Sustainability
Impact Assessment

Module 4

December 2009

**PERI-URBAN LAND USE RELATIONSHIPS – STRATEGIES AND SUSTAINABILITY ASSESSMENT TOOLS FOR URBAN-RURAL LINKAGES, INTEGRATED PROJECT, CONTRACT NO. 036921**

**D4.1.2**

# Examples of functional relationships in a RUR

**Using a stock-and-flow model**

**Dagmar Haase* (UFZ)**

*Responsible partner and corresponding author
Tel: +49 341 235 1950; Email: dagmar.haase@ufz.de

**Document status:**

| | |
|---|---|
| Draft: | completed |
| Submitted for internal review: | completed |
| Revised based on comments given by internal reviewers: | completed |
| Final, submitted to EC: | completed |

SIXTH FRAMEWORK PROGRAMME

# Contents

# Abstract

The major purpose of this document is to present a system dynamics model which is able to compute both growth and shrinkage processes. We uncover nonlinear dynamics and feedbacks between demography, housing preferences and supply of residential space.

**Popular science description of main results**

In Eastern Germany, demographic change and population decline brought up massive changes of the housing stock since after the fall of the Berlin wall in 1990. Urban planners and policy makers face complex problems caused by residential vacancies, demolition actions and the handling of urban brownfields in the inner city in consequence of this demographic decline along with further pressure through an increasing suburbanisation. We present a system dynamics model which is able to compute both growth and shrinkage processes. We uncover nonlinear dynamics and feedbacks between demography, housing preferences and supply of residential space. The simulations on our study area, the city of Leipzig, further show that despite population shrinkage the increasing number of single households leads to a growing total housing supply and a high demand of central housing structures. Beyond that, residential vacancies in certain housing segments will remain regardless population growth. Simultaneously, the model shows that despite population shrinkage and oversupply of flats, there is a negative net-demand on living space in affordable prefabricated housing estates as the percentage of low-income households will increase. These findings help planners to modify or adapt their views on desired or undesired urban futures.

**Classification of results / outputs:**

For the purpose of integrating the results of this deliverable into the PLUREL Explorer dissemination platform as fact sheets and associated documentation please classify the results in relation to spatial scale; DPSIR framework; land use issues; output indicators and knowledge type.

| | |
|---|---|
| Spatial scale for results:<br>**Regional, national, European** | **Regional**<br><br>**A system model of a RUR.** |
| DPSIR framework:<br>**Driver, Pressure, State, Impact, Response** | **All**<br><br>**It is the nature of a system model to compute causal feedbacks in form of closed loops.** |
| Land use issues covered:<br>**Housing, Traffic, Agriculture, Natural area, Water, Tourism / recreation** | **All**<br><br>**Housing.** |
| Scenario sensitivity:<br>**Are the products / outputs sensitive to Module 1 scenarios?** | **Yes**<br><br>**The model incorporates the population scenarios of M1.** |
| Output indicators:<br>**Socio-economic & environmental external constraints; Land Use structure; RUR Metabolism; ECO-system integrity; Ecosystem Services; Socio-economic assessment Criteria; Decisions** | **Yes**<br><br>**Land Use, Socio-economic assessment Criteria, Decisions.** |
| Knowledge type:<br>**Narrative storylines; Response functions; GIS-based maps; Tables or charts; Handbooks** | **Yes**<br><br>**Response functions.** |
| How many fact sheets will be derived from this deliverable: | 1 |

# 1 Introduction

Demographic change, suburban growth and inner-city shrinkage are challenges for urban planners and policy-makers in post-industrial, modern societies (Batty, 2001; Champion, 2001; Kasanko et al., 2006). Particularly cities situated until 1990 behind the iron curtain after 1990 entered a phase of extreme population dynamics – that is rapid and massive inner-city decline along with suburban growth (Kabisch, 2005). An example for those developments is the city of Leipzig, Germany.

After the German reunification in 1990, dramatic changes regarding urban residential land occurred in Leipzig, such as urban sprawl along with residential vacancies up to >30% and demolition of the housing stock (Banzhaf et al., 2007; Haase et al., 2007). Apart from population losses due to migration into the western part of Germany, the main reason for the simultaneity of sprawl and shrinkage lies in both the quantitative and qualitative change of demography-driven housing-demand-patterns by firstly typical suburbanites such as family households and, secondly, “non-traditional” household types such as cohabitating flat-sharers, single-parent families or patch-work families with specific housing preferences (a.o. Börsch-Supan et al., 2001). The absolute and relative growth of the latter group was proven to lead to current reurbanisation processes in inner-city residential areas (Buzar et al., 2007; Haase, 2008) whereas the first group drives ongoing suburban growth (Couch et al., 2005). But demographic change is by far no phenomenon of former socialist countries: in entire Europe the population gets older and traditional family households decrease which implies strong changes in the housing demand (Kaa, 1987, 2004). Population shrinkage of urban regions is meanwhile a trend in all parts of Europe (Kabisch & Haase, in press), but which is so far not very well included in urban simulation models. Present simulation models focus on urban sprawl and growth (Schwarz et al., in press).

Simulation models can help to understand complex dynamics and to derive scenarios for the future (Verburg et al., 2004). In the past, planners directed their actions bearing in mind unrealistic growth scenarios and intentionally or unintentionally supported urban sprawl. Therefore, we see an urgent need to develop quantitative predictions of the housing stock development under conditions of shrinking population.

We develop a system dynamics model to describe an urban region with a closer focus on the interaction between demography, housing demand and supply, respectively. In doing so, we intend to uncover relations between household development of both declining and growing but ageing populations, respective housing preferences and their impact on the housing stock by using population scenarios. A generic view of these relations for a growing and a shrinking city is crucial (Jessen, 2006). This view should first of all include a demand perspective for residential land use change driven by population dynamics. The supply side has to involve variables indicating growth and shrinkage of the built-up space (urban structural types - UST)..Furthermore, the model approach aims at being a helpful tool for understanding complex housing demand-supply processes based on household location preferences, choices and feedbacks of this decision-making.

To tackle the above raised issues this study pursues the following goals:

- Building-up a model that represents dynamics and feedbacks between population development and households, residential demand and housing supply of an urban region.
- Uncovering relationships and feedbacks between population dynamics (growth and shrinkage) and households, household preferences and residential demand, residential demand and housing supply including vacancies.
- Answering the following questions asked by urban planners and policy makers coping with either population growth or shrinkage:
    - Is a currently shrinking city confronted with ongoing residential land consumption?
    - Does an increasing individualisation increase the housing demand?

The paper is organised as follows: After introducing the problem of modelling urban housing demand under conditions of demographic change, section 2 provides some detail on the modelling approach, the software chosen and the case study of Leipzig. The model components and equations are discussed in section 3 before coming to the major results (section 4) and their discussion in section 5. The paper closes with an outlook concerning future amplifications of the model.

# 2 Modelling demographic effects on housing demand

### State-of-the-art in urban causality modelling

In the past, a variety of simulation models for urban land use changes was developed in order to assist urban planning (see reviews by EPA, 2000; Berling-Wolff and Wu, 2004; Haase and Schwarz, 2009). Four different urban modelling approaches can be distinguished: (1) system dynamics, (2) spatial economics / econometric models, (3) cellular automata and (4) agent-based models. (1) System dynamics models are – in their standard application – not spatially explicit. Rather, the structure of combining stocks, flows and feedback mechanisms leads to a set of differential equations (Sterman, 2000). The outcome of these equations can be simulated, given values for parameters and initial conditions (for urban system dynamics, see e.g. Forrester, 1969; Haghani et al., 2003a, b; Raux, 2003). (2) Spatial economics / econometric models (for instance Nijkamp et al., 1993; Mankiw and Weil, 1989) mainly look at demography and household-driven demand-supply relations in urban regions, such as housing market developments. (3) Land use change models use cellular automata with 2-dimensional grids. Each cell symbolises a patch of land, and change rules depend on the one hand on empirical data regarding land use changes in the past and on the other on suitability and zoning regulations (e.g. Verburg and Overmars, 2007; Landis and Zhang, 1998a, b; Engelen et al., 2007). Cells change their state simultaneously according to the same rules, and the state of a cell in time t solely depends on the state of neighbouring cells in t–1. (4) Agent-based models consist of autonomous individuals (agents) that are usually located on a spatially explicit grid. They perceive their environment and interact with one another (Parker et al., 2003). In urban land use models, they represent, for example, households relocating their homes (e.g. Strauch et al., 2003; Salvini and Miller, 2005; Ettema et al., 2007; Loibl et al., 2007; Waddell et al., 2003).
Shrinkage poses challenges for these simulation models because the models were mostly developed for growing cities in industrialised countries. In order to expand such simulation models to also cover urban shrinkage, (1) residential vacancy as an output variable, and (2) the processes of deconstruction and demolition of vacant residential fabric both need to be included. Only few existing simulation models explicitly include vacancy and demolition of residential housing stock (e.g. Forrester, 1969; Sanders & Sanders, 2004; Eskinasi & Rouwette, 2004).

### A new system dynamics approach

Building upon these findings, we decided to build a new urban simulation model that includes both urban growth and urban shrinkage. Although our new model is calibrated using regional and survey data from the urban region of Leipzig, the model approach is applicable to other urban regions in Europe implying the same mix of traditional and non-traditional household types (Haase & Haase, 2007).
System dynamics represent an appropriate tool to identify general causal-feedback loops occurring in an urban region and to build a comprehensive model that encompasses both growth and shrinkage. We chose the system dynamics approach for the following reasons: (1) In a system dynamics model, specific variables interact in form of causal feedback loops which, depending on their polarity, change the system state in a (mostly) non-linear

way (Forrester 1971, 1979; Dhawan, 2006; Sterman, 2002). Both for growth and shrinkage, the possibility of including feedback loops into a model are very important, because on the one hand, growing industrial or residential areas might grow even faster because they attract more growth, and on the other, a declining residential area becomes more unattractive for residents to live there and therefore declines even faster.
(2) System dynamics models are in general not spatially explicit, although sectors or other spatial units can be introduced into such models (Sanders & Sanders, 2004). For setting up a new model approach, it is actually a good starting point to first work with summarised, non-spatial data to capture the main causal relations. For modelling shrinkage, this is another clear advantage, as empirical data on the spatial distribution of vacant residential or commercial areas are hard to find.
(3) System dynamics models are suitable and often used to derive scenarios and future projections (see examples in Eppink et al., 2004; Forrester, 1969; Onsted, 2002; Raux, 2003; Sanders and Sanders, 2004). In the case of simulating urban growth and shrinkage, this is extremely helpful for scientists as well as practitioners in order to estimate future land use changes as well as demand for residential land.
In our model, the population development (input variable) affects the demand on housing area which (indirectly) depends on e.g. housing costs and urban green (system parameter) and leads to a modification of the housing area, housing vacancy etc. (output variables). Mathematically spoken, system dynamics models consist of differential equations which are estimated for each time step (in our model: once per year). The model presented was implemented using the modelling environment Simile (version 4.7) by Simulistics (Simulistics Ltd., 2007). Simile provides a graphical user interface and is based on C++ (Muetzefeldt & Massheder 2002; Muetzelfeldt, 2002). The specifications of our model in terms of variables and equations are given in section 3.

### The case study

The region of Leipzig in Germany was chosen as an example for the quantification of causal loops. Leipzig is a stagnating-to-shrinking rural-urban region of half a million inhabitants and is located in Eastern Germany. The compact, monocentric city region holds both, one of the biggest Wilhelminian-time (1890-1918) housing estates all over Germany and one of the largest socialist prefabricated high-rise housing complexes (Haase & Nuissl, 2007). In the 19th century, Leipzig experienced a period of vibrant industrial growth, making it the country's fourth largest city when it reached its population peak with more than 700,000 inhabitants in the early 1930s (Couch et al., 2005). Between WW II and 1990, the city started to lose population during the socialist period.
Since the German reunification, the development of the city has mainly been influenced by de-industrialisation, further population losses and residential vacancies. During the 15 years after the reunification, the city lost about 100,000 inhabitants (1989: 530,000; 1998: 437,000). In 2006, Leipzig counted 505,000 inhabitants. Simultaneously with the population decline, urban sprawl emerged at the cities' periphery. Scattered commercial and residential development occurred in the surrounding rural landscape (Nuissl & Rink, 2005). Leipzig is of a quasi radial structure: the Wilhelminian-time multi-storey housing estates form the inner residential ring around the town centre. A second ring consists of mixed residential-industrial areas characterised by multi-storey row houses and villas. As kind of a third ring single houses and residential parks follow along the urban-to-rural gradient adjacent to villages of the suburban and rural surroundings (Appendix).

# 3 The model

### Structure

The system considered in the model is a city and its closer surroundings. Here, we find typical housing types as described in section 3.2. Structurally, the model can be distinguished into a demand and a supply part. The focus of the model on demography and housing (Figure 1) due to our objectives results from the following reasons: Firstly, the wide discussion among urban planners and environmental scientists about the necessity to include current demographic change and respective housing preferences better into current urban land use change models. Secondly, also the data availability in our case study was limited to the eight preference variables used (eq.3). However, the model approach is open and flexible to incorporate more, e.g. economic and labour market-related preference variables.

The system dynamics model presented uses population and household dynamics to compute a household-preference driven demand for eight urban structural types of residential area. The respective supply, represented by the housing stock of each UST in turn influences this demand. Based on the demand-supply ratio residential vacancy and demolition of housing stock is determined besides new construction. Thereby, components for shrinkage and growth are included. In the following, the model components are introduced in more detail (Figure 1).

Population is dynamically estimated by fertility, mortality and migration. It is classified in age cohorts. These age cohorts are classified into different HHT (eqs.5 and 6). Households have specific preferences regarding the area they want to live in, for example regarding surrounding urban green, housing costs, the house type, the social neighbourhood and crime rates (Figure 1). The housing supply, here described as urban structure types (UST), is also characterised by these variables.

In total, seven HHT (see below for more details) decide on their living space based on their specific preferences. If there is not enough demand for a certain UST, living space is abandoned and residential vacancy is created. After a while, vacant housing space if not demanded is demolished and is changed into open land. If the demand for a certain structural type increases, open land is converted into new housing area due to new construction. Figure 1 shows that the change of the supply side, reflected in the real estate, affects the conditions of the UST which again influence the demand as described in section 3.2). Thus, a feedback from supply to demand is considered.

