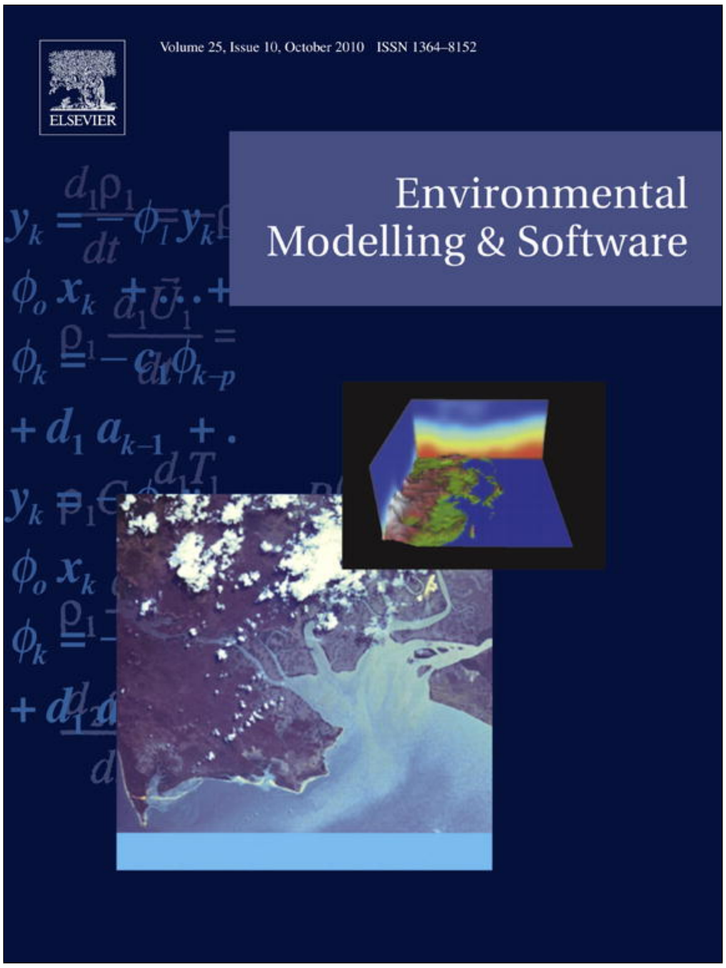
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Modeling and simulating residential mobility in a shrinking city using an agent-based approach

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ABSTRACT

Shrinking cities are characterized by a huge oversupply of dwellings and resulting residential vacancies. Discussions among urban planners and policymakers in Europe have focused on the consequences of urban shrinkage following demographic transition, fertility decline and individualization. In this study, the shrinking city of Leipzig in Eastern Germany is singled out as a case basis for the study of residential mobility and land use change using agent-based modeling techniques, in which social scientists developed a concept of household types based on empirical data that form a unique base; these techniques were used to construct a data-driven, agent-based model. The spatially explicit simulation model RESMOB*city* presented here 'translates' these empirical data via behavioral rules of households. It computes spatially explicit household patterns, housing demands and residential vacancies. Based on three scenarios, population growth, stagnation and shrinkage, we show that population might stabilize within the coming years. The number of households is expected to further increase. We demonstrate that a selective demolition of vacant housing stock can counteract the enormous oversupply of dwellings and better balance housing demand and the number of available flats. Scenario simulation shows that the model can reproduce observed patterns of population, inner-urban migration and residential vacancy in a spatially explicit manner and thus can be applied to the analysis of scenarios of demographic change in urban regions. The presented model acts as a tool supporting the testing of hypotheses in social science research and allowing the quantification of land-use scenarios in urban regions based on household choices.

Software availability

Name of the software: RESMOB*city*
Availability: http://www.transfer.ufz.de/index.cgi?dir=%2Fwww%2Fhttp_data%2Ftransfer%2Falok%2Fhaase%2FRESMOBcity (login: alok, password: 06alok05;/haase/RESMOBcity/)
Developer: Dagmar Haase
Year first available: 2009
Software required: Sun Java (JRE/JDK version 1.6 and higher)
Operation systems: Windows
Programming language: Java
License: Sun Microsystems, Inc. Binary Code License Agreement for the JAVA SE RUNTIME ENVIRONMENT (JRE) VERSION 6 and JAVAFX RUNTIME VERSION 1

1. Introduction

1.1. The research challenge

Residential mobility is one of the major drivers of urban land-use change. Numerous studies of residential mobility in continental Europe, the UK and the US have been carried out in attempts to explain mobility patterns based on housing choices and spatial segregation of the urban population (e.g., Börsch-Supan and Pitkin, 1988; Börsch-Supan et al., 2001; Lindberg et al., 1992). For a number of decades, developments such as urban growth and sprawling settlements dominated housing markets and residential mobility (Antrop, 2004; Kazepov, 2005; Loibl and Tötzer, 2003). Because it is increasingly occurring worldwide, urban shrinkage is currently a hot topic among urban planners (Rieniets, 2006, 2009). Shrinking cities hold huge oversupplies of dwellings and resulting vacancies (Haase et al., 2007; Jessen, 2006).

