-2095
living_units_high_car_acc_om	-25.41	-10341
living_units_high_car_acc_smc	33.95	20366
living_units_high_pt_acc	2.32	6958
living_units_high_pt_acc_o1	-48.78	-718
living_units_high_pt_acc_om	-32.70	-9451
living_units_high_pt_acc_smc	22.54	8170

It is interesting to see that some curves encounter a flat after a while. High accessibility parcels seem no longer available at that point. Spatial planning organisations may react in such a situation to provide new development opportunities of that kind. The plot also shows that the

Figure 12: High accessibility developments in the Canton according to developer type



"stocks" do not run out at the same time. Depending on the scenario the shortage is earlier or later. The drop in high car accessibility developments originates from new transport conditions[4] since buildings are not destroyed.

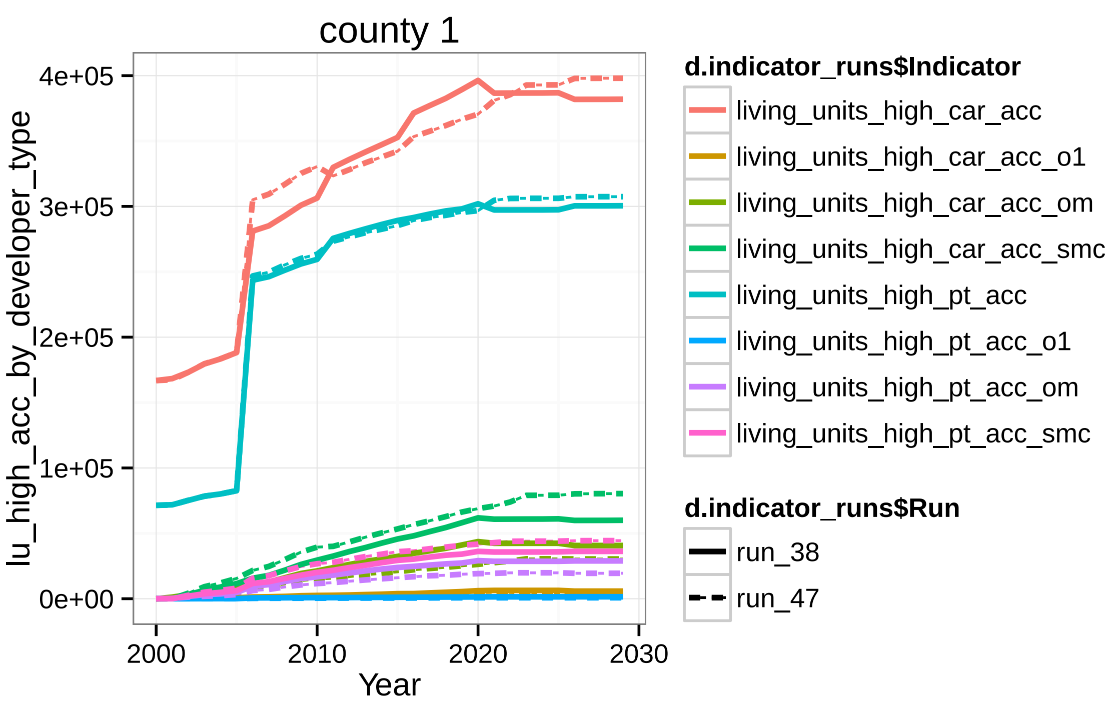
Figure 13 shows at the top all living units in the study area on highly accessible parcels. Therefore, the number of living units developed in the simulation is smaller. The plot shows that a large increase of high accessible living units actually happens through real estate supply unrelated mechanisms. These can include better conditions on the transport system or better distribution of jobs in respect to the residential places. Nevertheless, at the end of the simulation more high accessible living units are provided in the scenario. This is related to the availability of suitable parcels.

Spatial variation Highly car accessible parcels are only found in a subset of all municipalities. These are shown in Fig. 14 and explain the median and quartile zeros of the statistics in Table 6. In the scenario we see an increase of provided living units in Winterthur.

It is surprising that *O1* developments show more deviation since the share of *Smc* developers has been increased. But since all compete for the same parcels, *O1* developers get likewise effected.

[4]Car accessibility is decreasing (Fig. 19)

Figure 13: High accessibility living units in the Canton according to developer type



(a) O1 (b) Om (c) Smc

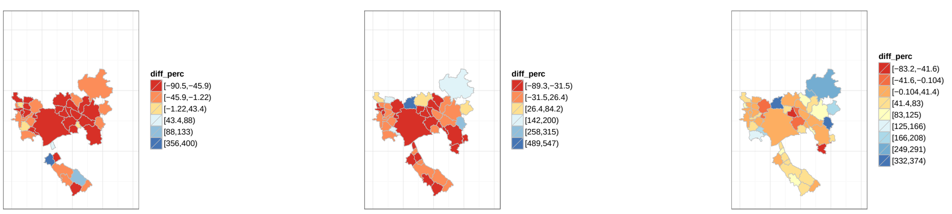


Figure 14: Spatial variation in supply on highly accessible parcels by developer type [Living units].