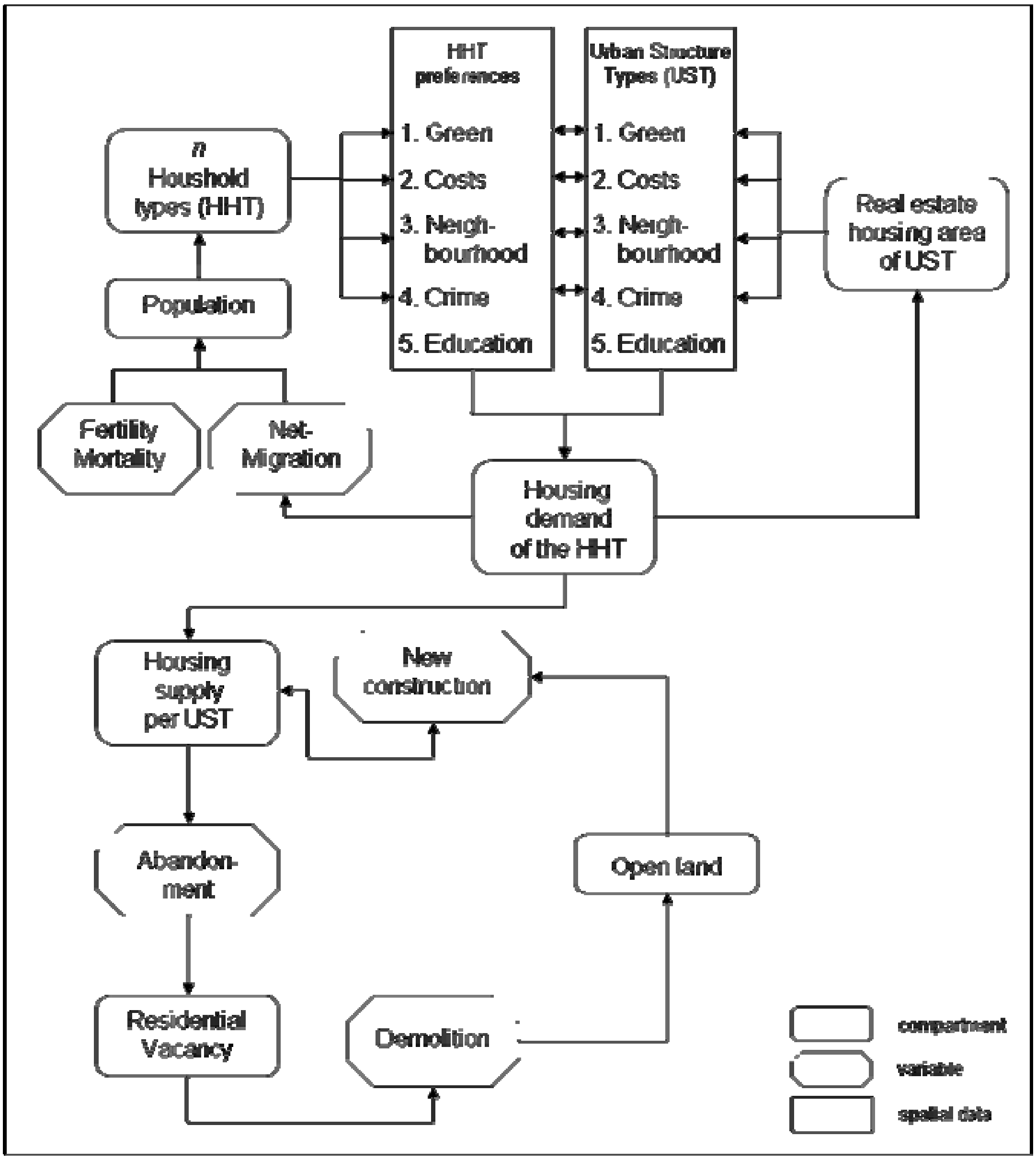



Figure 1: Simplified model structure including the main model components.

**Model components**

<u>Population</u>

One of the main parts of the simulation model is the total population number $P$ which depends on the temporal dependence $dP/dt$ of total fertility $F$, mortality $\mu$ due to life expectancy and net-migration. Individuals may enter a population cohort $i$ of a region either by birth $K$ or by in-migration $I$. Exchange of persons between cohorts is unidirectional from younger to older cohorts reflecting the ageing process. Leaving cohorts occurs either by ageing, out-migration $O$ or dying $\mu_i$ coded as cohort output (eq.1):

$$\frac{dP_i}{dt} = \sum_{i=2}^{3} F_i \cdot P_i - \mu_i \cdot P_i + I_i - O_i + K_i \cdot P_{i-1} - K_{i+1} \cdot P_i \qquad (1)$$

with $F_i = 0$, $\mu > 0$, $I, O > 0$.

*Households*
Empirical research showed that household characteristics significantly influence the specific housing demand per person (Buzar et al., 2007). Therefore, the aggregation of individual persons of age classes into households is relevant, especially in terms of residential preferences. Households vary considerably in form and size and this variety even increases within the context of demographic change (Kaa, 2004) as they get smaller and less stable, they are defined more subject-oriented, and living arrangements are adapted to individual life scripts (Buzar et al., 2005; Ogden & Hall, 2000).
Households have been classified according to their type based on recent empirical data for different European cities: family with dependent children, elderly one-person households and couples (co-habitation living form) and those called 'new' or 'non-traditional' household types, namely young one-person households, young couples or cohabitation households, single-parents and unrelated adults sharing a common flat (Buzar et al., 2007). In the model, the distribution matrix of these seven household types $\overrightarrow{HHT}$ at a point in time *t* is coded as follows (eq. 2):

$$\overrightarrow{HHT}_{1\ldots7} = M_{1\ldots7}(t)\vec{P} + N(t)\vec{P} \qquad (2)$$

*M(t)* has a linear trend according to the changes assumed to come along with demographic changes due to the second demographic transition such as an increase of single households and a decrease of the classical family household (cf. Kaa, 2004).
A specific mean income $MI_k$ is further assigned to each household (Haase, A. et al., 2005) (which a.o. determines the preference for large houses, flats and green space). Due to limited empirical data, an income variation is randomly created whereas a threshold determines to which preference set of a HHT is given priority (Figure A1). A household with high income is less restricted by the price of a flat but looks more at the housing conditions such as the green space availability or the security.

*Urban Structure Types (UST)*
We coded eight urban structure types that are representative for European urban regions including the core city and the periurban area (Ravetz, 2000): For the core city these are town centre (1), Wilhelminian-time old built-up blocks (inner city housing estates, 2), multi-storey row housing estates (built-up in the 1960-70ies, 3), prefabricated multi-storey housing estates (from socialist times, 4), villas (5), residential parks (mainly made up by small uniform single houses, 6) and single houses (7). The periurban area is represented by suburban villages (8).

*Housing preferences*
The concept of residential segregation suggests that household patterns do not occur by accident but can be related to the attractiveness of a place *i* which depends on the housing preference variables (Gober, 1990; Wegener & Spiekermann, 1996; Kemper, 2001). Next to the income as a household type specific variable, the real estate market in form of space availability / supply *SS*, the building state *BS*, the costs for buying or renting a flat or a house *C* play an important role. Moreover, the direct social and environmental neighbourhood are decisive for a residential choice (Haase et al., 2008).
In the model, crime rate *Cr*, green supply *G*, surroundings *Su*, social neighbourhood *So*, centrality *Ct* and education facilities *E* represent the neighbourhood. Rules for housing demand and its magnitude based on preference variables were derived from different questionnaire surveys conducted in Leipzig to identify housing satisfaction (Haase, 2008; Haase et al., 2005; Kabisch, 2005). The availability of such housing satisfaction data is crucial for the model transfer to other urban regions.
Based on a ranking of the relative importance of neighbourhood characteristics for the residents we chose a simple additive weighting for coding the attractiveness of a place for each household. It ranks the included variables (controlled by the variable's importance) according to their estimated importance and weighting. Additive weighting assumes additive aggregation of the criterion values which are normalised to make them comparable by means of the value functions. These convert the multidimensional values

of the attractiveness matrix into non-dimensional values ranging between 0 and 1. The attractiveness of a place $A_{kj}$ to live is coded as given in eq.3:

$$A_{kj} = CtP_k \cdot CtC_j + SutP_k \cdot SutC_j + CP_k \cdot CC_j + BSP_k \cdot BSC_j + CrP_k \cdot CrC_j$$
$$+ EP_k \cdot EC_j + GP_k \cdot GC_j + SoP_k \cdot \sum_{j=1}^{7} (SoC_j \cdot SoPM_k) \qquad (3)$$

The multiplication of the household specific preferences (*k*) and the given site conditions of the neighbourhood (*j*) produce a maximum preference and an apriori probability of the household distribution within the eight UST. Preference variables such as *CtP* or *SutP* are static parameters, the condition variables such as *Ctc* or *SutC* depend on the demand–supply relation (Appendix A1). Rising living costs of an UST may have a negative effect on its attractiveness and, by implication, on the UST demand, too.
Depending on the number of persons per household, we calculate the number of housing demanders $DP_{kj}$ (eq.4) and the respective housing area demand in hectares (eq.5):

$$DP_{kj} = A_{kj} \cdot HHT_k \quad \text{with} \quad \frac{dDP_{kj}}{dHHT_k} \geq 0 \,,\; t > 0 \qquad (4)$$

$$DLS_{kj} = \frac{LSC_k \cdot DP_{kj}}{10000} \quad \text{with} \quad \frac{dDLS_{kj}}{dDP_{kj}} \geq 0 \,,\; t > 0 \qquad (5)$$

$LSC_k$ is the housing area per capita in m². $DLS_{kj}$ represents the demanded living space for each HHT *k* and UST *j* the supplied living space $SLS_{kj}$ is calculated using the newly built-up area $co_{kj}$, the flat abaondoment and depletion of the housing stock $df_{kj}$, the demolition $dl_{kj}$ and the re-filled vacancies $ru_{kj}$ which is considered because of reurbanisation trends (Buzar et al., 2007):

$$\frac{SLS_{kj}}{dt} = co_k \cdot SLS_{kj} - df_k \cdot SLS_{kj} - dl_k \cdot SLS_{kj} + RuR_k \cdot SLS_{kj}$$
$$\text{with } t > 0 \qquad (6)$$

The residential vacancy $V_j$ is determined by the annual demolition rate $dl_j$. The parameter $co_{kj}$ ,$df_{kj}$, $dl_{kj}$, $ru_{kj}$ are all highly influenced by the demand on living space $DLS_{kj}$. The demand adaption as a consequence of a changing supply is regulated by the changing condition variables of each UST, e.g. housing costs or crime rate (Figure A1). Here, further testing and more empirical data are necessary for a precise validation of that context. Any causal loop from housing supply to household structure is not considered so far.
Finally, the net-demand on housing area is consequently (eq.7):

$$NDLS_k = DLS_k - SLS_k \qquad (7)$$

*Vacancies and demolition*
In the case of non-satisfaction of residential demands of households out-migration increases. Simultaneously, the share of residential vacancy increases in some parts of the city which do not or only partially fulfil the housing requirements of the households (Kabisch, 2005). Vacancy occurs either in the form of single dwellings within a house, or could also increase to completely vacant housing estates (100% vacancy). We further assume that, according to the life-cycle or 'ageing' process of a residential house, after being vacant for over five years a house proves to be uninhabitable, and both maintenance and reconstruction costs exceed by far the rental income through new residents (in this low income area of Leipzig). More attractive houses regarding their urban structure type can be re-filled (cf. eq.14). The resulting demolition $dl_i$ rate is coded accordingly in the model (see appendix). The open land reflecting partly the space supply for new constructions changes as a consequence of the total new-built areas and the total pulled down living space at the time $t$. A complete description of the model variables including all initial values can be found in the appendix.

## Calibration and validation of the model

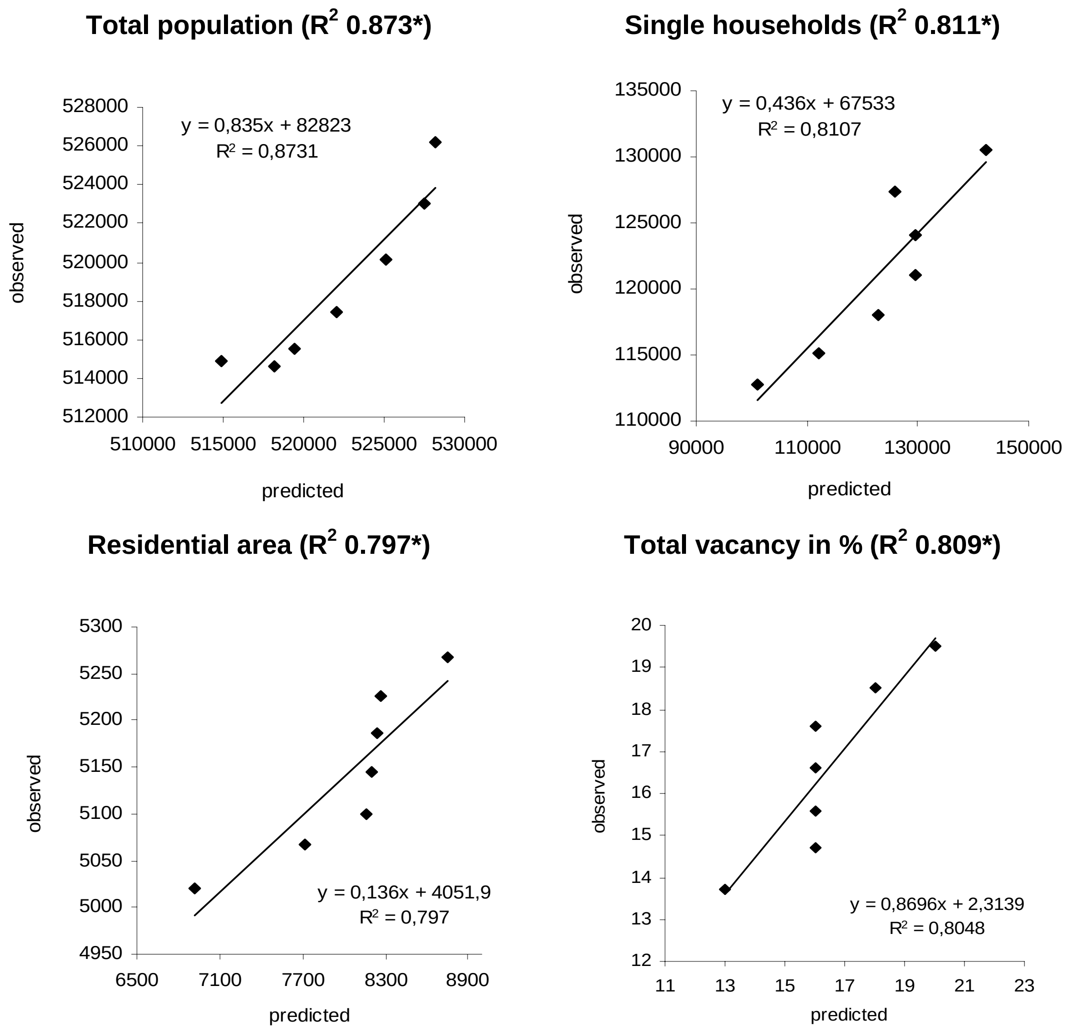
Before calculating different scenarios, the model functionality was tested in order to verify the model quality. Therefore, a time series produced by the model (with real data inputs) was compared to data from the case study. Table 1 provides an overview of all model variables that were used for model calibration. Data were taken from municipal statistics for the year 2005 (City of Leipzig, Saxony; Table 1).