Urban shrinkage is a complex phenomenon resulting from processes of de-industrialization and out-migration and resulting population decline (Rieniets, 2009). In European cities, shrinkage

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also occurs due to processes of demographic change such as aging and a decrease in fertility (Kaa, 2004). An increase in the number of one and two-person households, as well as a shift in age-spectra and new forms of patchwork families, are also occurring (Lesthaeghe and Neels, 2002; Ogden and Hall, 2000). Such demographic features considerably affect residential location choices and land use within a city (Torrens, 2002) regardless of whether a city is growing or shrinking.

The eastern German city of Leipzig provides a perfect case for the study of demographic change and shrinkage and for the modeling of residential mobility and the creation of housing vacancies because it is representative of these general patterns worldwide. Because social scientists have developed a concept of household typology under demographic change (Buzar et al., 2005, 2007), such a case study offers a unique database for testing hypotheses on the behavior of urban residents with respect to residential decision-making. As argued by Haase and Haase (2007), this empirical database offers a unique base for construction of a data-based, agent-based model (ABM).

1.2. Objectives

The major objective of this paper is to simulate processes and patterns of residential mobility in a shrinking city using principles grounded in the social science concept of household types and using empirical data related to this concept. We aim to foster ABM development that covers human decision-making tested on independent data. By developing and applying a spatially explicit ABM named RESMOB*city*, we derive scenarios of diverging population and household trajectories and analyze the resulting residential land-use patterns. With the model RESMOB*city*, we present the first complex model

- that describes household agents developed based on a social science concept that reflects demographic transition and
- that is able to simulate urban population growth and shrinkage processes.

Because it is grounded in new and broad empirical data and concepts, we believe that the model provides an innovative contribution to the application of modeling techniques to challenging questions of social and land use science.

2. System analysis: given knowledge of processes, data and modeling concepts

2.1. A case in point for urban-shrinkage modeling: Leipzig

After the German reunification in 1990, most eastern German cities faced dramatic losses of inhabitants due to declining birth rates, job-driven out-migration to the western part of the country and a widespread catch-up suburbanization (Couch et al., 2005; Nuissl and Rink, 2005). From 1990 onwards, eastern Germany faced a loss of about 1.2 million people (8% of the entire stock; Kabisch et al., 2006). Most eastern German cities, among them Leipzig, lost between 10 and 25% of their residents in a short period of time (the mean value for large cities from 1990 to 1999 is about 16%). Accordingly, the population density of Leipzig dramatically decreased from 3.5 inh./m^2 in 1990 to 1.6 inh./m^2 in 2008. Economic resurgence of the city after 1998 and a new wave of reurbanization allowed net migration to increase and turned the balance of population to slightly positive. During the two most recent decades, the number of households have increased by 30%, and a simultaneous decline in the average household size, from >2.3 in 1989 to 1.8 in 2008, has occurred (Haase and Haase, 2007; Kabisch et al., 2009). Such processes of urban shrinkage are not limited to eastern Germany but are now faced by about 20% of the European city regions, predominantly in eastern Europe (e.g., Silesian cities and Romanian and Czech cities) but also in Central France, Napoli and Genova (cf. Kabisch and Haase, in press).

As a consequence of the demographic and economic decline, flats and housing stock have been falling vacant to an increasing degree despite the increasing number of households. Residential vacancy is no longer restricted to uninhabitable housing as it was during GDR times but also affects completely renovated building stock (Kabisch et al., 2006). Based on the present rate of increase in number of households we expect that supply will continue to exceed demand, even if present household numbers continue to increase until about 2017. Entire residential districts, parts of which have been demolished, exhibit vacancy rates >30 or even up to 50% (Jessen, 2006). Demolition produces new spatial patterns such as perforated structures with decreasing house density, demolished sites along the urban periphery, demolition corridors within a city and housing islands.[1]

2.2. New processes: second demographic transition and urban shrinkage

The demographic and shrinkage processes described above are not implemented in most recent land-use change simulation models (e.g., MedAction, Geonamica, UrbansSim, Sleuth, and GLUE-S). We thus offer a concept for translation of the above-described patterns that allows them to be used to identify distinguishable processes that can be coded in a dynamic model. This model is supported by references to social science concepts that aim to explain residential decision-making processes and respective household distribution patterns. By incorporating these concept patterns into the model, we can separate demographics from land use-related processes. Both processes are ultimately linked through the decision-making of people in urban regions, which affects their residential mobility.

The major demographic change occurring at present is described as the Second Demographic Transition (SDT) Lutz, 2001; this transition summarizes the current change and diversity of living arrangements other than marriage, the disconnection between marriage and procreation and the lack of a constant population. Additionally, urban populations face decline in many European countries (Kabisch and Haase, in press), though this decline is frequently neutralized by immigration. Extra gains in longevity in tandem with sustained sub-replacement fertility will produce a major additional aging effect as well (Cloet, 2003; Lesthaeghe and Neels, 2002).

The spatial differentiation of urban neighborhoods along different paths such as development, renewal, and decline, as well as large-scale demolition of entire housing estates, are not explainable by time series of demographic and economic variables obtained from local district statistics (Wegener and Spiekerman, 1996; Haase and Haase, 2007). Particularly in cities with declining populations, residential mobility is of major importance in determining the shape of residential land use. The total population and number of households are less important than general patterns and housing preferences when characterizing specific urban geodemographics (Gober, 1990; Kemper, 2001).