A deviation of -100% occurs if a municipality did not get any project in the scenario but only in the baseline.

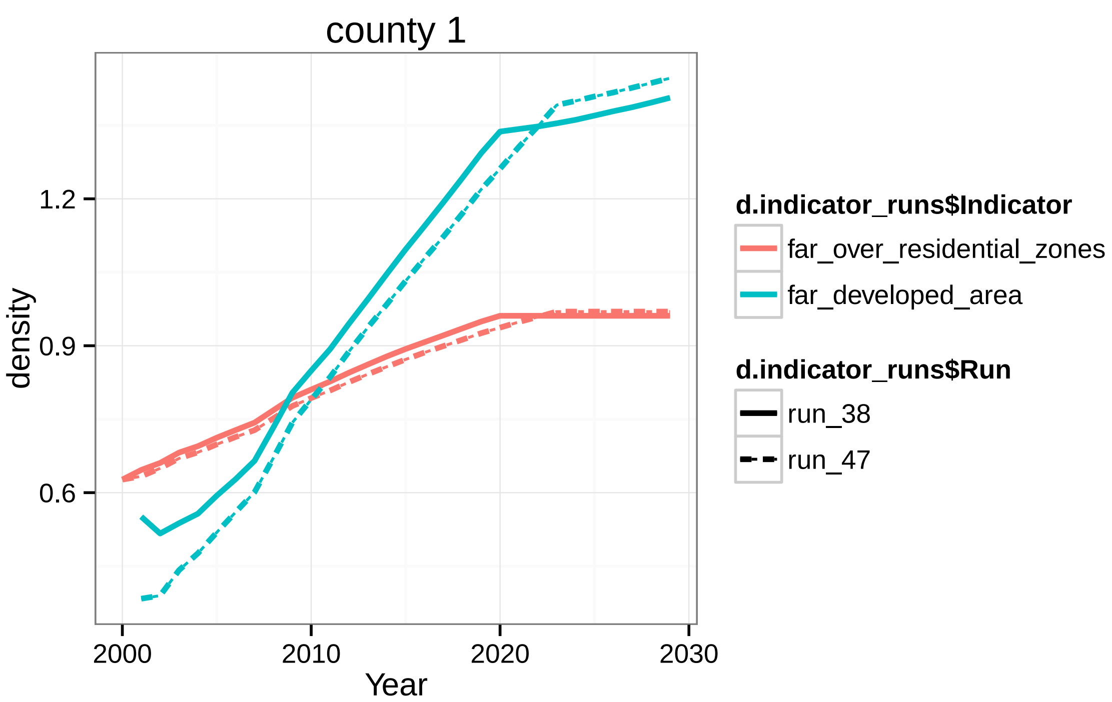
Density All density indicators show higher density for the scenario (Table 9). This seems to be the consequence from different project structures the developer types are associated with. The increase in density is almost 2% higher where development occurs. However, the effect is also visible over all residential zones (0.89%). A consolidated developer industry also seems to produces a higher living unit density in residential zones by 2.85%

Dynamics A look at the dynamics reveals that density overtakes only in the last 10 years of

Table 9: Effects on built space density in 2029

	[%]	Abs. Deviation
far_over_residential_zones	0.89	0.0085
far_developed_area	2.84	0.0400
living_units_ratio_over_residential_zones	2.85	0.0001

Figure 15: Density measured as floor area ration (FAR) in residential zones and developed area