Table 1: Variables used to calibrate the model (all initial values can be found in the appendix).

| **Population** | **Household types** | **Housing market** |
|---|---|---|
| Population ($P_i$) | Distribution matrix ($DM_{xk}$) | City area ($CA$) |
| Fertility ($F_i$) + trend* ($FT_i$) | Housing preferences ($CtP_j$, $SuP_j$, $CP_j$, $BP_j$, $CrP_j$, $EP_j$, $GP_j$, $SoP_j$) | Site conditions ($CtP_k$, $SuP_k$, $CP_k$, $BP_k$, $CrP_k$, $EP_k$, $GP_k$, $SoP_k$) |
| Mortality ($M_i$) + trend* ($MT_i$) | Mean income ($MI_j$) | Housing area ($SLS_k$) |
| In-migration ($IM_i$) + trend* ($TOM_i$) | | Vacancy ($V_k$) |
| Out-migration ($OM_i$) + trend* ($TOM_i$) | | Open land ($SS$) |
| | | Number of floors ($St_k$) |
| | | Housing floor density ($FSM_k$) |

* derived from statistical data from 1999-2005

Using an independent time series of municipal statistics from 1992-2005 (City of Leipzig, 1993-2006), major variables of the simulation model were validated. Figure 2 reports the regression coefficients and curves obtained. They show for all variables tested that the model results are in good and significant accordance with the statistical data (R-square >0.7). In order to make sure that the validation of the model is correct and does not relate to the calibration data two independent data sets (municipal and federal census) were used.




** $p < 0.01$ * $p < 0.05$ (t-test)

Figure 2. Regression coefficients obtained during the model validation using municipal statistics (issued by the city of Leipzig, 1993-2006).

## Scenarios

In the introduction we asked several questions on how housing demand and supply and residential vacancy will be affected if the population in an urban area either grows or declines. Therefore, a scenario matrix was set up summarising population growth, population shrinkage and a baseline development (representing a continuation of recent population development trends) using major demographic variables such as fertility, mortality, net-migration, percentage of single and family households since they considerably shape the population dynamics of an urban region (Table 3). The simulation covers a time horizon of about 25 years (2005-2030 for each of the scenarios).

Table 2. Calculation of fertility, mortality, net-migration, percentage single households and families based on municipal and regional statistics. FT = measured fertility rate 1999-2005, MT = measured mortality rate 1999-2005, IMT and OMT = measured migration rates 1999-2005.

| Scenario | Fertility (F) | Mortality (M) | In-Migration (IM) Out-Migration (OM) | % Single households (S) | % Families (Fa) |
|---|---|---|---|---|---|
| **Shrinkage** | *F= (F0*FT)*(-0.2)* | *M= (M0*MT)*(-0.2)* | *IM= IM0+IMT*(-1),*<br>*OM= OM0+OMT*(-0.95)* | *S= S(t-1)*(1+0.002*t)* | *Fa= Fa(t-1)* (1+0.002*t)* |
| **Baseline** | *F= (F0*FT)*(0.8)* | *M= (M0*MT)*(0.8)* | *IM= IM0+IMT*(1),*<br>*OM= OM0+OMT*(0.96)* | *S= S(t-1) +S*0.008*t* | *Fa= Fa(t-1)+Fa*0.008*t* |
| **Growth** | *F= (F0*FT)*(2)* | *M= (M0*MT)*(1.5)* | *IM= IM0+IMT*(1.01),*<br>*OM= OM0+OMT*(1.01)* | *S= S(t-1) +S*0.002*t* | *Fa= Fa(t-1)+Fa*0.002*t* |

# 4 Results and discussion

### Population development

The results of the scenarios show a differentiated picture for population development: Starting from today's population of the urban region (514,904) the baseline scenario shows a non-linear but gradual population growth (564,585) until 2030 (Figure 3). Compared to this, in the shrinkage scenario, the population number falls remarkably, again non-linear, under 400,000. Assuming a constant increase of fertility and net-migration, the population rises above 640,000 residents in 2030. Within only 25 years, the difference between growth and shrinkage scenario accounts for more than one fourth of the current total population number.

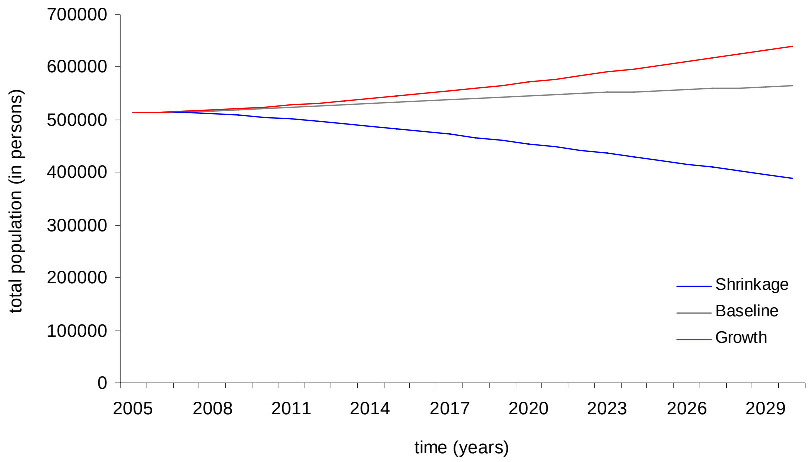



Figure 3. Total population in persons for baseline, growth and shrinkage scenario.

Looking at the age class development, the baseline, growth and shrinkage scenarios differ considerably: using the indicator of the young- (share of inhabitants <20 years old divided by the share of inhabitants >60 years) and old-age dependency rate (1/young-age dependency) we see that the young-age dependency in each of the three scenarios decreases – which means that the urban region will age. A considerable increase of the old-age dependency rate can be found in the shrinkage scenario: more than 2.5 persons >60 years equal one person <20 years. Figure A3 (Appendix) reports that in the shrinkage scenario the decrease of the population accelerates after 2015. Due to an aging population housing preferences and demands of elderly people will attract special attention on future housing markets (Kaa, 2004; Buzar et al., 2007).

### Household development

The growth of the total number of households in both the baseline and the growth scenarios is caused by an increase of the number of persons living in (young and elderly) single households (Figure 4). This is in accordance with current observations of household number (Buzar et al., 2007). The main reason is assumed to be on-going individualisation trends (Odgen & Hall, 2000). In particular the growth scenario reports a non-linear growth of young singles which has doubtless implications on needs of housing area. After an initial increase, the number of single households decreases in the shrinkage scenario. Compared to the increase of persons living in single households, the number of family household members dramatically decreases in all three scenarios. Contrariwise, the number of single-parent families increases in both baseline and growth scenario (Figure 4).

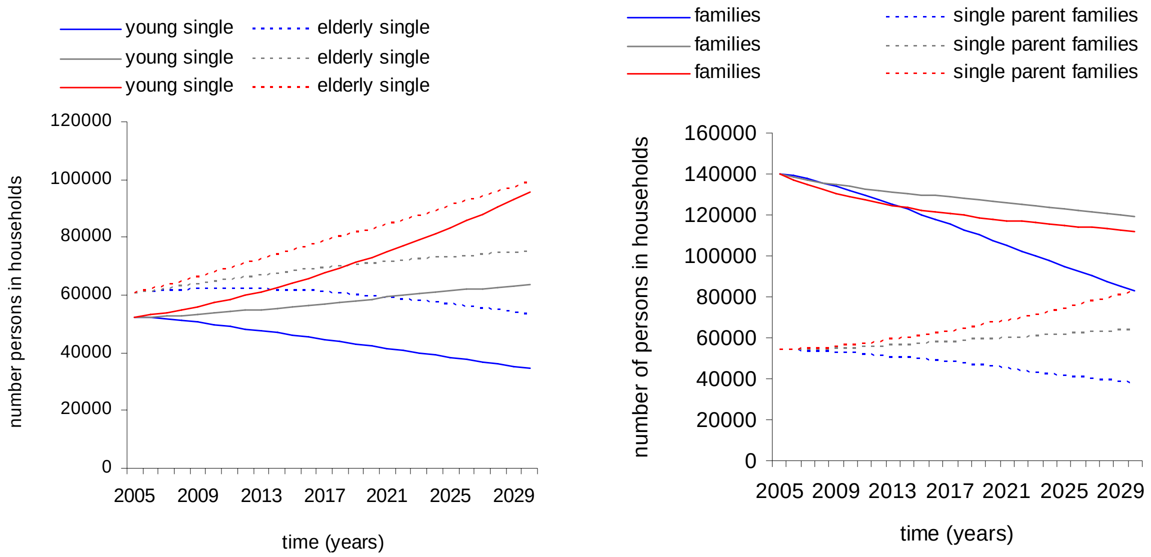



Figure 4. Development of the number of persons living in young and elderly single households compared to those living in family households with children. Blue = shrinkage, grey = baseline, red = growth.

### Housing demand and supply

Figure 5 depicts the net-demand-supply from 2005-2030. We see a completely different picture for the growth and the shrinkage scenario: Whereas the housing supply exceeds the respective demand in times of population shrinkage, in times of population growth the housing supply dramatically decreases - assuming that individual living space will not be reduced (Priemus, 2003).

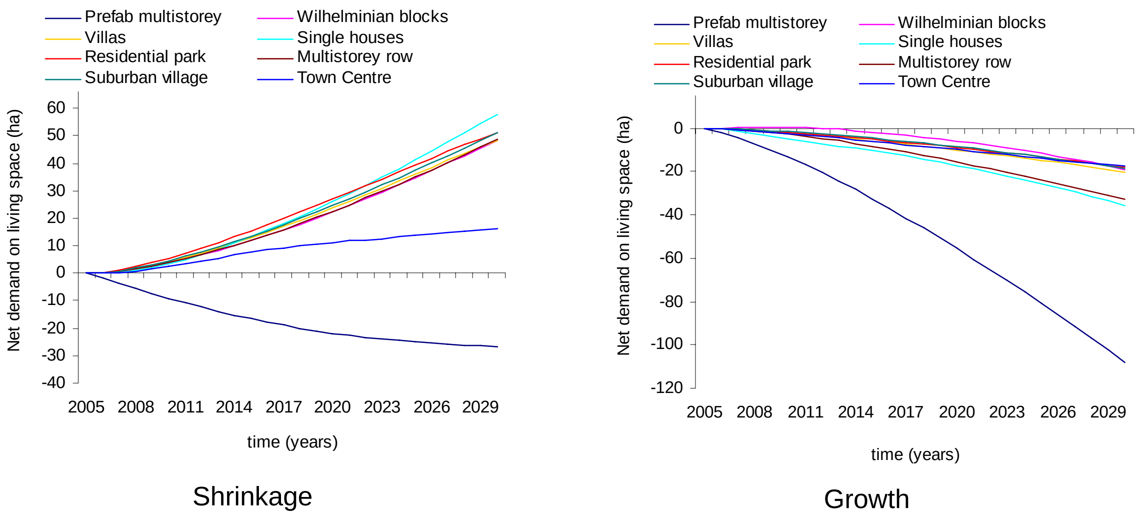



Figure 5. Net demand-supply-relation on living space in the different urban structure types for the growth and shrinkage scenario.

In the growth scenario, an undersupply of prefabricated multi-storey houses is simulated – something one would not expect based on the low image of this urban structure type today (Kabisch et al., 1997). In the simulation, there is a growing interest in affordable flats by low-income and single-parent family households which can be provided by prefabricated large housing estates. As Figure 5 shows, the undersupply levels-out by about 30%. In all other urban structure types an oversupply is computed even for the growth scenario although there are high preferences by most of the households for single houses, Wilhelminian-style old built-up houses or residential parks and villas. The sharp decrease of housing demand is caused by the reduction of the population by >100,000 residents until 2030 in the shrinkage scenario which can neither be moderated by an increase of the number of households nor by the demolition of vacant houses.

### Vacancies and demolition of residential supply

As discussed in the introduction section, residential vacancy is a major issue of urban land use development, particularly under conditions of shrinkage. It is a consequence of an oversupply with living space (apartments, houses). Figure 6 gives an idea about the proportions of residential vacancy in the different urban structure types.