[1] As a new intervention strategy, a federal program of urban restructuring (titled in German 'Stadtumbau Ost') operates in terms of a guideline to organize and finance the demolition of overhanging housing stock (350,000 flats) and revaluation of the remaining residential areas.

Residential mobility thus belongs to a set of crucial processes that determine whether parts of a city are developed (built-up) or faced with vacancy and demolition (Torrens, 2002; Rees et al., 1996). At present, both increasing household diversification and declining population force cities into competition to attract new inhabitants or at least to motivate their residents to remain (Kabisch, 2005). Thus, a more fragmented residential land use emerges in which stable neighborhoods occur in the vicinity of those falling vacant; furthermore, the fact that some neighborhoods remain locked in the poverty trap is seen as a danger for the future of cities. Finally, by 'shrinkage' we denote a land use pattern in urban regions that is characterized by a high and increasing vacancy rate, demolition of buildings without rebuilding and an increase in open space and urban brownfield sites (Rieniets, 2009; Banzhaf et al., 2007). In shrinking cities, residential facilities show a surplus of vacant dwellings and an open residential market with a large number of affordable flats spread over the entire urban area (Jessen, 2006).

2.3. Methods of simulating residential mobility

Urban land use change, the development of built-up areas and the creation of residential vacancies result from actions by urban agents, e.g., people living in the urban region. This idea differs from concepts of land use change modeling that rely on statistical evidence of land use transitions (Silva and Clarke, 2002; Torrens, 2007; White et al., 1997; Wu and Webster, 1998; Wu, 1998). Agent-based models posit autonomous individuals (agents) who perceive their environment and interact with each other (Parker et al., 2003). Applications of agent-based modeling in land use change are usually spatially explicit, and agents represent, for example, households that are relocating their homes (Loibl and Töetzer, 2003; Waddell et al., 2003) or individuals using transport systems (Miller et al., 2004). Agent-based systems have recently gained popularity in migration and residential mobility research and in land use change modeling; in such modeling, individual agents interact with one another and with larger housing markets while also creating synthetic submarkets (Matthews et al., 2007; Evans and Manson, 2007). Agent-based approaches allow modeled representations of a range of different individual agents that act on the system under consideration, which in this case is the housing sector of a shrinking city, Batty, 2001). Such an ABM is based on the preference-driven decision-making of agents (residents) regarding their mobility and location (Earnhart, 2002; Loibl and Tötzer, 2003; Caruso et al., 2005). The preference profiles of the respective agents and their responses to contextual and environmental constraints represent are the major structural determinants of an ABM (Janssen and Ostrom, 2006; Garía and Hernández, 2007; Castle, 2006; Deadman, 1999; Wegener and Spiekerman, 1996).

Some of the recent applications of ABMs include the reproduction of demographic features as a means of understanding the evolution of society and the evaluation of economic systems (Gilbert and Doran, 1994; Kohler and Gumerman, 2000; Fontaine and Rounsevell, 2009). Some of these models seek to link human and natural systems at different spatio-temporal scales to understand changes in land use (Torrens, 2002; Parker et al., 2003). There are further decision-making-oriented models of the urban housing market (Eskinasi and Rouwette, 2004) and of segregation at the local district level (Pancs and Vriend, 2003). With some exceptions (e.g., Fontaine and Rounsevell, 2009), these models have no spatial representation.

In contrast to many of the urban models that are based on the urban growth paradigm of the 1980s/1990s (Schwarz et al., in press), it is still a challenge to model residential mobility in a shrinking city. Another problem of most existing ABMs is their limited empirical foundation and the resulting difficulties that occur in attempts to validate them (Evans and Manson, 2007). Recent studies have made greater efforts to validate ABMs than was the case during the inception of ABM applications (Janssen and Ostrom, 2006). Particularly in terms of land use change ABMs, a quality assessment can be performed either by matching the land use patterns produced by the