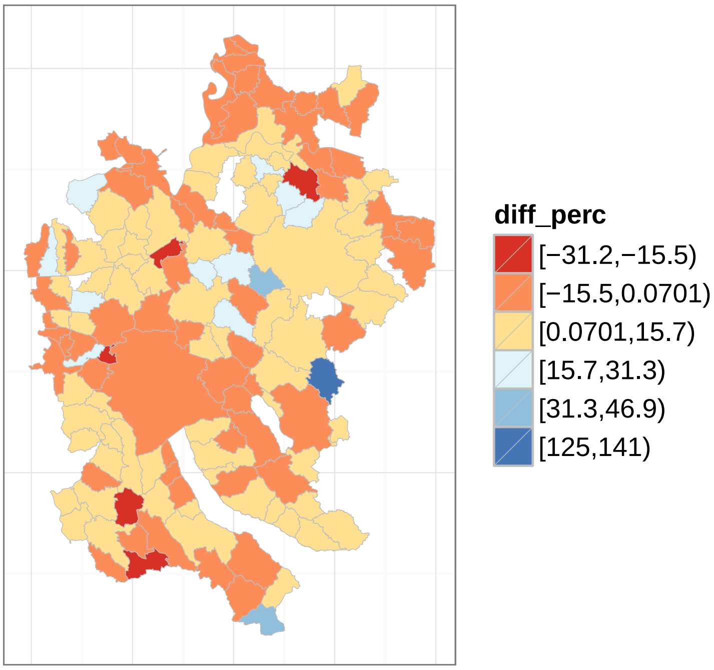


simulation (Fig. 15). The timing of the kinks suggest that it is again related to shortage of development opportunities (Fig. 17). The plot shows as well that the dynamic depends on the scope of the indicator. Only looking at developed areas shows much more dramatic change compared to all residential area. From the dynamics we conclude that the baseline population would create denser built space if appropriate parcels were available.

Spatial variation The consolidation leads to higher densities in rural municipalities (Fig. 16). This is counter intuitive but consistent with the estimation of location choice models. It is again some few municipalities which benefit from less densification.

Median and mean are positive which means that a majority of municipalities gets more densely

Figure 16: Spatial variation of FAR over municipalities



built than in the baseline. While the minimum deviation is -30% the maximum is 140% which is substantially denser. The median FAR deviation in residential zones is 0.8% (Table 6).

Land consumption Land consumption indicators in Table 11 show that there is a problem regarding available land for residential development. The number of parcels for residential development cannot be calculated for 2029. In 2018 the relative deviation is a staggering percentage of 854% which is due to the small number of parcels left in the baseline. This becomes clear when checking the time series of the indicators (Fig. 17). The scenario uses 2.7% less land in 2029 than the baseline according to the building footprints. This figure is inaccurate because some of these buildings are not located on a parcel. This hypothetical condition is miss leading and has to be corrected. The developer model with flexible templates would produce more realistic results. The signs of the indicator are however equal in 2018 when still all developments can be located. By the end of the simulation floor capacity for the whole area is 1% higher in the scenario.

Dynamics Figure 17 shows the much higher demand for residential parcels. They are fully consumed around 2020 in both scenarios. From then onwards, the simulation cannot locate residential development any more. Analysis of buildings without a parcel ID shows that this

Table 10: Effects on land consumption in 2029

	[%]	Abs. Deviation
sum_of_building_footprints	-2.69	-1909629
floor_capacity_county	1.06	815741
parcels_for_residential_development	NA	0
parcels_for_nonresidential_development	-11.98	-904

Table 11: Effects on land consumption in 2018 and 2029

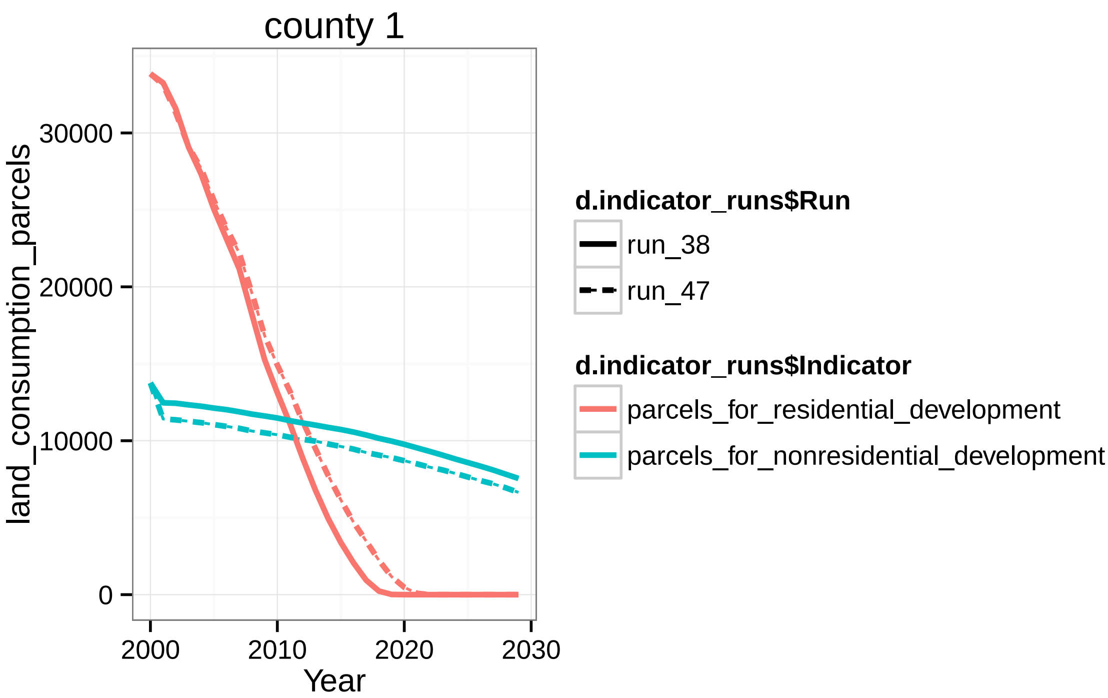
	2018		2029	
	[%]	Abs. Deviation	[%]	Abs. Deviation
sum_of_building_footprints	-1.94	-1242663	-2.69	-1909629
floor_capacity_county	0.74	581371.897999987	1.06	815741
parcels_for_residential_development	853.85	1998	NA	0
parcels_for_nonresidential_development	-10.74	-1091	-11.98	-904