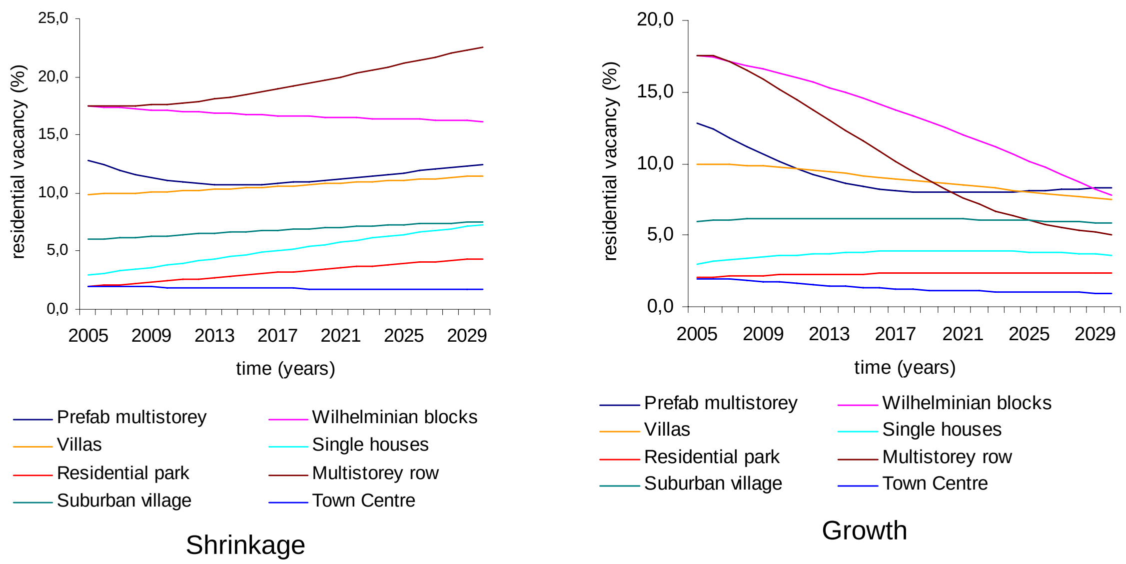



Figure 6. Residential vacancy in the 8 urban structure types for the growth and the shrinkage scenario.

The overall share of vacancy increases in the shrinkage scenario up to 13% by 2030, whereas it is considered to fall to 6% in the growth scenario (starting with 12.3% in 2005). Even in the baseline scenario, residential vacancy will decrease to 9.1%. In the growth scenario, demolition predominantly impacts the proportion of residential vacancy in the prefabricated multi-storey housing estates as they are less attractive than other UST for better-of single and family households with higher income and for most of the urban planners, too. This somehow contradicts the discussed undersupply of prefabricated housing shown in Figure 5 and makes clear that current demolition policy does underestimate the demand on affordable flats in such prefab housing estates caused by a future increase of low-income household types.
The reduction of vacancy in the inner-urban Wilhelminian-time blocks results most of all from their rising attractiveness for a growing number of households. Demolition does not occur in single housing areas. Therefore, we find a slight increase in the single house vacancy in the shrinkage scenario. There is no empirical evidence from European urban regions that single houses are demolished on a larger scale even if vacancy appears (Kasanko et al., 2006).

The total residential area of the urban region, summing up demand and supply on living space as well as residential vacancy moderated by demolition measures, shows again a very diverging picture. The graphs in Figure 7 report that Leipzig will face an increase of the total residential area in case of population growth, which means that the urban region will expand and, assuming a constant or even increasing living space per capita, further land take will happen. In the baseline scenario, remaining residential vacancy and low population growth lead to smart urban growth.
Compared to that, in case of urban shrinkage, residential land will decrease – in the model, this leads to an increase in open land – that is in case of all residential area out of use will be redeveloped and given back to nature (Figure 7). Open land take does not happen in case of the baseline scenario – here the surplus in residential land compared to the start of the simulation in 2005 is buffered with a densification of the existing urban space and an infill of vacancies. We observe a dramatic decrease of open land in the growth scenario.

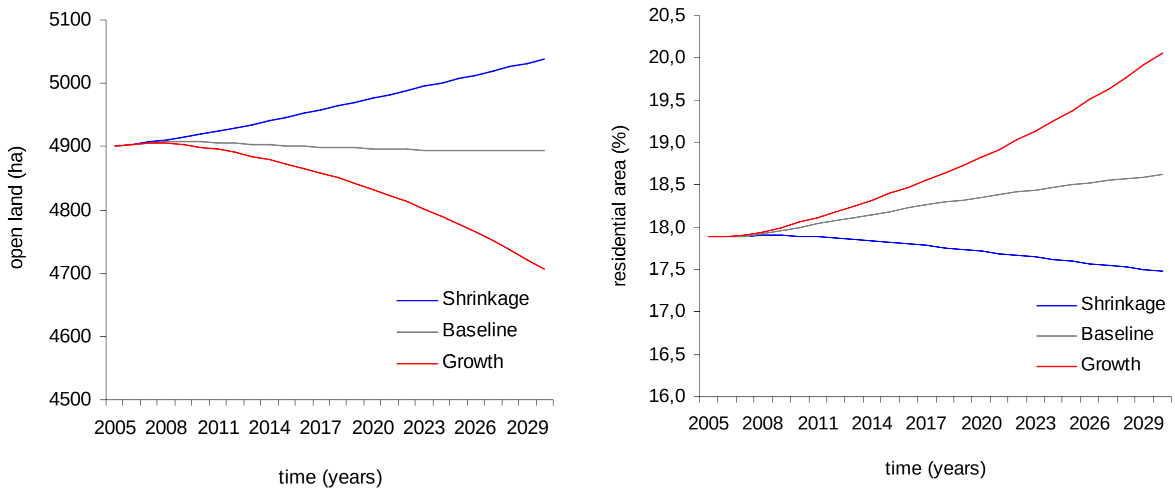



Figure 7. Development of open land and residential area in the three scenarios, baseline, growth and shrinkage.

Figure 7 further shows that an alteration in the distribution of households – that is according to the second demographic transition an increase of single households and the reverse development for family households – has an impact on the growth/decline of the total residential area.

# 5 Conclusions

Based on the results of the system dynamics simulation model we can show a range of very interesting pathways of how population dynamics and demographic change will affect housing demand, supply of residential land and open land in an urban region. The results of the population development simulations show that currently shrinking cities and urban regions can expect very different futures: further decline is only one of them. In accordance with recent findings on reurbanisation trends in urban regions formerly faced with population decline (Turok & Mykhnenko, 2006; Storper & Manville, 2006) both baseline and growth scenarios indicate that urban regions might grow after a phase of decline again.
Are currently shrinking cities confronted with further residential land consumption? And, further, does an increasing individualisation increase the housing demand? In two of the scenarios, the baseline and the growth scenario, we state an increase of single households – that is younger and elderly ones. This leads to an increase in the total housing demand in both scenarios (cf. Figures 3 and A4). Compared to this, in the shrinkage scenario neither the number of single households nor the housing demand increases. In Leipzig, we stated until 2007 an increase of the total number of households (City of Leipzig). However, the expected increase in housing area weakens and is expected to abate within the coming years completely.
As shown in the summarising Figure 8, a growing number of single households leads to an increasing demand of living space and residential land take in case of both total population growth or shrinkage due to the positive trend of per capita living space. A total decline of population does not "solve" the land consumption problem of urban region as long as per capita demands are rising and an individualisation leads to an increase in total household numbers (Karsten, 2003; Lee et al., 2003).

| | Population | Singles | Vacancy | Resid. Land | Open Land |
|---|---|---|---|---|---|
| Growth | ↗ | ↗ | ↘ | ↗ | ↘ |
| Baseline | ↗ | ↗ | → | → | → |
| Shrinkage | ↘ | ↘ | ↗ | → | → |

Figure 8. Major trends of the growth, baseline and shrinkage scenarios.

The results of our model report that young single households could play an important role for a new inner-city development in the Wilhelminian-time ring – that is the process of reurbanisation – as particularly inner-city-situated urban structure types are positively influenced by an influx of young single households. This effect might be crucial to overcome residential vacancy in inner-city areas. Especially young singles demand a "functional social and cultural life" which is offered in the inner city (Favell, 2008). Beyond that, it was shown that the developments of family households imply the direction of the single-house progress linked to future land take. Vice versa, if the decrease of family households continues, former sprawling processes at the city's periphery can be expected to freeze.
Of particular interest for urban planners are housing demand and respective land use development trends. Former high vacancy rates of Leipzig's inner-city will balance the growing demand of living space of 31 hectare and continuing demolition will even lead to a reduction of the residential area of 10 hectare until 2020 (baseline; Tables A1-3). Hence, a high potential for open spaces and greenfield expansion exists, what could continue to rise the inner-city attractiveness. The rising demand for the inner-city Wilhelminian time built-up UST, defining the urban image, requires a reduction of the demolition rates (despite existing vacancies). With decreasing growth sprawl effecting residential areas of detached houses will increase of 80 hectare until 2020, while 34 hectare become available due to demolition in the segment of prefabricated multi-storey houses (baseline; Tables A1-3).

This elucidates the high brownfield exploitation capability for new constructions to prevent further space consumption and sealing.
The further perspective on using our model is the combination with a spatial cellular automaton to uncover local dynamics. The presented model delivers population dynamics and housing demand including internal causal feedback loops on the regional scale to avoid simple empirical trend implications.

# References


Banzhaf, E, Kindler, A, Haase, D, 2007, "Monitoring, mapping and modelling urban decline: a multi-scale approach for Leipzig" *EARSeL eProceedings* **6**(2), 101-114.

Batty M, 2001, "Polynucleated urban landscapes" *Urban Studies* **38** (4), 635-655.

Börsch-Supan, A, Heiss, F, Seko, M, 2001, „Housing demand in Germany and Japan" *Journal of Housing Economics* **10**(3), 229-252.

Buzar, S, Odgen, P, Hall, R, 2005, „Households matter: the quiet demography of urban transformation" *Progress of Human Geography* **29**(4), 413-436.

Buzar, S, Ogden, P, Hall, R, Haase, A, Kabisch, S, Steinführer, A, 2007, „Splintering urban populations: emergent landscapes of reurbanisation in four European cities" *Urban Studies* **44**(3), 5-6.

Champion, T, 2001 "Urbanization, suburbanization, counterurbanisation, reur-banisation", In: Paddison, R (Ed.) "Handbook of Urban Studies" London, pp 143-161.

City of Leipzig, 1997-2006. Municipal Statistics. Agency for Statistics and Elections. www.leipzig.de

Couch, C, Karecha, J, Nuissl, H, Rink, D, 2005 "Decline and sprawl: an evolving type of urban development — observed in Liverpool and Leipzig" *European Planning Studies* **13**(1), 117–136.

Dhawan, R, 2006, "System dynamics and its impact on managerial decision making" University of Sydney (Hrsg.), Sydney.

Engelen G, Lavalle C, Barredo J, van der Meulen M, White R, 2007 "The Moland Modelling Framework for Urban and Regional Land-use Dynamics", in *Modelling Land-Use Change, Progress and Applications* Eds E Koomen, J Stillwell, A Bakema, HJ Scholten (Springer, Dordrecht) pp 297-319

Eppink F, van den Bergh J, Rietveld P, 2004, "Modelling biodiversity and land use: urban growth, agriculture and nature in a wetland area" *Ecological Economics* **51** (3-4) 201-216

Eskinasi M, Rouwette E, 2004, "Simulating the urban transformation process in the Haaglanden region, the Netherlands", paper presented at the 2004 International System Dynamics Conference in Oxford, UK, http://www.roag.nl/tekst/HaaglandenFinalPaper.PDF

Ettema D, de Jong K, Timmermans H, Bakema A, 2007, "PUMA: Multi-Agent Modelling of Urban Systems" in *Modelling Land-Use Change, Progress and Applications* Eds E Koomen, J Stillwell, A Bakema, HJ Scholten (Springer, Dordrecht) pp 237-258

Favell, A, 2008, "Eurostars and Eurocities. Free movement and mobility in an integrating Europe", Blackwell Publishing, Malden & Oxford.

Forrester, J W, 1971, "Counterintuitve Behavior of Social Systems", In: Wright – Allen Press, Inc (Hrsg.): Collected Papers of J W Forrester, Cambridge.

Forrester, J W, 1969, "Urban Dynamics", In: M.I.T. Press, Cambridge.

Gober, P, 1990, "The Urban Demographic Landscape: A Geographic Perspective", In: Myers, D (Ed), "Housing Demography. Linking Demographic Structure and Housing Markets", University of Wisconsin Press, Madison & London, 232-248.

Haase, A, 2008, "Reurbanisation – an analysis of the interaction between urban and demographic change: a comparison between European cities", *Die Erde* **139**(4), 1-22.

Haase, A, Kabisch, S, Steinführer, A, Fritzsche, A, 2005, „Reurbanising the inner city: driving forces, target groups and their housing preferences", Final research report, part b sociology, ReUrban Mobil. Leipzig. www.reurban-mobil.com

Haase, D, Schwarz, N, 2009. Simulation models on human-nature interactions in urban landscapes – a review including system dynamics, cellular automata and agent-based approaches. Living Reviews in Landscape Research 3, 2.

Haase, D, Haase, A, Bischoff, P, Kabisch, S, 2008, „Guidelines for the 'Perfect Inner City' Discussing the Appropriateness of Monitoring Approaches for Reurbanisation" *European Planning Studies* **16**(8), 1075-1100.

Haase, D, Haase, A, 2007, "Do European social science data serve to feed agent-based simulation models on residential mobility in shrinking cities?", In: Grözinger, G, Matiaske, W, Spieß, K (eds.) "Europe and its Regions. The usage of European Regionalised Social Science Data", Cambridge Scholar Publishing, pp. 227-250.