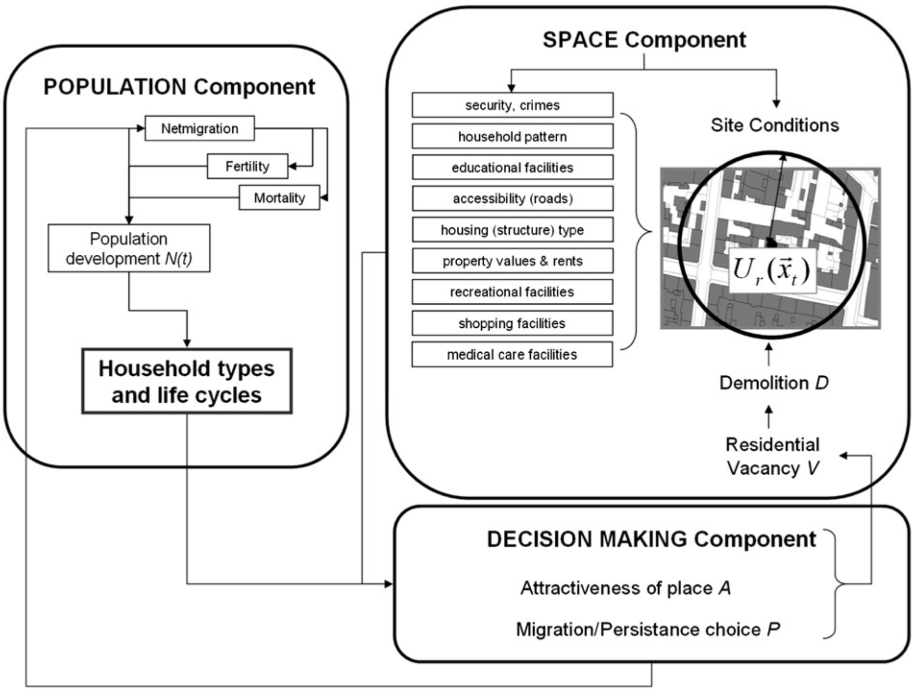


Fig. 1. RESMOB*city* concept –components, information flows and predictor variables. The agent-based model is a spatially explicit model and considers three main components: the population and household component, the spatial site component (where the population lives) and the decision-making component of the households. The households are mobile agents who can decide to change location at certain points in time, which are defined according to their life cycles (given in Table 1) according to specific rules that depend on their assigned attributes (site conditions $U_r(\vec{x})$).

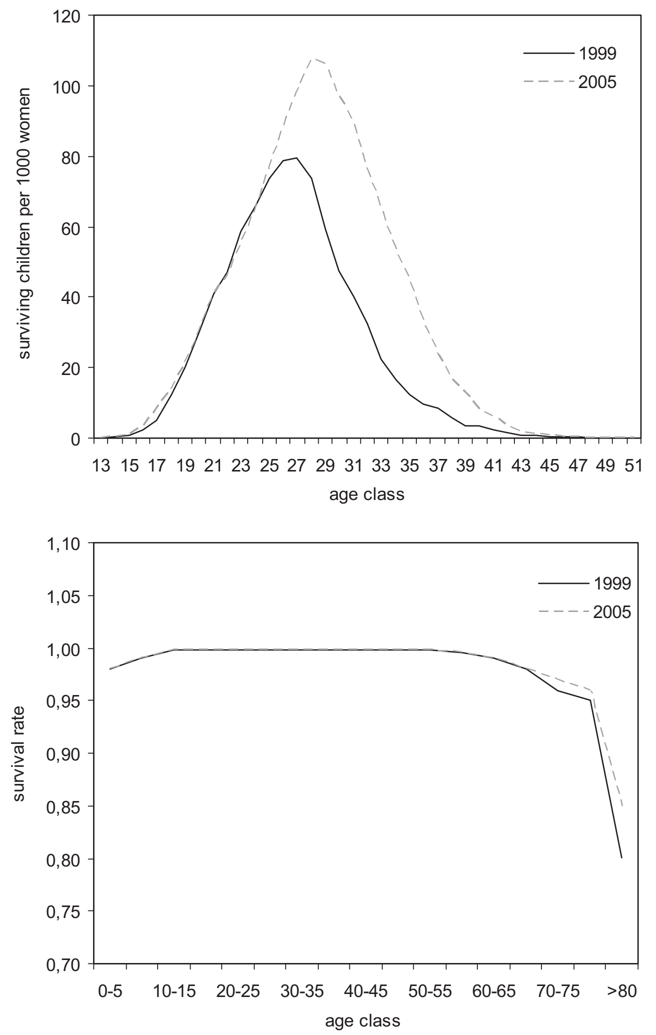


Fig. 2. Fertility and mortality curves are used to setup the population model. The data have been adopted from federal census data of Saxony dating for the two time slots that were used to define the three scenarios, 1999 and 2005.

model to observed data using error matricés (Pontius and Petrova, 2010; Pontius and Spencer, 2005), as with the use of a cellular automaton. Alternatively, attention can be focused on evaluating the spatial interactions inherent in the model by identifying spatial patterns that occur in a system as the result of spatial interactions (Evans and Manson, 2007). In this paper, each of these methods of model quality assessment was used to evaluate the specific output of our model.

3. Methods

3.1. Concept

The ABM RESMOB*city* is a spatially explicit model that includes three major components: (1) the population and household component, (2) the component of spatial locale of housing and (3) the decision-making component of the households. Fig. 1 illustrates these components and shows their interactions. The household decisions relate to the location of living, which depends on the recent life cycle of the agents as well as on the environmental and socioeconomic constraints of their environment, such as the price of a flat or house, accessibility of transport, and the social and recreational infrastructure forming the logic behind the decision-making.

3.2. Population

The process of population dynamics in RESMOB*city* is coded similarly to a Leslie-model and computes the population development using the parameters of fertility, mortality and net migration (Fig. 2). Parameters were derived from long-term census data of the Federal State of Saxony and the city of Leipzig (1993–2008).