is the case in the baseline from 2020 onwards and in the scenario from 2023. Non-residential development does not show such problems. Indeed, it seems that there is oversupply for non-residential land in the study area. Whereas demand for residential land is higher in the scenario, the opposite is true for non-residential land.

Spatial variation Changed development activity also leads to a different pattern in remaining floor capacities Fig. 18. It is basically the complementary map to Fig. 10 which features the provided units. There is no visible structure in the spatial distribution of deviations neither for residential nor for non-residential zones. Variation is higher in respect of residential capacity (8.4% sd) compared to 6% for non-residential (Table 6).

Compactness A way of measuring the *compactness* of spatial development is travelled vehicle distance. The simulation shows less compactness with 8.25% higher travelled vehicle distance. Given the higher development on highly accessible parcels, this result is surprising. Expected is more travel with PT since it is the more preferred mode in central areas. Compared to the baseline PT use increases 23%. This reflects not only longer distances per trip but also different mode shares. The scenario has a smaller car share (0.9%) and a larger PT share (12%). Note that the absolute deviation is the same but the car mode is dominant with a share of roughly 90%. The transport model thus is badly calibrated towards mode share. Current model split

Figure 17: Parcels for development over time according to main categories of use



(a) Residential zones (b) Non-residential zones

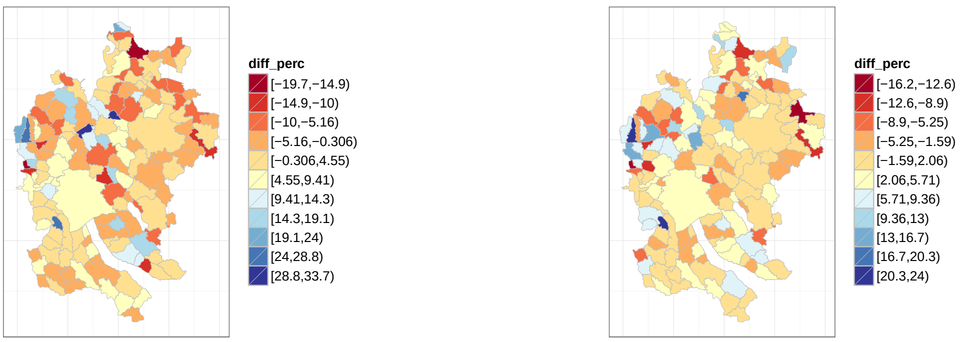


Figure 18: Floor capacity

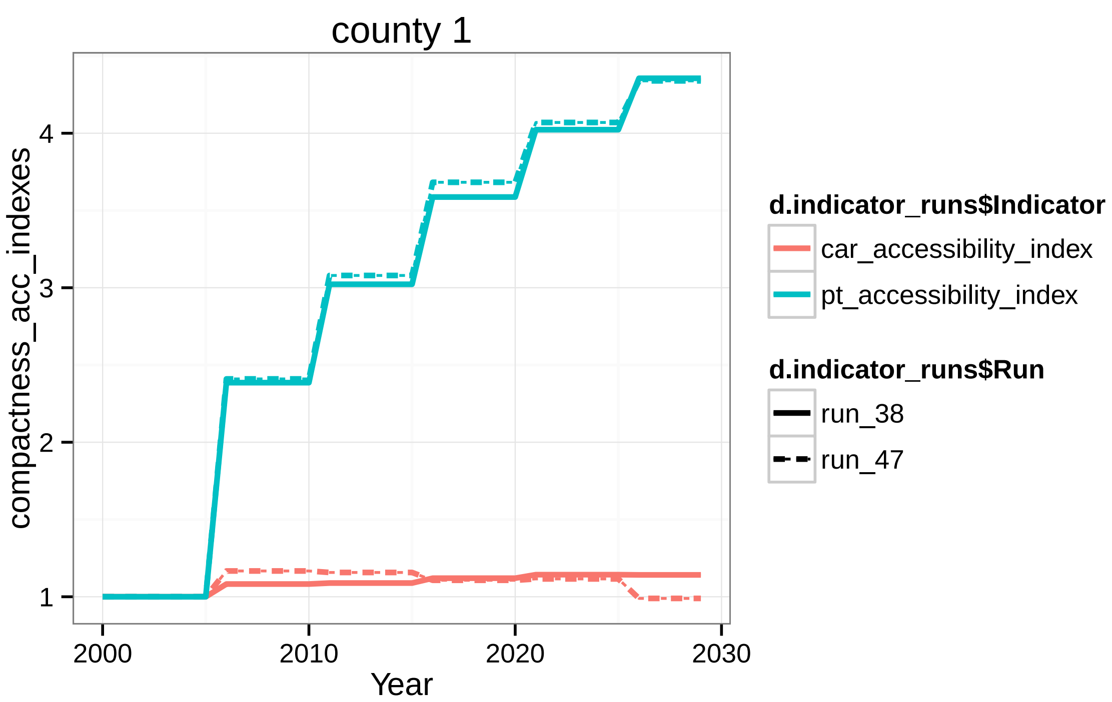
reported in the micro census is a car share of 58% and a PT share of 32% (Hofer, 2012). Car accessibility is substantially lower in the scenario with a reduction of 13%. PT accessibility in contrast is reduced by as little as 0.4%. Travel time – measuring another expenditure for transport – increases even more in the scenario (9.1%). Comparatively highest increase is found in areas around CBD's which indicates more congestion in the scenario.