Haase D, Seppelt R, Haase, A, 2007, "Land use impacts of demographic change – lessons from eastern German urban regions". Petrosillo, I, Müller, F, Jones, K B, Zurlini, G, Krauze, K, Victorov, S, Li, B L, Kepner, W G (Eds.) "Use of Landscape Sciences for the Assessment of Environmental Security", Springer, pp. 329-344.
Haase, D, Nuissl, H, 2007, "Does urban sprawl drive changes in the water balance and policy? The case of Leipzig (Germany) 1870-2003" *Landscape and Urban Planning* **80**, 1-13.
Haghani A, Lee S, Byun J, 2003a, "A System Dynamics Approach to Land Use / Transportation System Performance Modeling, Part I: Methodology" *Journal of Advanced Transportation* **37**(1) 1-41
Haghani A, Lee S, Byun J, 2003b, "A System Dynamics Approach to Land Use / Transportation System Performance Modeling, Part II: Application" *Journal of Advanced Transportation* **37**(1) 43-82
Jessen, J, 2006, "Urban Renewal – A Look Back to the Future. The Importance of Models in Renewing Urban Planning", *German Journal of Urban Studies* **45**(1), 1-17.
Kaa, D van de, 2004, "Is the Second Demographic Transition a useful research concept?", *Vienna Yearbook of Population Research* 2004, 4-10.
Kaa, D van de, 1987, "Europe's Second Demographic Transition". *Population Bulletin* 42, 1-57.
Kabisch, N, Haase, D, in press. "Diversifying European agglomerations: evidence of urban population trends for the 21st century." *Population, Space and Place*.
Kabisch, S, 2005, "Empirical analysis on housing vacancy and urban shrinkage." In: Vestbro, D U, Hürol, Y, Wilkinson, N (eds) "Methodologies in Housing Research", Gateshead, pp.188-205.
Kabisch, S, Kindler, A, Rink, D, 1997, Social Atlas of the City of Leipzig, Leipzig.
Karsten, L, 2003, "Family gentrifiers: challenging the city as a place simultaneously to build a career and to raise children", *Urban Studies* **40**, 2573-2585.
Kasanko, M, Barredo, J I, Lavalle, C, McCormick, N, Demicheli, L, Sagris, V, Brezger, A, 2006, "Are European Cities becoming dispersed?", *Landscape and Urban Planning* **77**, 111-130.
Kemper, F-J, 2001, "Wohnformen, Altersstruktur, Lebenszyklusphasen", *Berichte zur deutschen Landeskunde* **75**(2-3), 137-146.
Landis J, Zhang M, 1998a, "The second generation of the California urban futures model. Part I: Model logic and theory" *Environment and Planning B* **25** (5) 657-666
Landis J, Zhang M, 1998b, "The second generation of the California urban futures model. Part II: Specification and calibration results of the land-use change model" *Environment and Planning B* **25** (6) 795-824
Lee, G S, Schmidt-Dengler, P, Felderer, B, Helmenstein, C, 2003, "Austrian Demography and Housing Demand: Is There a Connection?", *Empirica* **28**, 259–276.
Loibl W, Tötzer T, Köstl M, Steinnocher K, 2007, "Simulation of Polycentric Urban Growth Dynamics through Agents" in *Modelling Land-Use Change, Progress and Applications* Eds E Koomen, J Stillwell, A Bakema, HJ Scholten (Springer, Dordrecht) pp 219-235
Mankiw, N G, Weil, D N, 1989, "The baby boom, the baby bust, and the housing market" *Regional Science and Urban Economics* **19**, 235-258
Muetzelfeldt, R, 2002, "Simulation models using the Simile visual modelling environment. Practical session.", Simulation European Advanced Study Course MODLUC: Modelling Land Use Change. Louvain.
Muetzelfeldt, R, Massheder, J, 2002, "The Simile visual modelling environment", *European Journal of Agronomy* **18**(3-4), 345-358.
Nijkamp, P, van Wissen, L, Rima, A, 1993, "A Household Life Cycle Model for Residential Relocation Behaviour" *Socio-Econ. Plann. Sci.* **27**(1), 35-53
Nuissl, H, Rink, D, 2005, "The 'production' of urban sprawl in eastern Germany as a phenomenon of post-socialist transformation", *Cities* **22**(2), 123-134.
Ogden, P, Hall, R, 2000, "Households, Reurbanisation and the Rise of Living Alone in the Principal French Cities, 1975–90." *Urban Studies* **37**, 367-390.
Onsted J, 2002 *SCOPE: A Modification and Application of the Forrester Model to the South Coast of Santa Barbara County,* http://www.geog.ucsb.edu/%7Eonsted/title.html
Parker DC, Manson SM, Janssen MA, Hoffmann MJ, Deadman P, 2003, "Multi-Agent Systems for the Simulation of Land use and Land cover Change: A Review" *Annals of the Association of American Geographers* **93**(2) 314-337

Priemus, H, 2003, “Changing Urban Housing Markets in Advanced Economies, Housing”, *Theory and Society* **21**, 2-16.
Raux, C, 2003, “A system dynamics model for the urban travel system”, paper presented at the European Transport Conference 2003, Strasbourg 8-10 October 2003, http://ideas.repec.org/p/hal/journl/halshs-00092186_v1.html
Ravetz, J, 2000, “City Region 2020. Integrated Planning for a Sustainable Environment”, London: Earthscan.
Salvini P, Miller E, 2005, “ILUTE: An Operational Prototype of a Comprehensive Microsimulation Model of Urban Systems” *Networks and Spatial Economics* **5**(2) 217-234
Sanders P, Sanders F, 2004, “Spatial urban dynamics. A vision on the future of urban dynamics: Forrester revisited”, paper presented at the 2004 International System Dynamics Conference at Oxford, UK, http://www.systemdynamics.org/conferences/2004/SDS_2004/PAPERS/119SANDE.pdf
Schwarz, N, Haase, D, Seppelt, R in press. Omnipresent sprawl? A review of urban simulation models with respect to urban shrinkage. *Environment and Planning B*.
Simulistics Ltd., 2007, “Simulistics Model Life. Welcome to Simulistics.”, URL: http://www.simulistics.com/, 10.01.09.
Sterman, J D, 2000, “Business Dynamics: Systems Thinking and Modeling for a Complex World.”, Irwin/McGraw-Hill (Hrsg.), Boston.
Sterman, J D, 2002, “All models are wrong. Reflections on becoming a system scientist.”, *System Dynamics Review* **18**(4).
Storper, M, Manville, M, 2006, “Behaviour, Preferences and Cities: Urban Theory and Urban Resurgence”, *Urban Studies* **43**, 1247-1274.
Strauch D, Moeckel R, Wegener M, Gräfe J, Mühlhans H, Rindsfüser G, Beckmann K.-J., 2003, “Linking Transport and Land Use Planning: The Microscopic Dynamic Simulation Model ILUMASS”, Proceedings of the 7th International Conference on GeoComputation, University of Southampton, United Kingdom, 8-10 September 2003, http://www.geocomputation.org/2003/Papers/Strauch_Paper.pdf
Turok, I, Mykhnenko, V, 2006, “Resurgent European Cities?”, *GaWC Research Bulletin* **216**(A).
Verburg P, Overmars K, 2007, Dynamic Simulation of Land-use change Trajectories with the CLUE-s Model”, in *Modelling Land-Use Change, Progress and Applications* Eds E Koomen, J Stillwell, A Bakema, HJ Scholten (Springer, Dordrecht) pp 321-335
Verburg P, Schot P, Dijst M, Veldkamp A, 2004, “Land use change modelling: current practice and research priorities” *GeoJournal* **61**(4) 309-324.
Waddell P, Borning A, Noth M, Freier N, Becke M, Ulfarsson G, 2003, “Microsimulation of Urban Development and Location Choices: Design and Implementation of UrbanSim”, *Networks and Spatial Economics*, **3**(1) 43-67
Wegener, M, Spiekermann, G, 1996, “The potential of micro-simulation for urban models.”, In: Clarke, G P (ed.), “Microsimulation for urban and regional policy analysis”, *European Research in Regional Science* **6**, 149-163.

# Annex

### Description of variables

### Population

| | |
|---|---|
| Pop class, $P_x(t)$ | Population of the study area classified into $x$ age cohorts |
| Birth-inmig, $bi_x(t)$ | Increase of each cohort $x$ by in-migration and birth |
| Death-outmig, $do_x(t)$ | Decrease of each cohort $x$ by out-migration and death |
| Ageing-in, $ai_x(t)$ | Increase of each cohort $x$ through the cohort transition |
| Ageing-out, $ao_x(t)$ | Decrease of each cohort $x$ through the cohort transition |
| Fertility, $F_x(t)$ | Fertility rate per cohort |
| Mortality, $M_x(t)$ | Mortality rate (probability of dying) per cohort $x$ |
| In-mig, $IM_x(t)$ | Persons moving into the study area, classified into $x$ age cohorts |
| Out-mig, $OM_x(t)$ | Persons leaving the study area, classified into $x$ age cohorts |
| Age groups, $SPG_p(t)$ | Classification of the population into age groups $p$ (20, 20-60 and >60) |

### Household types

| | |
|---|---|
| Household types, $HHT_k(t)$ | Population number per HHT $k$ |
| Middle income, $MI_k(t)$ | Annual middle income per HHT $k$ |
| Distribution matrix, $DM_{kx}(t)$ | Transition matrix for HHT $k$ out of age cohorts $x$ |
| Change matrix, $CDM_m$ | Change of distribution matrix $DM_{kx}(t)$ |
| Social matrix, $SoM_{kk}(t)$ | Attributable preference among two HHT $k$ regarding vicinity |
| Attractivity, $A_{ik}(t)$ | Probability of housing decision per HHT $k$ and UST $i$, taken into account preferences of $k$ and conditions of $i$ |
| Valuations ($CtV_k(t)$, $SuV_k(t)$, $CV_k(t)$, $BSV_k(t)$, $CrV_k(t)$, $EV_k(t)$, $GV_k(t)$, $SoV_k(t)$) | Basic preference of each $n$ (see a.x., p.40) per HHT without considering the household income |
| Preference valuation, $PV_n(t)$ | Weighting parameter for the preference variables $n$ depending on the middle income $MI_k(t)$ |
| Preferences ($BSP_k(t)$, $CP_k(t)$, $CrP_k(t)$, $CtP_k(t)$, $EP_k(t)$, $GP_k(t)$, $SoP_k(t)$, $SuP_k(t)$) | Attributable preference of variable $n$ for each HHT $k$ |

### Real estate, housing area of UST

| | |
|---|---|
| Demand_HHT, $DP_{ik}(t)$ | Number of demanding persons per HHT $k$ and UST $i$ |
| Demand living space, $DLS_{ik}(t)$ | Demand of living space per HHT $k$ and UST $i$ in hectare |
| Supply _HHT, $SP_{ik}(t)$ | *De facto* number of persons living in UST $i$ per HHT $i$ |
| Supply living space, $SLS_{ik}(t)$ | *De facto* use of living space per HHT $k$ and UST $i$ in hectare, excluding vacancies |

| | |
|---|---|
| Vacancy, $V_i(t)$ | Vacant living space per UST *i* in hectare |
| Space Supply, $SS(t)$ | Total open land (available, potential building land) in hectare |
| Construction, $co_{ik}(t)$ | New built-up living space per HHT *k* and UST *i* in hectare |
| Deflation, $df_{ik}(t)$ | New vacant living space per HHT *k* and UST *i* in hectare |
| Reuse, $ru_{ik}(t)$ | New revitalised vacancies per HHT *k* and UST *i* in hectare |
| Demolition, $dl_i(t)$ | New pulled-down vacant living space per UST *i* in hectare |
| Demand residential area, area) per $DRA_i(t)$ | Potential (demand on) residential area (building area and plot UST *i* in hectare |
| Supply residential area, $SRA_i(t)$ | *De facto* residential area (building area & plot area), excluding vacancies per UST *i* in hectare |
| Total living space, $TLS_i(t)$ | *De facto* use of total living space per HHT *k* and UST *i* in hectare, including vacancies |
| Total residential area, $TRA_i(t)$ | *De facto* residential area building area & plot area) per UST *i* in hectare, including vacancies |
| Building area, $BA_i(t)$ | Total building area for each UST *i* in hectare |
| Rates ( $GR_i(t)$ , $ER_i(t)$ , $CrR_i(t)$ , $BSR_i(t)$ , $CR_i(t)$ ) | Change rates of UST *i* regarding preference variables *n* (see a.x., p.40) |
| Conditions ( $BSC_i(t)$ , $CC_i(t)$ , $CrC_i(t)$ , $EC_i(t)$ , $GC_i(t)$ , $SoC_{ik}(t)$ , $SuC_i(t)$ ) variables *n* | Normalized condition of each UST *i* regarding preference |
| Building State, $BS_i(t)$ | State of restoration per UST *i* (means of each UST) |
| Centrality, $Ct_i$ | Weighted distance to centre per UST *i* (const. values) |
| Cost, $C_i(t)$ | Average rent per UST *i* in Euro |
| Crime, $Cr_i(t)$ | Number of delicts per UST *i* |
| Education, $E_i(t)$ | Number of institutions of education (schools, kindergartens) per UST *i* |
| Green, $G_i(t)$ | Green space per person and UST *i* (park density, lot green) |
| Surroundings, $Su_i$ | Living settings in neighbourhoods of UST *i*, gained by different describing parameters e.g. cleanness, noise (const. value) |

**Indices**

*t = time*

$$t \in R,\ t > 0$$

*i = population cohorts*

$$i = \begin{pmatrix} 0-15 \\ 16-25 \\ 26-35 \\ 36-45 \\ 46-55 \\ 56-65 \\ 66-75 \\ 75+ \end{pmatrix}$$

$$x \in N, x \leq 8$$

*k = household types (HHT)*

$$k = \begin{pmatrix} young\ one\text{-}person\ household\ (<45\ years) \\ elderly\ one\text{-}person\ household\ (>45\ years) \\ young\ cohabitation\ household\ (<45\ years) \\ elderly\ cohabitation\ household\ (>45\ years) \\ family\ with\ dependent\ children\ <18\ years \\ \text{sin}\,gle\ parent\ with\ dependent\ children\ <18\ years \\ unrelated\ adults\ (flat\text{-}sharers)\ <45\ years \end{pmatrix}$$

$$k \in N, k \leq 7$$

*j = urban structure types (UST)*

$$j = \begin{pmatrix} prefabricated\ multiy\text{-}storey \\ Wilhelminian\ blocks \\ villas \\ \text{s}ingle\ (one/two\ family)\ houses \\ residential\ park\ \ \text{s}ince\ 1990 \\ multi\text{-}storey\ row \\ suburban\ village \\ city\ centre \end{pmatrix} \qquad j \in N, i \leq 8$$

*n = characterization variables*

$$n = \begin{pmatrix} centrality \\ hou\text{s}ing\ surrounding \\ hou\text{s}ing\ cost \\ building\ state \\ crime\ rate \\ education\ facilities \\ green\ supply \\ social\ neighbourhood \end{pmatrix} \qquad n \in N, l \leq 8$$

$p$ = *age classes* $p = \begin{pmatrix} minors\ (< 20\ years) \\ employable\ age\ (20\text{-}60\ years) \\ pensioners\ (> 60\ years) \end{pmatrix}$