In the model, individuals may enter the population of the city either by birth or by in-migration. Exchange of persons between age classes are unidirectional from younger to older, reflecting the aging process. Leaving an age class can occur by aging, out-migration or dying. (Eq. (1)): Let $\vec{N}$ be a vector of n age classes of the population at time t_i, and S be the transition matrix for each age class:

$$\vec{N}(t_{i+1}) = S\cdot\vec{N}(t_i)+\vec{M}(t_i) = \begin{pmatrix} n_1 & \cdots & n_n \\ s_1 & \ddots & \vdots \\ \vdots & \ddots & 0 \\ 0 & \cdots & s_{n-1} \end{pmatrix}\cdot\vec{N}(t_i)+\vec{M}(t_i) \quad (1)$$

where $N_i(t)$ $(i = 1,\ldots,n)$ is the number of persons in age class i at time t and s_i is the survival probability of the age classes $1,\ldots,n$, e.g., $1-s_1$ denotes the infant mortality. Without loss of generality, we use time intervals of five years for the age classes. M denotes the net migration, which can be assumed to be a time-dependent driving force. The number of women in childbearing age classes, as well as the total fertility rate (TFR), which represents the number of (living) children per woman, constitute important factors. Based on the known parameters, the remaining unknown coefficients of the Leslie-model were identified by calibrating the population dynamics with the current demographic change, fertility and mortality census data of Saxony. The fertility peak is located in the age classes of 25–35. Due to a drop in fertility after 1990 (Council of Europe, 2004), we generally assume a low TFR of ≤ 1.1 children per woman. Conversely, mortality is assumed to increase in the future and to comprise values of 0.8 in the age class >80 (Fig. 2).

3.3. Households

Households were chosen to represent the agents. We distinguish the derivation of the agents from the population dynamics related to decision-making in the next section. By so doing, a link between the process of population dynamics and the socioeconomic processes of household decision-making is created. The core idea is to aggregate individuals of the population into households based on the modeled age structure. Empirical research has shown that household characteristics are a reliable proxy for residential decision-making at the person level (Buzar et al., 2007; Haase and Haase, 2007).

Household configurations change over time by birth, marriage, death and divorce. There is an existing overlay of dynamics of household development and demography (Leslie-model). We apply a concept of household types based on findings of social science regarding demographic transitions (Buzar et al., 2005, 2007); in such transitions, households become smaller and change more quickly, and living arrangements are adapted to individual life scripts (van de Kaa, 2004; Ogden and Hall, 2000). In RESMOB*city*, we define household types in accordance to Buzar et al. (2007), including more traditional

- family households with dependent children,
- elderly one-person households and

Table 1
Household types (H) and their demographic properties, the number of persons per H and average survival time T_j (years; according to Buzar et al., 2005) of staying in one place (in one flat) and share of age classes N_i per household type H_i.[a]

H	Age classes involved	Number of persons	Survival time T_j (years)
Young single (YS)	18–<45	1	5
Young cohabitation (YC)	18–<45	2	5
Elderly single (ES)	>45	1	20
Elderly cohabitation (EC)	>45	2	30
Family with dependent children (F)	18–<45; <18	3–5	18
Single parent family with dependent children (SPF)	18–<45; <18	1–3	12
Unrelated flatsharers (FS)	18–<45	2–4	5

N_i

H_j	$N_{i\ 1\ldots4}$	$N_{i\ \ldots-6}$	$N_{i\ 7\ldots8}$	$N_{i\ 9\ldots10}$	$N_{i\ 11\ldots12}$	$N_{i\ 13..14}$	$N_{i\ 15\ldots16}$	$N_{i\ 17}$
YS	0	0.22	0.24	0.22	0	0	0	0
YC	0	0	0	0	0.21	0.23	0.29	0.4
ES	0	0.11	0.18	0.27	0	0	0	0
EC	0	0	0	0	0.34	0.64	0.61	0.3
F	0.7	0.3	0.28	0.35	0.35	0.09	0	0
SP	0.3	0.13	0.12	0.11	0.1	0.04	0	0
FS	0	0.24	0.18	0.05	0	0	0.1	0.3

[a] The results of questionnaire surveys conducted in several districts of Leipzig were used to determine the age class proportions for each of the household types. In doing so, the proportions found in the questionnaire sample were transferred to the total population of the city in 1990 as the starting year of the simulation.

Table 2
Weights w_{ij} of the attractiveness A of a location $\vec{x}$ for the household types $1 \ldots m$ using the descriptors $I_{1 \ldots k}$.