Dynamics The time series of these indicators show little variation over the scenarios. An interesting thing can be observed in the accessibility indexes where in the scenario car accessibility gets

Table 12: Effects on settlement compactness in 2029

	[%]	Abs. Deviation
person_meter_traveled	8.25	12939635
person_meter_traveled_car_county	8.90	12292668
person_meter_traveled_pt_county	23.12	2475654
person_minutes_traveled	9.13	16678
person_minutes_traveled_car_county	8.63	12476
person_minutes_traveled_pt_county	20.06	5849
person_minutes_traveled_densification	33.44	2418
share_persons_car_county	-0.92	-0.008
share_persons_pt_county	11.59	0.008
car_accessibility_index	-13.33	-0.152
pt_accessibility_index	-0.38	-0.017

Figure 19: Mode specific accessibility indexes over time



worse. The contrary is the case in the baseline (Fig. 19). At this point it is not clear whether this is due to worse travel times on the road or worse spatial constellation of jobs versus residential locations. The stair like curve is an artefact of running the travel model only every fifth year.

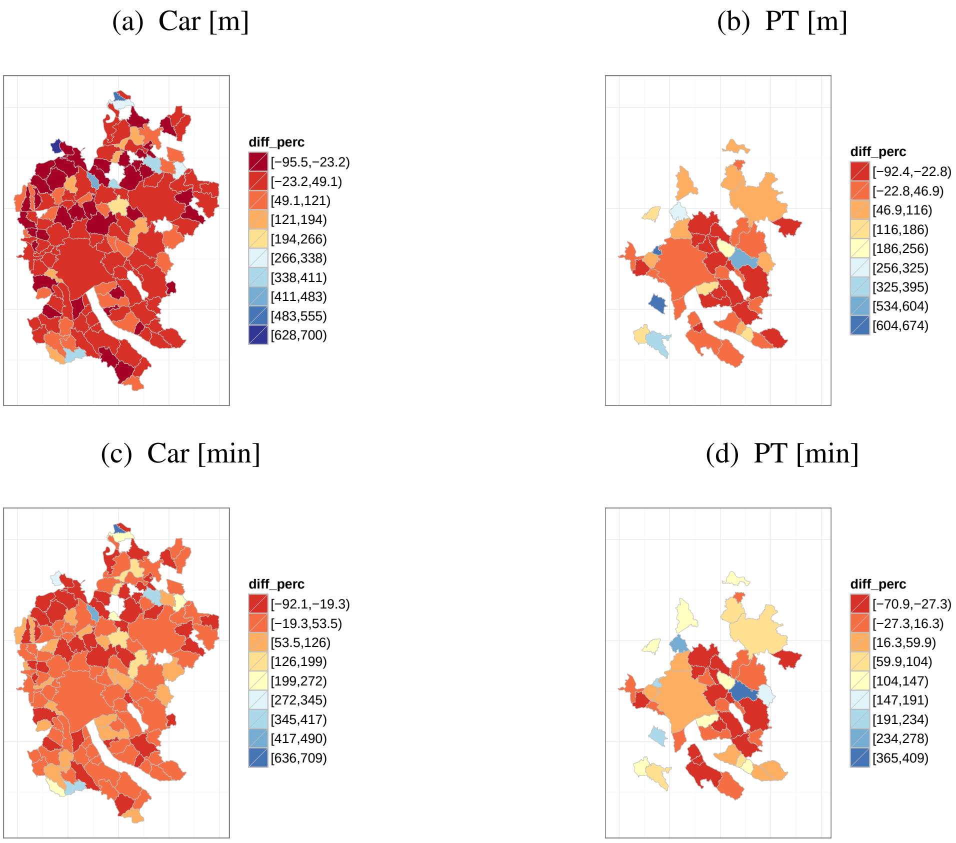


Figure 20: Compactness of society

Spatial variation The reason why some municipalities are not shown is that not from all municipalities a inhabitant gets simulated. This is especially unfortunate and inadequate for PT which shows a lower coverage of the study area. The mode share is much too low as discussed before. It clearly shows the problematic of simulating 10% samples in context of a LUTI model. For the municipalities with simulated inhabitants we see travel distance and travel time reductions which are fairly well distributed. However, municipalities in the North seem to profit a little bit more. In respect of public transport it is after all the Glatttal which benefits. Variation is highest with respect to distance travelled by car (110% sd). The spread is however larger in terms of travel time by car.