$p \in N, p \le 3$

$m$ = *change rate (HHT-Matrix)*

$m \in N, m \le 4$

$l$ = *parameter of rates*

$l \in N, l \le 4$

**Population**

Birth-inmig, $bi_x(t)$ $bi_x(t) = f_{bi}([F_x \cdot P_x], IM_x)$ ,

$bi_x = IM_x$ $t > 0\ and\ x > 1$

Death-outmig, $do_x(t)$ $do_x(t) = f_{do}([M_x \cdot P_x], OM_x)$

$, t > 0$

Ageing-in, $ai_x(t)$ $ai_x(t) = f_{ai}(ao_{(x-1)})$

$ai_x = ao_{(x-1)} \quad t > 0\ and\ x > 1$

Ageing-out, $ao_x(t)$ $ao_x(t) = f_{ao}(P_x)$

$$ao_x = \frac{1}{10} \cdot P_x \quad t > 0\ and\ x \ne 1$$

$$ao_1 = \frac{1}{15} \cdot P_1 \quad t > 0\ and\ x = 1$$

Fertility, $F_x(t)$ $\frac{dF_x}{dt} = FT_x \cdot \left(1 - \frac{SS_{T1}}{SS}\right) \quad t > 0$

Mortality, $M_x(t)$ $\frac{dM_x}{dt} = -MT_x \quad t > 0$

In-mig, $IM_x(t)$ $IM_x(t) = f_{IM}([Gauss], TIM_x, SS)$

$$\frac{\partial IM}{\partial TIM} \ge 0, \ \frac{\partial IM}{\partial SS} \ge 0$$

$$IM_x = (N_{xIM}(\mu_x, \sigma_x) + TIM_x) \cdot \left(1 - \frac{SS_{T2}}{SS}\right) \qquad N = Gauss\text{-}distribution$$

$\mu_x = [1690;\ 7553;\ 5756;\ 2558;\ 1416;\ 1096;\ 822;\ 822]$ $\mu_k = mean$

$\sigma x = [100;\ 150;\ 150;\ 100;\ 100;\ 100;\ 50;\ 50]$ $\sigma_k = standard\ deviation$

Out-mig, $OM_x(t)$ $OM_x(t) = f_{OM}\left(\left[Gauss\right], TOM_x, SS\right)$ $\frac{\partial OM}{\partial TOM} \geq 0$, $\frac{\partial OM}{\partial SS} \leq 0$

$$OM_x = \left(N_{xOM}(\mu_x, \sigma_x) + TOM_x\right) \cdot \left(1 - \frac{SS_{T2}}{SS}\right)^{-1}$$ $N = Gauss\text{-}distribution$

$\mu_x = \left[2185;\ 4369;\ 5248;\ 3386;\ 2130;\ 1420;\ 993;\ 993\right]$ $\mu_k = mean$

$\sigma x = \left[100;\ 150;\ 150;\ 100;\ 100;\ 100;\ 50;\ 50\right]$ $\sigma_k = standard\ deviation$

Age groups , $SPG_p(t)$ $SPG_1 = \frac{P_1 + 0.5 \cdot P_2}{SumP}$

$p = 1$ $SPG_2{}' = \frac{0.5 \cdot P_2 + P_3 + P_4 + P_5 + 0.5 \cdot P_6}{SumP}$

$p = 2$

$SPG_3 = \frac{0.5 \cdot P_6 + P_7 + P_8}{SumP}$

$p = 3$

**Household types**

Middle income, $MI_k(t)$ $MI_k = N_{kMI}(\mu_k, \sigma_k)$

$N = Gauss\text{-}distribution$

$\mu_k = mi_k = \left[920;970;1892;1708;2226;1283;844\right]$ $\mu_k = mean$

$\sigma_k = 50$

$\sigma_k = standard\ deviation$

Distribution matrix, $DM_{kx}(t)$

if $k = 1,2,6$ then $(1 + CDM_m)$

if $k = 3,4,5$ then $(1 - CDM_m)$

if $k = 1,2$ *then* $m = 1$

if $k = 3,4$ *then* $m = 2$

if $k = 5$ *then* $m = 3$

if $k = 6$ *then* $m = 4$

Preference variables, such as $C\,Preference$, $CP_k(t)$ are determined by their valuation (find below) and their ratio out of the summed preference

Centrality valuation, $CtV_k(t)$

$$CtV_k = \left[0;\ 0{,}1283;\ 0{,}1516;\ 0{,}1272;\ 0{,}0749;\ 0{,}1190;\ 0{,}2700\right] \cdot PV_1$$

Surroundings valuation, $SuV_k(t)$

$$SuV_k = \left[0;\ 0{,}1130;\ 0{,}1220;\ 0{,}1674;\ 0{,}2561;\ 0{,}1712;\ 0{,}0137\right] \cdot PV_2$$

Cost valuation, $CV_k(t)$

$$CV_k = \left[0{,}3263;\ 0{,}1819;\ 0{,}1381;\ 0{,}0647;\ 0;\ 0{,}0986;\ 0{,}0813\right] \cdot PV_3$$

Building state valuation, $BSV_k(t)$

$$BSV_k = \left[0;\ 0{,}1306;\ 0{,}1691;\ 0{,}1193;\ 0{,}0847;\ 0{,}1303;\ 0{,}2265\right] \cdot PV_4$$

Crime valuation, $CrV_k(t)$

$$CrV_k = [0,0947;\ 0,1279;\ 0,0841;\ 0,1529;\ 0,2722;\ 0,1347;\ 0] \cdot PV_5$$

Education valuation, $EV_k(t)$

$$EV_k = [0,3149;\ 0,1198;\ 0,1101;\ 0,0846;\ 0;\ 0,0770;\ 0,2101] \cdot PV_6$$

Green valuation, $GV_k(t)$

$$GV_k = [0;\ 0,1062;\ 0,0750;\ 0,1797;\ 0,3122;\ 0,1262;\ 0,0684] \cdot PV_7$$

Social valuation, $SoV_k(t)$

$$SoV_k = [0,2642;\ 0,0923;\ 0,1502;\ 0,1044;\ 0;\ 0,1430;\ 0,1300] \cdot PV_8$$

Social matrix, $SoM_{kk}(t)$

$$SoM_{kk} = SoM_{kk}(0) \cdot SoP_k$$

Preference valuation, $PV_n(t)$ $\quad \text{if } MI_k > mi_k \text{ then } PV_n = [2;\ 3;\ 6;\ 3;\ 4;\ 2;\ 3;\ 3]$

$$\text{if } MI_k < mi_k \text{ then } PV_n = [1;\ 2;\ 8;\ 2;\ 3;\ 1;\ 2;\ 2]$$

$$mi_k = [920;970;1892;1708;2226;1283;844] \qquad mi_k = mean$$

**Real estate, housing area of UST**

Vacancy, $V_i(t)$ $\quad \dfrac{dV_i}{dt} = \sum_{k=1}^{7} df_{ik} - \sum_{k=1}^{7} ru_{ik} - dl_i$

Demolition, $dl_i(t)$ $\quad dl_{ik}(t) = f_{dl}(DLS_{ik}, DlR_i) \quad \dfrac{\partial dl_{ik}}{\partial DLS_{ik}} \geq 0,\ \dfrac{\partial dl_{ik}}{\partial DlR_i} \geq 0$

$$dl_i = DLS_i \cdot DlR_i \qquad V_i > 0$$

Demand living space_HHT, $DLS_{ik}(t)$ $\quad DLS_{ik}(t) = f_{DLS}(DP_{ik}) \quad \dfrac{dDLS_{ik}}{dDP_{ik}} \geq 0$

$$DLS_{ik} = \frac{LSC_k \cdot DP_{ik}}{10000}$$

Demand_HHT, $DP_{ik}(t)$ $\quad DP_{ik}(t) = f_{DP}(HHT_k, A_{ik}) \quad \dfrac{dDP_{ik}}{dHHT_k} \geq 0$

$$DP_{ik} = \frac{A_{ik}}{\sum_{k=1}^{7} A_{ik}} \cdot HHT_k$$

Supply _HHT, $SP_{ik}(t)$ $\quad DSP_{ik}(t) = f_{SP}(SLS_{ik}) \quad \dfrac{dSP_{ik}}{dSLS_{ik}} \geq 0 \quad SP_{ik} = \dfrac{SLS_{ik} \cdot 10000}{LSC_k}$

Supply living space, $SLS_i(t)$ $$SLS_i = \sum_{k=1}^{7} SLS_{ik}$$

Demand living space, $DLS_i(t)$ $$DLS_i = \sum_{k=1}^{7} DLS_{ik}$$

Supply residential area, $SRA_i(t)$ $$SRA_i = \frac{SLS_i \cdot FSM}{FSD_i}$$

Demand residential area, $DRA_i(t)$ $$DRA_i = \frac{DLS_i \cdot FSM}{FSD_i}$$

Total living space, $TLS_i(t)$ $$TLS_i = V_i + SLS_i$$

Total residential area, $TRA_i(t)$ $$TRA_i = \frac{TLS_i \cdot FSM}{FSD_i}$$

Building area, $BA_i(t)$ $$BA_i = \frac{TLS_i}{St_i}$$

Space Supply, $SS(t)$ $$\frac{\mathrm{d}SS}{\mathrm{d}t} = dl_i - \sum_{k=1}^{7} co_{ik}$$

UST-valuing conditions per UST (green supply, crime rate) are calculated by the describing UST variable and the difference to the previous year as a ratio of the sum of one condition variable at time *t*

Describing UST variables are calculated by multiplying their amount at time *t* and their respective rates (see below)

Green rate, $GR_i(t)$ $$GR_i(t) = f_{GR}(dl_i, co_i, SP_i) \quad \frac{\partial GR_i}{\partial dl_i} \geq 0, \ \frac{\partial GR_i}{\partial co_i} \leq 0,$$

$$\frac{\partial GR_i}{\partial SP_i} \leq 0 \qquad GR_i = \frac{\sum_{k=1}^{7} dl_{ik} - \sum_{k=1}^{7} co_{ik}}{\sum_{k=1}^{7} SP_{ik}} \cdot GPa$$

Education rate, $ER_i(t)$ $$ER_i(t) = f_{ER}(PE)$$

$$\frac{\mathrm{d}ER_i}{\mathrm{d}PE_i} \geq 0$$

$$ER_i = \left( \frac{PE_i}{PE_i(t-dt)} - 1 \right) \cdot EPa \cdot dt \qquad t > 0$$

Crime rate, $CrR_i(t)$ $$CrR_i(t) = f_{CrR}\left( \left[ SP_i / SRA_i \right], SV_i \right), \frac{\partial CrR_i}{\partial \left[ SP_i / SRA_i \right]} \geq 0,$$

$$\frac{\partial CrR_i}{\partial SV_i} \geq 0$$

$$CrR_i = \left( \left( \frac{\sum_{k=1}^{7} SP_{ik}}{SRA_i} \right) \cdot \left( \frac{\sum_{k=1}^{7} SP_{ik}\left(t-dt\right)}{SRA_i(t-dt)} \right)^{-1} - 1 \right) \cdot 0.5 + \left( \frac{SV_i}{SV_i\left(t-dt\right)} - 1 \right) \cdot 0.5 \cdot CrPa$$

$$-0.1 < CrR_i < 0,1$$

Building state rate, $BSR_i(t)$ $\quad BSR_i(t) = f_{BSR}(DLS)$

$$\frac{\mathrm{d}BSR_i}{\mathrm{d}DLS_i} \geq 0$$

$$\frac{\mathrm{d}BSR_i}{\mathrm{d}t} = \left( \frac{DLS_i}{DLS_i(t-dt)} - 1 \right) \cdot \sum_{i=1}^{8} \left( \frac{DLS_i}{DLS_i(t-dt)} - 1 \right)^{-1}$$

Cost rate, $CR_i(t)$ $\quad CR_i(t) = f_{BSR}(DLS_i, SLS_i)$ $\quad \frac{\partial CR_i}{\partial DLS_i} \geq 0$,

$$\frac{\partial CR_i}{\partial SLS_i} \leq 0 \qquad CR_i = \frac{DLS_i - SLS_i}{SLS_i} \cdot CPa$$

**Initials and parameter**

Pop class

$$P_x(0) = (57113;\ 70064;\ 83662;\ 76672;\ 62729;\ 77499;\ 49088;\ 38077)$$

Fertility $\quad F_x(0) = (0;0.015;0.027;0,0036;0;0;0;0)$

Mortality $\quad M_x(0) = (0.002;0;0;0;0;0.005;0.009;0.08)$

Vacancy $\quad V_i(0) = \left[0.10;\ 0.38;\ 0.15;\ 0.03;\ 0.03;\ 0.15;\ 0.08;\ 0.02\right]$

City area $\quad CA = 26761$

Space supply $\quad SS(0) = 1960 \cdot 2.5$

Supply living space $\quad SLS_i(0) = (267.2;\ 657.6;\ 886.6;\ 314.8;\ 77.2;\ 207.2;\ 205.9;\ 141.3)$

Reuse rate $\quad RR_i(0) = (0;\ -0.095;\ -0.095;\ 0;\ 0;\ 0;\ -0.025;\ 0)$

Deflation rate

$$VR_i(0) = (0.023;\ 0.001;\ 0,001;\ 0.0021;\ 0.001;\ 0.0077;\ 0.001;\ 0.001)$$

Demolition rate

$$DlR_i(0) = (0.011;\ 0.00114;\ 0.00114;\ 0.00015;\ 0.00008;\ 0.00114;\ 0.00114;\ 0.0001)$$

Construction rate

$$CoR_i(0) = (0;\ 0.0024;\ 0.002;\ 0.0332;\ 0.01;\ 0.0005;\ 0.0005;\ 0.0005)$$

Green area $\quad G_i(0) = (2.43;\ 0.92;\ 4.09;\ 8.81;\ 3.62;\ 2.26;\ 3.61;\ 0.59)$

Education $\quad E_i(0) = (0.17;\ 0.13;\ 0.12;\ 0.05;\ 0.06;\ 0.14;\ 0.07;\ 0)$

Crime $\quad Cr_i(0) = (130;\ 159;\ 155;\ 84;\ 90;\ 100;\ 106;\ 250)$

Building state $\quad BS_i(0) = (0.073;\ 0.112;\ 0.165;\ 0.097;\ 0.100;\ 0.134;\ 0.099;\ 0.220)$

Cost $\quad C_i(0) = (5;\ 5.5;\ 6.25;\ 6.5;\ 6.25;\ 5;\ 5.5;\ 6.5)$

Centrality $\quad Ct_i = (0.064;\ 0.127;\ 0.175;\ 0.090;\ 0.070;\ 0.089;\ 0.075;\ 0.309)$