Descriptor $I_{1 \ldots k}$	Young single	Young cohab.	Elderly single	Elderly cohab.	Families	Single-parent families	Flat-sharer
Young single	0.053	0.048	0.011	0.010	0.018	0.028	0.052
Young cohabitation	0.018	0.018	0.068	0.062	0.018	0.018	0.013
Elderly single	0.048	0.060	0.023	0.021	0.018	0.018	0.039
Elderly cohabitation	0.018	0.018	0.068	0.062	0.018	0.018	0.013
Families	0.024	0.024	0.023	0.021	0.018	0.046	0.064
Single-parent families	0.024	0.036	0.023	0.021	0.036	0.046	0.026
flat-sharer	0.036	0.036	0.023	0.021	0.018	0.018	0.077
City center	0.031	0.033	0.032	0.016	0.015	0.022	0.021
Multi-story 1960s	0.033	0.033	0.032	0.016	0.015	0.022	0.021
Prefab estates GDR	0.045	0.023	0.034	0.016	0.013	0.013	0.003
Residential park 1990s	0.000	0.031	0.005	0.027	0.036	0.037	0.015
Single house area	0.000	0.014	0.027	0.033	0.026	0.017	0.013
Tenement blocks 1870s	0.059	0.026	0.027	0.012	0.016	0.015	0.064
Villas	0.000	0.002	0.020	0.043	0.026	0.013	0.046
Multi-story suburbia 1990s	0.026	0.026	0.023	0.023	0.024	0.020	0.018
Sport, leisure	0.036	0.048	0.011	0.010	0.036	0.037	0.039
Parks,	0.024	0.024	0.045	0.041	0.027	0.028	0.026
Allotments	0.012	0.024	0.056	0.051	0.036	0.018	0.013
Cemetery	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Open land, farmland	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Pastures, grassland	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Forest	0.024	0.036	0.045	0.041	0.027	0.028	0.013
Brownfields	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Rivers	0.048	0.040	0.023	0.041	0.018	0.018	0.013
Lakes	0.024	0.024	0.023	0.041	0.046	0.037	0.013
Crime rate > mean	0.060	0.038	0.023	0.021	0.009	0.009	0.064
Crime rate < mean	0.012	0.024	0.045	0.041	0.036	0.037	0.013
School <250 m	0.012	0.024	0.011	0.010	0.055	0.074	0.013
School <500 m	0.012	0.024	0.011	0.010	0.055	0.074	0.013
School >500 m	0.012	0.002	0.011	0.010	0.055	0.074	0.013
Shop <250 m	0.012	0.012	0.056	0.051	0.036	0.028	0.013
Shop <500 m	0.024	0.024	0.045	0.041	0.027	0.028	0.026
Shop >500 m	0.060	0.048	0.011	0.010	0.018	0.018	0.064
Maximum flat/land price (€)	0.060	0.039	0.034	0.062	0.091	0.046	0.026
Rent <5€/m^2	0.024	0.042	0.045	0.041	0.018	0.028	0.052
Rent >5€/m^2	0.048	0.030	0.011	0.021	0.046	0.018	0.013
Public transport <500 m	0.024	0.024	0.045	0.041	0.027	0.028	0.026
Public transport >500 m	0.060	0.046	0.011	0.010	0.018	0.018	0.064

- elderly couples (mostly married) as well
  as a group of new or non-traditional household types, such as
- young one-person households,
- young unmarried couples or cohabitation households,
- single parents and
- unrelated adults sharing a common flat.[2]

Table 1 lists the households and their decision-making parameters[3] related to choice of housing location.

The functional relationship between the age structure of a population and the distribution of its households is defined by a matrix, Φ, which maps the total population N with n age classes to m household types in the form (see Table 2):

$$H_j(t) = \sum_{i=1}^{n} \Phi_{i,j} N_i(t), \text{ with } \sum_{i=1}^{n} \Phi_i \le 1 \qquad (2)$$

where H_j is the number of households of type j and Φ is the distribution of n age classes of a population N at time t. Questionnaire surveys conducted in Leipzig in several municipal local districts (Kabisch, 2005) were used to determine the age class proportions for each of the household types. In so doing, the proportions found in the questionnaire sample were extrapolated to the total population of the city in 1990 as the starting year of the simulation. Similarly, the total population number and age class distribution can be derived from the household pattern at a time t to check the plausibility of the household formation algorithm. In the dynamic simulation, households can be tracked throughout all life stages. The basic characteristics of households are given in Table 1. Young singles, young cohabitation and flat-sharer households have a higher flexibility in their residential choice than elderly single and cohabitation households or families. The household transition dynamics from one type to another functions according to a transition and persistence restriction matrix.

In RESMOB*city*, household agents are assumed to be autonomous and goal-directed objects that are part of and respond to their environment, are economically independent and occupy one flat (Buzar et al., 2005; Haase et al., 2005). Given the real population of Leipzig (approx. 510,000 in 2008), the model consists initially of approx. 250,000 agents. Households interact through their preference-driven choices of housing locations and influence residential land use accordingly.

3.4. *Decision-making of the household agents*

Housing choices are determined by variables including social environment (social class, lifestyle, household type), income, financial budget and the accessibility of public infrastructure. Because a shrinking city with an unsaturated housing market provides an oversupply of affordable flats (Jessen, 2006), more variables regarding housing choice than simply affordability must be taken into account. Thus, in the model, households' preferences are driven by the multifactorial indicator matrix A denoting the attractiveness of a potential housing unit or location.