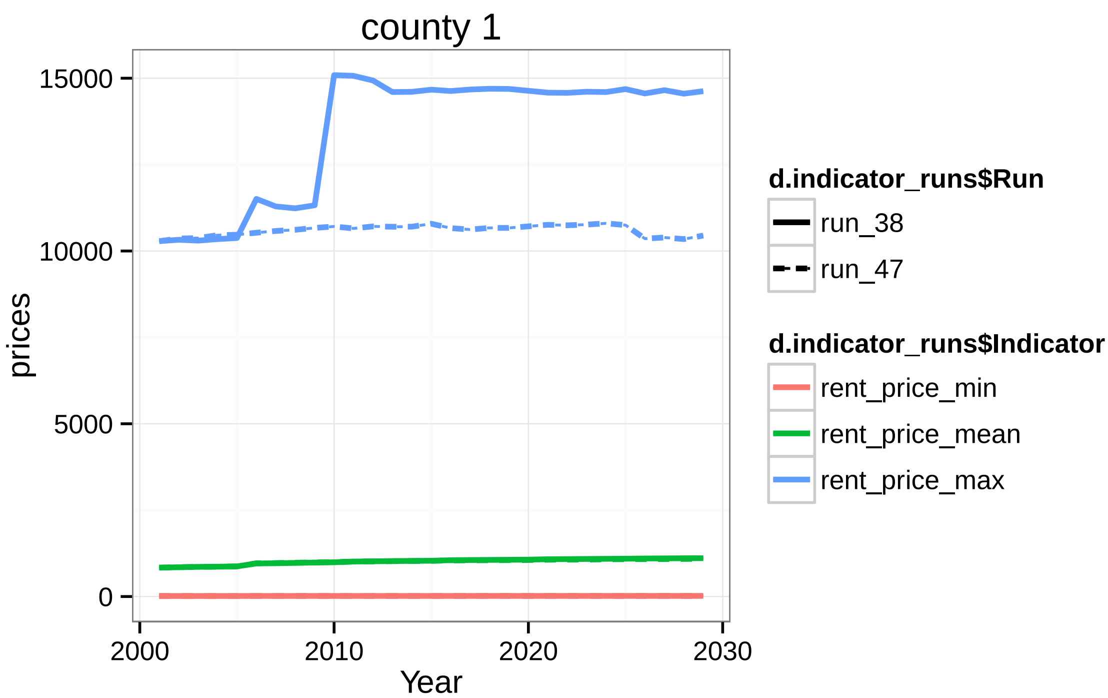
Rent prices The only simulated price at this point is rent price. The scenario shows lower prices which is mainly due to lower maximum prices (Table 13). For maximum prices the relative deviation is almost 30%. In contrast, the minimum price is higher by 1.84%. The reduced variance of prices is also shown in the smaller sd.

Dynamics The divergence of the maximum price seems to be a development in 2010 (Fig. 21). It is possible that we see only one exceptional event. However, boxplots of the prices per year

Table 13: Effects on rent prices in 2029

	[%]	Abs. Deviation
rent_price_min	1.84	0.34
rent_price_mean	-1.73	-19.22
rent_price_max	-28.57	-4178.79
rent_price_standard_deviation	-5.01	-24.51