Surroundings $Su_i = (0.05;\ 0.104;\ 0.114;\ 0.127;\ 0.145;\ 0.142;\ 0.142;\ 0.112)$

Distribution matrix Pop_HHT

$$DM_{kx}(0) = \begin{pmatrix} DM_{11} & \cdots & DM_{k8} \\ \vdots & \ddots & \vdots \\ DM_{7x} & \cdots & DM_{kx} \end{pmatrix} = \begin{pmatrix} 0 & 0.21 & 0.21 & 0.15 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0.25 & 0.25 & 0.4 & 0.45 \\ 0 & 0.15 & 0.17 & 0.3 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0.3 & 0.63 & 0.5 & 0.25 \\ 0.7 & 0.25 & 0.3 & 0.35 & 0.35 & 0.09 & 0 & 0 \\ 0.3 & 0.15 & 0.12 & 0.13 & 0.1 & 0.03 & 0 & 0 \\ 0 & 0.24 & 0.2 & 0.07 & 0 & 0 & 0.1 & 0.3 \end{pmatrix}$$

Social matrix

$$SoM_{kk} = \begin{pmatrix} SoM_{11} & \cdots & SoM_{7k} \\ \vdots & \ddots & \vdots \\ SoM_{k7} & \cdots & SoM_{kk} \end{pmatrix} = \begin{pmatrix} 0.048 & 0.238 & 0.048 & 0.238 & 0.190 & 0.190 & 0.048 \\ 0.217 & 0.043 & 0.217 & 0.043 & 0.174 & 0.174 & 0.130 \\ 0.048 & 0.238 & 0.048 & 0.238 & 0.190 & 0.190 & 0.048 \\ 0.111 & 0.111 & 0.111 & 0.111 & 0.222 & 0.222 & 0.111 \\ 0.111 & 0.111 & 0.111 & 0.111 & 0.222 & 0.222 & 0.111 \\ 0.235 & 0.059 & 0.235 & 0.059 & 0.059 & 0.059 & 0.294 \\ 0.208 & 0.042 & 0.208 & 0.042 & 0.167 & 0.167 & 0.167 \end{pmatrix}$$

Distribution matrix UST_HHT

$$ID_{ik} = \begin{pmatrix} ID_{11} & \cdots & ID_{7i} \\ \vdots & \ddots & \vdots \\ ID_{k8} & \cdots & ID_{ki} \end{pmatrix} = \begin{pmatrix} 0.197 & 0.255 & 0.099 & 0.140 & 0.176 & 0.088 & 0.045 \\ 0.188 & 0.179 & 0.086 & 0.193 & 0.130 & 0.098 & 0.126 \\ 0.012 & 0.092 & 0.175 & 0.215 & 0.264 & 0.085 & 0.158 \\ 0 & 0.147 & 0.035 & 0.218 & 0.479 & 0.091 & 0.029 \\ 0.032 & 0.101 & 0.096 & 0.189 & 0.404 & 0.160 & 0.019 \\ 0.150 & 0.256 & 0.130 & 0.136 & 0.146 & 0.120 & 0.062 \\ 0.147 & 0.207 & 0.100 & 0.199 & 0.206 & 0.114 & 0.027 \\ 0.015 & 0.268 & 0.127 & 0.176 & 0.215 & 0.127 & 0.072 \end{pmatrix}$$

Space supply threshold $SS_{T1} = 50$; $SS_{T2} = 150$, $SS_{T3} = 800$

Fertility trend $FT_2 = \text{-}0.0003 \cdot Log10(t) + 0.0005$

$$FT_3 = \text{-}0.0004 \cdot Log10(t) + 0.0009$$

$$FT_4 = \text{-}0.00026 \cdot Log10(t) + 0.0007$$

$$FT_{1,5,6,7,8} = 0$$

Mortality trend $MT_x = 0.0026 \cdot Log10(t) - 0.0124$

In-mig trend $TIM_1 = 77.36 \cdot t^{(-1.0673)}$

$$TIM_2 = 313.6 \cdot t^{(-1.0673)}$$

$$TIM_3 = 263.4 \cdot t^{(-1.0673)}$$

$$TIM_4 = 117.1 \cdot t^{(-1.0673)}$$

$$TIM_5 = 64.8 \cdot t^{(-1.0673)}$$
$$TIM_6 = 50.2 \cdot t^{(-1.0673)}$$

$$TIM_7 = 37.6 \cdot t^{(-1.0673)}$$

$$TIM_8 = 37.6 \cdot t^{(-1.0673)}$$

Out-mig trend $TOM_x = TIM_x \cdot (-1)$

Change distribution matrix $\mathrm{CDM_m} = [0.01;\ 0.01;\ 0.01;\ 0.005]$

Living space consumption $LSC_k = [54;\ 54;\ 37,5;\ 35;\ 31;\ 35;\ 37]$

Storey $St_i = [8;\ 4.2;\ 3.2;\ 2;\ 4.5;\ 5.5;\ 3.4;\ 5.4]$

Floor space multiplier $FSM = 1.25$

Floor space density $FSD_i = [1.1;\ 1.6;\ 0.6;\ 0.2;\ 0.7;\ 0.7;\ 0.4;\ 2.7]$

Green parameter $GPa = 1000$

Education parameter $EPa = 0.5$

Crime parameter $CrPa = 0.4$

Building state parameter $BSPa = 1$

Cost parameter $CPa = 0.05$

Table A1. Numbers of residential area, vacancy and remaining open land differentiated according to urban structural types for 2005-2030 for the shrinkage scenario

| | | 2005 | 2010 | 2015 | 2020 | 2025 | 2030 |
|---|---|---|---|---|---|---|---|
| Scenario "Shrinkage" | | | | | | | |
| Total vacancy | in % | 12.3 | 12.1 | 12.3 | 12.6 | 13.0 | 13.3 |
| Inhabited residential area in hectare | town centre | 308.7 | 295.1 | 276.3 | 255.5 | 234.8 | 215.1 |
| | Wilhelminian-time old built-up blocks | 728.4 | 726.7 | 722.9 | 717.8 | 712.2 | 706.5 |
| | multi-storey row housing estates | 186.5 | 188.7 | 189.2 | 188.7 | 187.8 | 186.7 |
| | prefab multi-storey housing estates | 2590.4 | 2590.4 | 2575.8 | 2556.0 | 2533.9 | 2510.5 |
| | villas | 145.3 | 146.5 | 146.2 | 145.5 | 144.8 | 144.4 |
| | residential parks | 429.6 | 427.6 | 420.6 | 410.5 | 399.5 | 388.4 |
| | single houses | 498.2 | 499.2 | 497.5 | 494.6 | 491.2 | 487.8 |
| | suburban villages | 11.0 | 11.6 | 12.1 | 12.5 | 12.9 | 13.2 |
| Total residential area plus vacancy in hectare | town centre | 354.0 | 332.1 | 309.6 | 287.5 | 266.1 | 245.8 |
| | Wilhelminian-time old built-up blocks | 883.0 | 876.4 | 868.6 | 860.1 | 851.5 | 842.9 |
| | multi-storey row housing estates | 207.0 | 210.0 | 211.2 | 211.5 | 211.3 | 210.9 |
| | prefab multi-storey housing estates | 2670.5 | 2692.8 | 2702.5 | 2706.9 | 2708.5 | 2708.0 |
| | villas | 148.3 | 150.1 | 150.7 | 150.8 | 150.8 | 150.9 |
| | residential parks | 521.1 | 519.3 | 515.8 | 511.4 | 506.6 | 501.7 |
| | single houses | 529.9 | 533.0 | 533.2 | 531.9 | 529.9 | 527.5 |
| | suburban villages | 11.3 | 11.9 | 12.3 | 12.8 | 13.1 | 13.4 |
| Open Area | in hectare | 4900.0 | 4919.0 | 4946.0 | 4976.1 | 5007.1 | 5038.1 |
| Share residential area | in % | 17.9 | 17.9 | 17.8 | 17.7 | 17.7 | 17.5 |

Table A2. Numbers of residential area, vacancy and remaining open land differentiated according to urban structural types for 2005-2030 for the baseline scenario

| | | 2005 | 2010 | 2015 | 2020 | 2025 | 2030 |
|---|---|---|---|---|---|---|---|
| Scenario "Shrinkage" | | | | | | | |
| Total vacancy | in % | 12.3 | 12.1 | 12.3 | 12.6 | 13.0 | 13.3 |
| Inhabited residential area in hectare | town centre | 308.7 | 295.1 | 276.3 | 255.5 | 234.8 | 215.1 |
| | Wilhelminian-time old built-up blocks | 728.4 | 726.7 | 722.9 | 717.8 | 712.2 | 706.5 |
| | multi-storey row housing estates | 186.5 | 188.7 | 189.2 | 188.7 | 187.8 | 186.7 |
| | prefab multi-storey housing estates | 2590.4 | 2590.4 | 2575.8 | 2556.0 | 2533.9 | 2510.5 |
| | villas | 145.3 | 146.5 | 146.2 | 145.5 | 144.8 | 144.4 |
| | residential parks | 429.6 | 427.6 | 420.6 | 410.5 | 399.5 | 388.4 |
| | single houses | 498.2 | 499.2 | 497.5 | 494.6 | 491.2 | 487.8 |
| | suburban villages | 11.0 | 11.6 | 12.1 | 12.5 | 12.9 | 13.2 |
| Total residential area plus vacancy in hectare | town centre | 354.0 | 332.1 | 309.6 | 287.5 | 266.1 | 245.8 |
| | Wilhelminian-time old built-up blocks | 883.0 | 876.4 | 868.6 | 860.1 | 851.5 | 842.9 |
| | multi-storey row housing estates | 207.0 | 210.0 | 211.2 | 211.5 | 211.3 | 210.9 |
| | prefab multi-storey housing estates | 2670.5 | 2692.8 | 2702.5 | 2706.9 | 2708.5 | 2708.0 |
| | villas | 148.3 | 150.1 | 150.7 | 150.8 | 150.8 | 150.9 |
| | residential parks | 521.1 | 519.3 | 515.8 | 511.4 | 506.6 | 501.7 |
| | single houses | 529.9 | 533.0 | 533.2 | 531.9 | 529.9 | 527.5 |
| | suburban villages | 11.3 | 11.9 | 12.3 | 12.8 | 13.1 | 13.4 |
| Open Area | in hectare | 4900.0 | 4919.0 | 4946.0 | 4976.1 | 5007.1 | 5038.1 |
| Share residential area | in % | 17.9 | 17.9 | 17.8 | 17.7 | 17.6 | 17.5 |

PLUREL

Table A3. Numbers of residential area, vacancy and remaining open land differentiated according to urban structural types for 2005-2030 for the growth scenario

| | | 2005 | 2010 | 2015 | 2020 | 2025 | 2030 |
|---|---|---|---|---|---|---|---|
| Scenario "Shrinkage" | | | | | | | |
| Total vacancy | in % | 12.3 | 11.6 | 10.8 | 10.2 | 9.6 | 9.1 |
| Inhabited residential area in hectare | town centre | 308.7 | 300.0 | 289.1 | 274.6 | 258.1 | 240.6 |
| | Wilhelminian-time old built-up blocks | 728.4 | 730.7 | 735.9 | 742.8 | 750.1 | 757.3 |
| | multi-storey row housing estates | 186.5 | 191.8 | 200.5 | 208.7 | 215.9 | 222.1 |
| | prefab multi-storey housing estates | 2590.4 | 2612.9 | 2646.6 | 2670.3 | 2688.8 | 2704.2 |
| | villas | 145.3 | 147.6 | 152.2 | 156.5 | 160.1 | 163.1 |
| | residential parks | 429.6 | 435.3 | 447.1 | 460.5 | 473.7 | 486.0 |
| | single houses | 498.2 | 502.8 | 512.4 | 522.7 | 532.5 | 541.6 |
| | suburban villages | 11.0 | 12.5 | 14.6 | 16.6 | 18.2 | 19.3 |
| Total residential area plus vacancy in hectare | town centre | 354.0 | 335.2 | 318.3 | 301.7 | 284.6 | 266.9 |
| | Wilhelminian-time old built-up blocks | 883.0 | 877.0 | 871.7 | 867.3 | 863.1 | 859.1 |
| | multi-storey row housing estates | 207.0 | 212.8 | 222.0 | 230.6 | 238.3 | 245.0 |
| | prefab multi-storey housing estates | 2670.5 | 2711.6 | 2760.2 | 2799.1 | 2832.7 | 2863.1 |
| | villas | 148.3 | 151.0 | 156.1 | 160.9 | 165.0 | 168.5 |
| | residential parks | 521.1 | 520.3 | 522.6 | 526.9 | 532.5 | 539.0 |
| | single houses | 529.9 | 536.3 | 547.5 | 559.1 | 570.2 | 580.4 |
| | suburban villages | 11.3 | 12.7 | 14.8 | 16.8 | 18.4 | 19.5 |
| Open Area | in hectare | 4900.0 | 4906.7 | 4901.6 | 4896.6 | 4893.6 | 4893.1 |
| Share residential area | in % | 17.9 | 18.0 | 18.2 | 18.4 | 18.5 | 18.6 |