Indicators that are used to estimate household preferences are aggregated in an attractiveness matrix summarizing a set of descriptors $I_{1 \ldots k}$ (Table 2). These indicators result from the findings of household-based questionnaire surveys conducted in Leipzig and other European cities (Buzar et al., 2007; Steinführer, 2005;

[2] Within the Second Demographic Transition, worldwide households change considerably in size and form (Buzar et al., 2005, 2007). Households become smaller and less stable and are defined as more subject-oriented, and living arrangements are adapted to individual life scripts (Kaa, 2004; Ogden and Hall, 2000). Within the FR5 EU Project Re Urban Mobil (www.re-urban.com), households in selected districts in four European cities were classified according to their types. The resulting clusters of classic household types (i.e., family, elderly one-person households and couples) and those designated "new" or non-traditional household types (i.e., young one-person households, young couples, single parents, unrelated adults sharing a common flat) provide a highly innovative conceptual model of the residential agents living in a city region. In this paper, we dropped this aspect of "new household types" and simply explain the need of households for an aggregated description of activities in the urban area. For further information on the household type concept, please refer to the literature discussed above.

[3] Derived according to the empirical results of the FR5 EU Project Re Urban Mobil (www.re-urban.com).

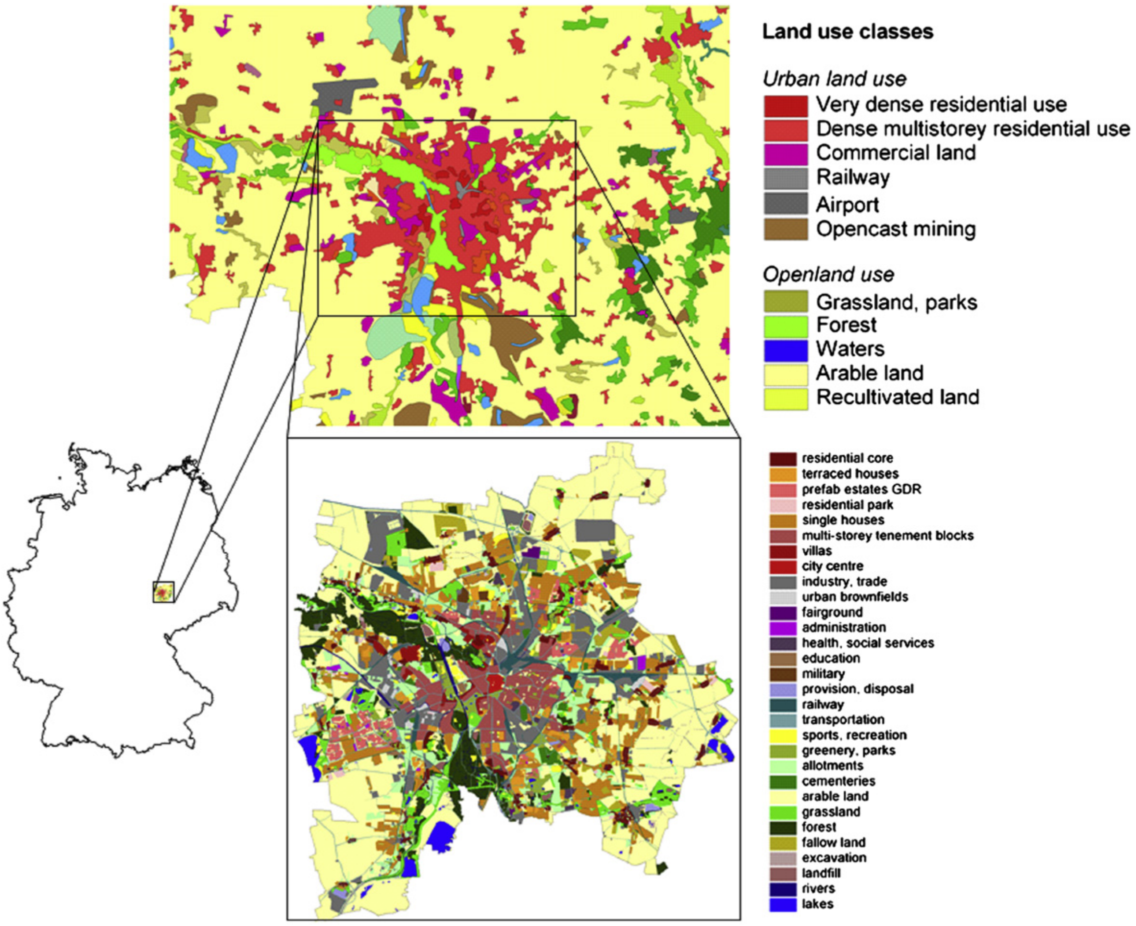


Fig. 3. Land use (upper map) and residential pattern (lower map) in the region and city of Leipzig (data sources: Corine Land Cover, 2000, EEA; own data).

Steinführer et al., in press) in the form of systematic variable rankings, proportions, and choices. The weights w are derived using the ordination (ranking) of individual systematic variables obtained in the surveys. Quantitative rankings or proportions given as answers in the questionnaires were translated to preference probabilities/weights between 0 and 1 for each indicator; qualitative valuations given in Likert scales were similarly standardized between 0 and 1. Answers in form of Boolean values (yes/no) were coded as 1 and 0. In addition to descriptors obtained from the questionnaire, descriptors used in preference profiles developed by other ABM (Clark and Huang, 2003) are also considered. The preference descriptors $I_{1...k}$ represent the socio-demographic (household patterns in the neighborhood), economic (costs, flat and house prices), spatial (accessibility, distances) and recreational (greenery, waters) environment of the households expressed in a mean attractiveness $A_j(\vec{x})$ of a household type j and a residential location $\vec{x}$ (flat, tenement block) and its surroundings denoted by $U_r(\vec{x})$. U specifies the surrounding of a location $\vec{x}$ with radius $r = 500$ m in the RESMOB*city* (see Fig. 3).