Figure 21: Rent price statistics over time

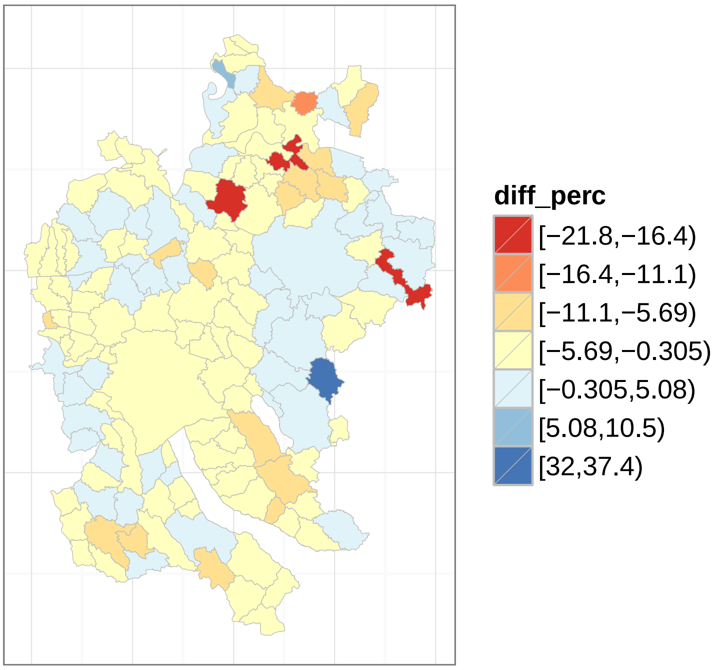


would be a more appropriate visualisation.

Spatial variation Simulation results show rent price increase after all in peripheral municipalities. This is again not expected but in line with predicted densification in these areas (Fig. 22).

The statistics of deviations per municipality show that price increase is concentrated on the fourth quartile of the distribution Table 6.

Figure 22: Spatial variation of rent price mean in 2029



4 Conclusions and outlook

Considering developer types does not improve overall simulation performance. If particular questions shall be answered, it is however necessary to include them. One difficulty is to update the developer population. A ideal model would also keep consistency with households and firms, *i.e.* the developers are either private households or firms. Such a model would need additional data on property transactions and ownership. Records of individual mutations in the land register exist but could not be acquired due to privacy issues.

The consolidated real estate industry would lead to more central development. Still, other indicators do not show more compact and resource friendly development. These results have to be read with care since the simulation is too immature to be confident in the numbers. The exercise has more proof of concept nature and illustrates the potential of a fully operational model. It is worth while mentioning that a lot more information is in the data but has not yet been assessed with the presented indicators.

Indicators such as the number of buildings are biased with the current structure. For correction the project structure needs to be implemented properly. *I.e.* a separate project entity should be related to buildings which are again related to units of use.

There are no satisfactory calibration methods and tools for LUTI models available so far. Attempts for large-scale dynamic transport microsimulation models have been made (Flötteröd et al., 2012) and should be followed for LUTI simulations.

5 References

Balmer, M. (2007) Travel demand modeling for multi-agent traffic simulations: Algorithms and systems, Ph.D. Thesis, ETH Zurich, Zurich, May 2007.

Batty, M. (2009) Urban modeling, in R. Kitchin and N. Thrift (eds.) *International Encyclopedia of Human Geography*, 51–58, Elsevier, Oxford, ISBN 978-0-08-044910-4.

DiPasquale, D. (1999) Why don't we know more about housing supply?, *The Journal of Real Estate Finance and Economics*, **18** (1) 9–23.

Dong, H. and J. Gliebe (2011) Forecasting location of new housing in integrated models of land use, *Transportation Research Record: Journal of the Transportation Research Board*, **2255**, 79–90. ,.

Flötteröd, G. (2009) Cadyts – a free calibration tool for dynamic traffic simulations, paper presented at the *Proceedings of the 9th Swiss Transportation Research Conference*, 18, Ascona.

Flötteröd, G., M. Bierlaire and K. Nagel (2011) Bayesian demand calibration for dynamic traffic simulations, *Transportation Science*, **45** (4) 541–561, ISSN 0041-1655, 1526-5447.

Flötteröd, G., Y. Chen and K. Nagel (2012) Behavioral calibration and analysis of a large-scale travel microsimulation, *Networks and Spatial Economics*, **12** (4) 481–502, ISSN 1566-113X, 1572-9427.

Gilbert, N. and P. Terna (2000) How to build and use agent-based models in social science, *Mind & Society*, **1** (1) 57–72.

Gmünder, M., N. Braun, V. Killer and B. Vitins (2010) Agglomerationsdefinition schweiz, *Schlussbericht*, **Schlussbericht**, IVT, ETH Zürich und B, S, S. Volkswirtschaftliche Beratung, Basel / Zürich.

Haider, M. and E. Miller (2004) Modeling location choices of housing builders in the greater toronto, canada, area, *Transportation Research Record: Journal of the Transportation Research Board*, **1898**, 148–156. ,.

Hofer, T. (2012) Mobilität im kanton zürich, *Technical Report*, **10/07**, Statistisches Amt des Kantons Zürich, Zürich.

Hunt, J. D., D. S. Kriger and E. J. Miller (2005) Current operational urban land-use–transport modelling frameworks: A review, *Transport Reviews*, **25** (3) 329–376.

Killer, V. (2011) Understanding overlapping functional commuting regions with confidence ellipses and social network methods, *Technical Report*, **714**, IVT, ETH Zurich, Zurich.

Löchl, M. (2010) Application of spatial analysis methods for understanding geographic variation of prices, Ph.D thesis, ETH Zurich, Zurich.