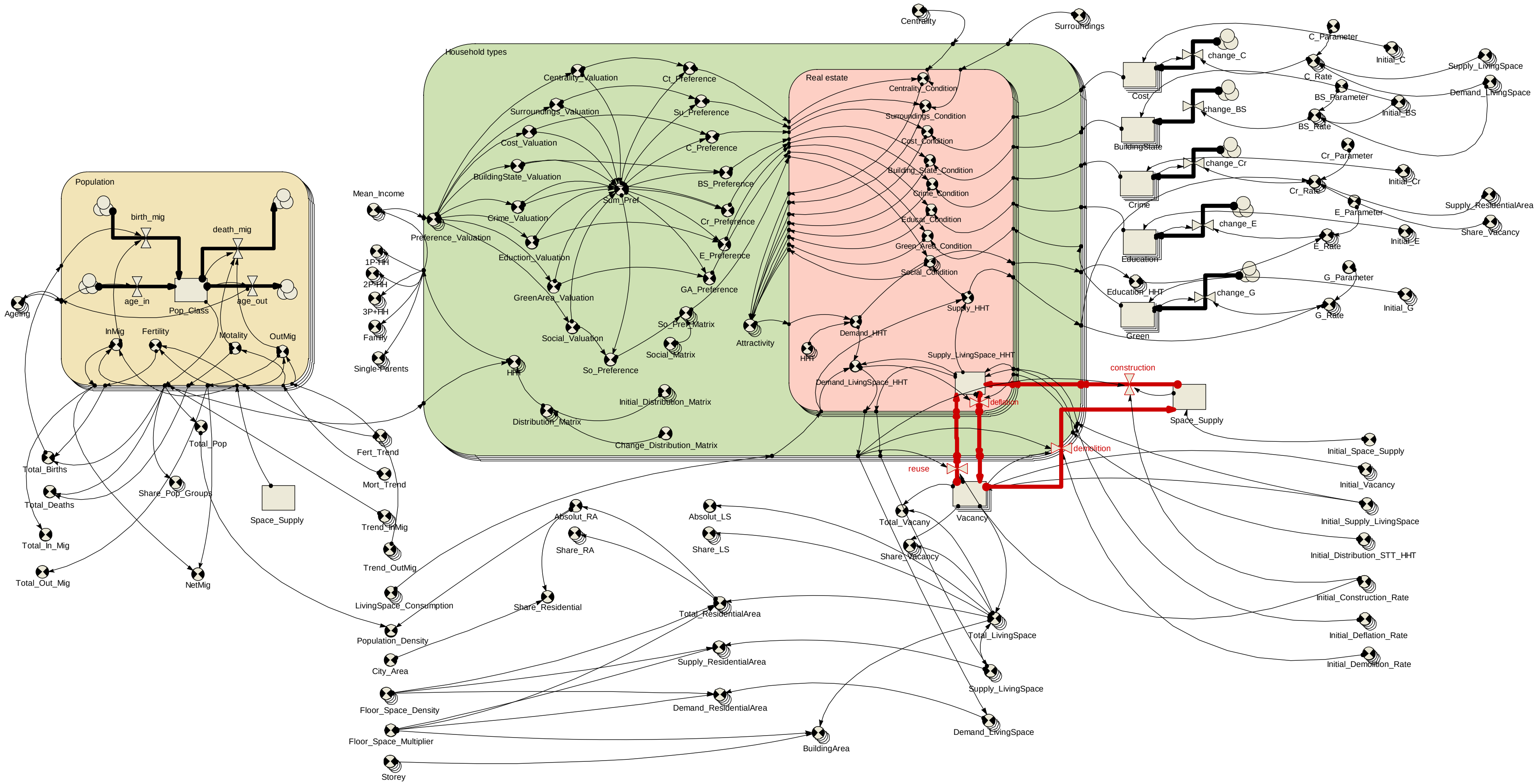
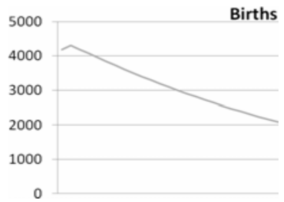
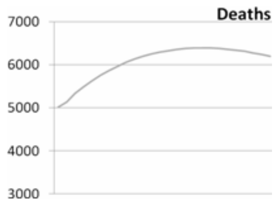
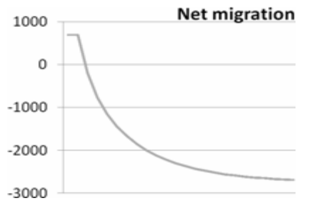
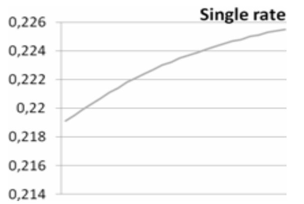
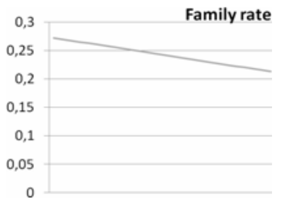
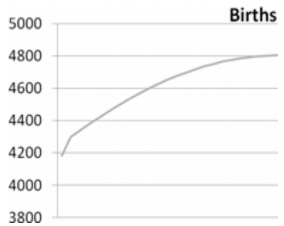
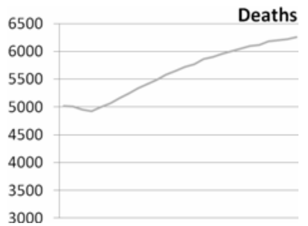
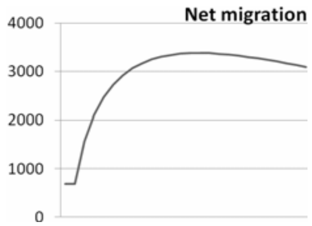
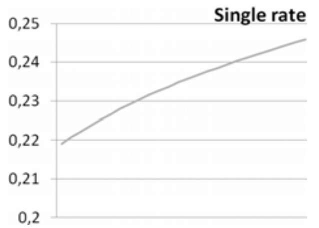
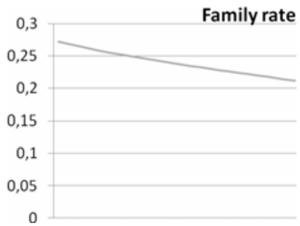
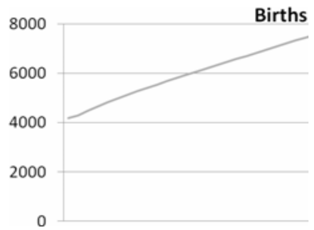
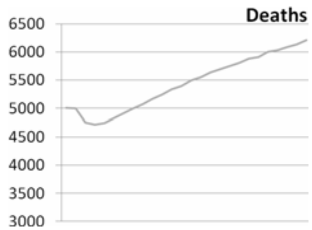
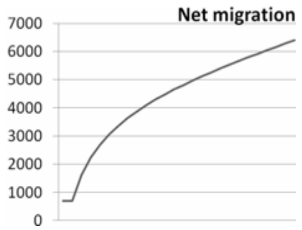
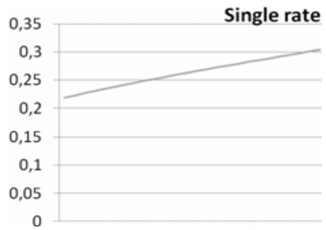
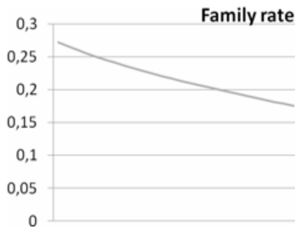



Figure A1. Detailed version of the model structure with all variables reported

Figure A2. Population projection for the three scenarios: shrinkage, baseline and growth

| Scenario | Fertility | Mortality | Net migration | % Single households | % Families |
|---|---|---|---|---|---|
| Shrinkage |  |  |  |  |  |
| Baseline |  |  |  |  |  |
| Growth |  |  |  |  |  |

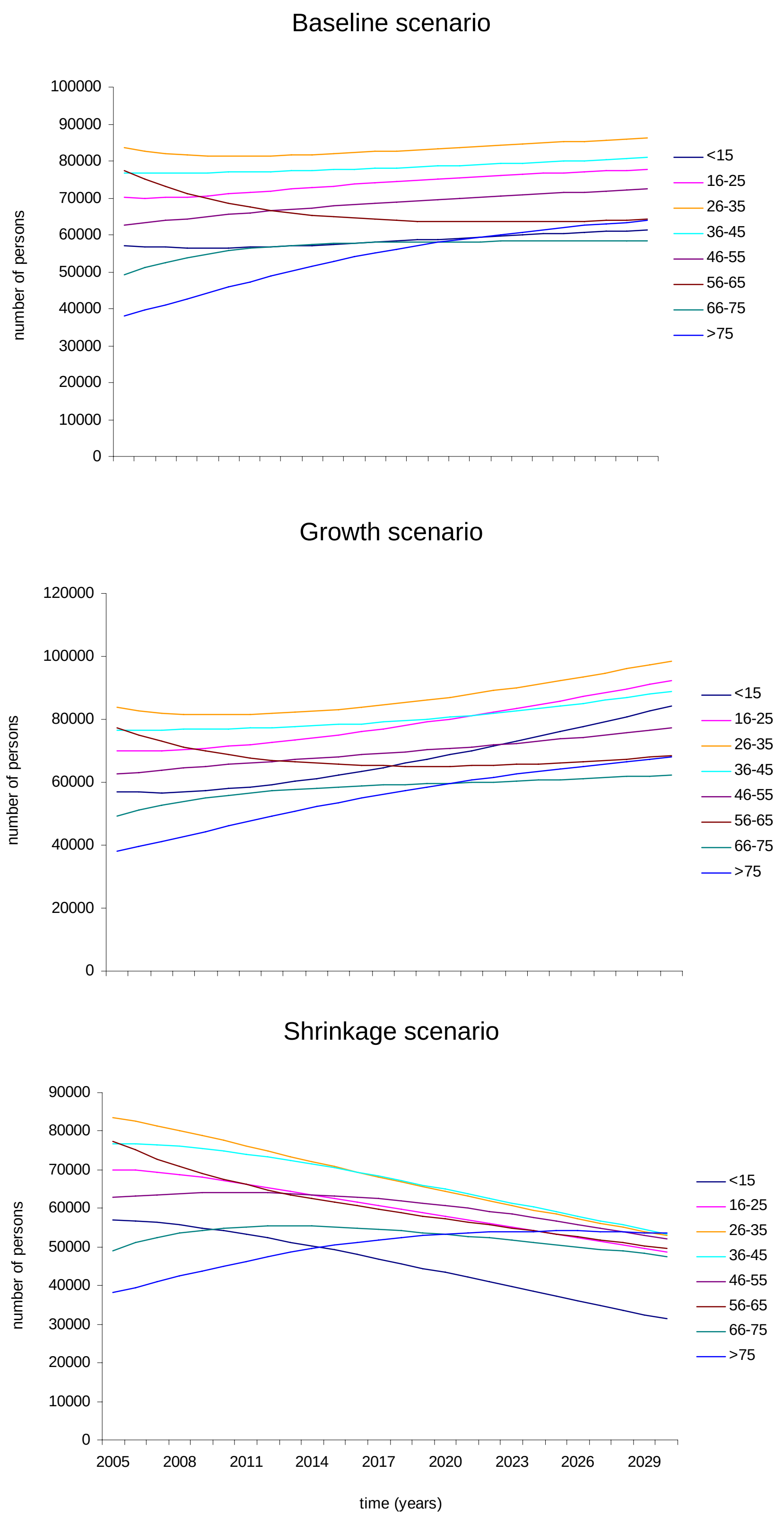



Figure A3. Development of the inhabitant age class structure for 2005-2030 for the baseline, growth and shrinkage scenario

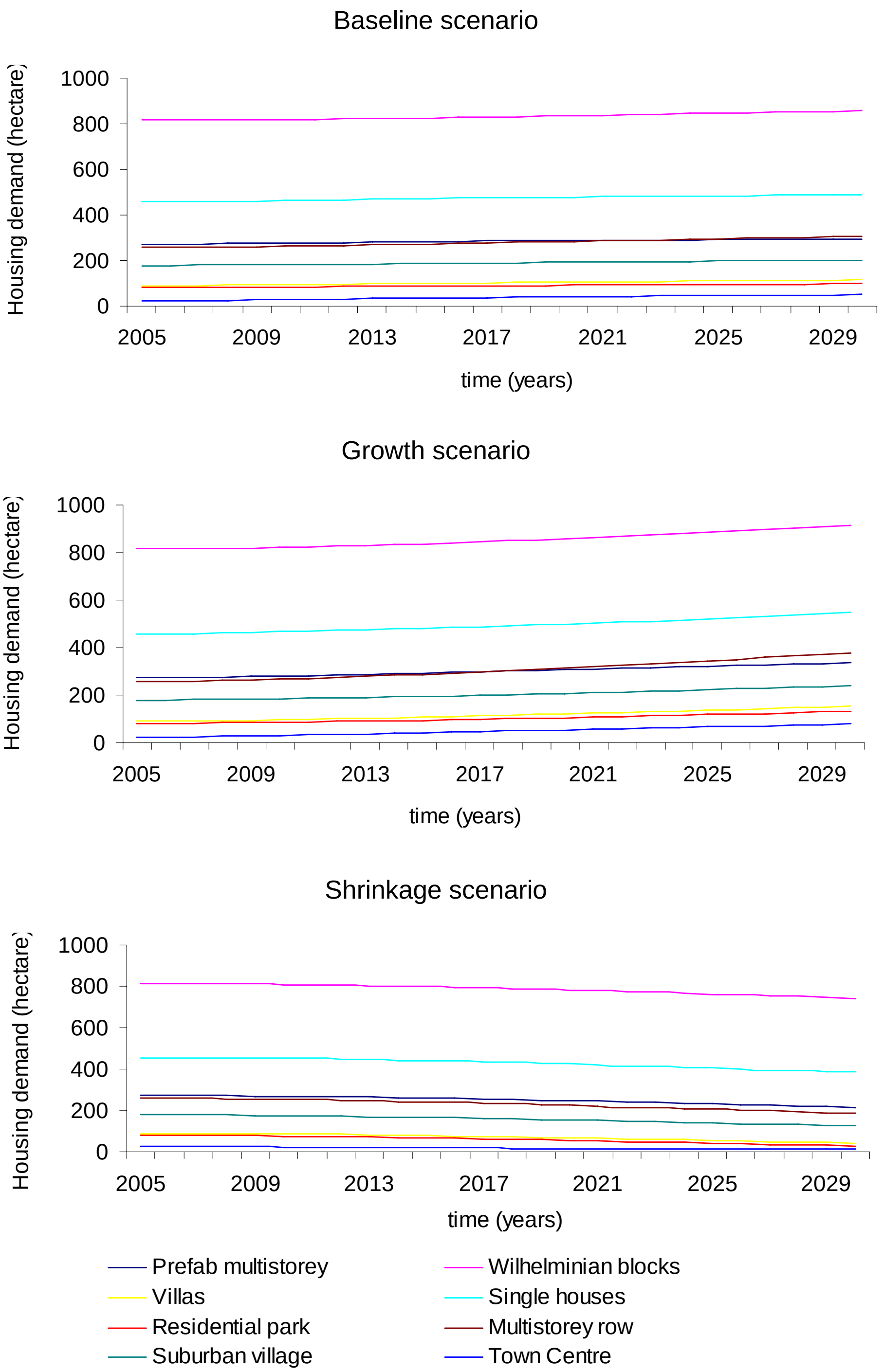



Figure A4. Housing demand for the baseline, growth and shrinkage scenario.