Malik, K. (2013) *Human Development Report 2013. The rise of the South: Human progress in a diverse world.*, 1 edn., United Nations Development Programme (UNDP), New York, ISBN 978-92-1-126340-4.

Schilling, H. (1973) Kalibrierung von widerstandsfunktionen, *Technical Report*, **73/1**, Lehrstuhl für Verkehrsingenieurwesen, ETH Zurich, Zurich.

Schirmer, P., C. Zöllig, K. Müller, B. R. Bodenmann and K. W. Axhausen (2011) The zurich case study of UrbanSim, paper presented at the *Proceedings of the 51th Congress of the European Regional Science Association*, Barcelona.

Schirmer, P., C. Zöllig Renner, K. Müller, B. R. Bodenmann and K. W. Axhausen (????) Transport and land use microssimulation on the canton of zurich using UrbanSim, in R. Hurtubia, M. Bierlaire, P. Waddell and A. de Palma (eds.) *Handbook on integrated transport and land use modeling for sustainable cities*, xx–xx, EPFL Press, Lausanne.

Schirmer, P. M., M. A. B. van Eggermond and K. W. Axhausen (2013) Measuring location in residential location choice: An empirical study on the canton of zurich, paper presented at the *Proceedings of the 13th International Conference on Computers in Urban Planning and Urban Management (CUPUM)*, Utrecht.

Schüssler, R. and P. Thalmann (2005) Was treibt und hemmt den wohnungsbau? ergebnisse einer bauträger- und investorenbefragung, *Technical Report*, **76**, Bundesamt für Wohnungswesen (BWO), Grenchen.

Staatskanzlei des Kantons Zürich (2012) Kantonale volksinitiative zum erhalt der landwirtschaftlich und ökologisch wertvollen flächen (kulturlandinitiative). abstimmungsergebnis, in *Zürcher Amtsblatt*, 1352–1356, Kanton Zürich, Zürich.

Thalmann, P. (2012) Housing market equilibrium (almost) without vacancies, *Urban Studies*, **49** (8) 1643–1658, ISSN 0042-0980, 1360-063X.

Turci, L., S. Pennec, L. Toulemon, A. Bringé, E. Morand and R. Baggio (2012) Demographic model user guide, *Technical Report*, **4.4**, INED, Paris.

UrbanSim Developers (2013) UrbanSim WebHome, `http://www.urbansim.org/Main/WebHome`.

Vrtic, M., P. Fröhlich, N. Schüssler, P. Kern, F. Perret, S. Pfisterer, C. Schulze, A. Zimmermann, U. Heidl and K. W. Axhausen (2005) Verkehrsmodell für den öffentlichen verkehr des kantons zürich, *Technical Report*, Amt für Verkehr des Kantons Zürich, IVT, ETH Zürich, Ernst Basler + Partner AG, Planung Transport Verkehr (PTV), Zürich.

Zöllig, C. (2013) Modelling real estate development with heterogeneous agents.

Zöllig, C. and K. W. Axhausen (2012) Heterogeneity of real estate developers in canton zurich, paper presented at the *Proceedings of the 12th Swiss Transport Research Conference*, Ascona.

Glossary

calibration Process of adapting a general model to specific circumstances. 8, 9

urban modelling The process of identifying appropriate theory, translating this into a mathematical or formal model, developing relevant computer programs, and then confronting the model with data so that it might be calibrated, validated, and verified prior to its use in prediction. (Batty, 2009, p. 51). 8

validation Process to prove that something is correct or works correctly. 9, 10, 13

Acronyms

ARE Cantonal Office for Spatial Development (Amt für Raumentwicklung). 4

BTM building transition model. 5, 6

CV coefficient of variation. 11

ELCM employment location choice model. 5–7

ERM employment relocation model. 5, 7

ETM employment transition model. 5, 7

FAR floor area ration. 23, 24

GUA geographical units of analysis. 1
GVZ building insurance Canton of Zurich (Gebäudeversicherung Zürich). 4
GWR federal building and housing register (Gebäude- und Wohnungsregister). 4, 12

HLCM household location choice model. 5, 7, 9
Hlt health. 7
HR hotels and restaurants. 7
HRM household relocation model. 5, 7, 9

LUTI land use transport interaction. 1–3, 5, 8, 26, 29

MATSim multi-agent transport simulation. 5, 8, 9
MFH multi family housing. 19
MNL multinomial logit. 5, 7

PLCM project location choice model. 5, 6
PT public transport. 8, 18, 19, 26, 29

REDM real estate development model. 1
REPM real estate price model. 5, 6

SAKZ cantonal office of statistics (Statistisches Amt Kanton Zürich). 9, 10
sd standard deviation. 12, 25, 27
SFH single family housing. 19
SQL structured query language. 3
Srv Service. 7

TAZ traffic analysis zone. 1

WLCM workplace location choice model. 5, 7