Table 3
Data used to run and test the RESMOB*city* model. The census data of the municipal statistics were used to calibrate the model; the independent micro census data of Saxony were used to validate the population model (cf. Fig. 7).

Variable	Data set; reference
Calibration	
Population	Micro-census of Saxony
Households	Micro-census of Saxony; Empirical survey UFZ 2003–2004
Rents, (Land) Prices	Information from local financial institutes; Municipality of Leipzig
Land Use	German topographic information system (ATKIS) 2006; Haase and Nuissl, 2007
Infrastructure (education, medical care)	ATKIS 2006; Haase and Nuissl, 2007; Municipal statistics
Transport	ATKIS 2006
Crimes	Municipal statistics
Residential vacancy	Municipal statistics
Shopping facilities	Municipal statistics; Internet survey of the shopping enterprises
Urban greenery	ATKIS 2006; Haase and Nuissl, 2007; Municipal Agency for Environmental Planning
Plausibility test	
Population	Municipal census data
Households	Municipal statistics

The spatial configuration and representation of the urban residential and open land use are defined by a regular lattice with cells and their location $\vec{x}$ with a grid cell size of 10 m. The attractiveness A of a place $\vec{x}$ for a household H_j to live is formally

$$A_j(\vec{x}) = \sum_{k=1}^{l} w_{j,k} I_k(U_r(\vec{x})), \text{ with } \sum_{i=1}^{n} w_{j,k} \le 1 \tag{3}$$

where A_j is the attractiveness between 0 and 1 (1 most attractive) of a location $\vec{x}$ for a household H_j, w is the weight of the preference descriptor I, and $I_{1...k}$ are the preference descriptors. For the model, it is crucial to create differentiated and, at best, "realistic" behavioral agent profiles for the household types.

Decision rules for residential migration are based on simple additive weighting of the type that is used by the most popular decision-making methods. This type of weighting ranks the included variables (controlled by expressing the indicator's importance) according to their estimated importance. Additive weighting assumes additive aggregation of the normalized descriptor values, which converts the multidimensional values of the attractiveness matrix into non-dimensional values ranging between 0 and 1.

Households migrate if a location $\vec{y}$ is more attractive than a location $\vec{x}$ and, further, if a household-specific time (designated by T_j) has passed since the household's last change of location. Thus, if time since last movement of a household j exceeds T_j years (Table 1; cf. Buzar et al., 2005), a list of locations that are more attractive than the recent location is generated.

$$M_j(\vec{x}) = \{\vec{y}_i,\ i = 1,2,...|\ A(\vec{y}_i) > A(\vec{x}),\ A(\vec{y}_i) > A(\vec{y}_{i+1}),\ i = 1,2,..\} \tag{4}$$

Note that the list of locations for movement M are sorted by its attractiveness.

Table 4
The three scenarios used to test the model.

	Fertility	Net migration	No. of households
Scenario *Stagnation*	linear extrapolation of trend 1999–2005	linear extrapolation of trend 1999–2005	300,000
Scenario *Growth*	2× linear extrapolation of trend 1999–2005	2× linear extrapolation of trend 1999–2005	320,000
Scenario *Shrinkage*	−2× linear extrapolation of trend 1999–2005	−2× linear extrapolation of trend 1999–2005	240,000

Thus, movement of households can easily be computed by moving through the list top-down seeking for matching free living space within the map of vacancies.

3.5. Residential land use, vacancy and demolition

In case of non-satisfaction with the residential location and after a series of attempts to find a new suitable flat, out-migration can increase. Simultaneously, the share of residential vacancy increases in those parts of the city that do not or only partially fulfill the housing preferences of the households. Residential vacancy is formally expressed as follows:

$$V(\vec{x},t) = F(\vec{x},t) - \sum_{j=1}^{m} H_j(\vec{x},t) \qquad (5)$$

where V is the residential vacancy in percent and F the number of available flats at a land parcel $\vec{x}$ and time t. Note that because new houses might be built up or demolished, F can vary in time. Demolition occurs when a households more than 90% vacancies over a time span of 5 years. Vacancy occurs at the level of single dwellings within a house; it can also increase to completely vacant housing estates (100% vacancy). We further assume that a house becomes unlivable after being vacant for over 5 years; at that time, its maintenance and reconstruction costs exceed by far the rental income that would be obtained through new residents. The resulting demolition rate, D_F, of flats is coded accordingly in the model.

4. Implementation

4.1. Model setup and iterations

The spatial discretization of the simulation model refers to a classification of the city area into local districts and detailed land parcels. These result from an intersection of the vector-based municipal local districts and the land use map. This procedure creates the spatial model units and the number of houses and flats in each. The initial values for the first model iteration are taken from either empirical or census data and from municipal statistics provided on raster maps, using the above-mentioned information and data from Table 3. After each run, a range of output files is created that contains all output variables including age classes, household type numbers, number of (filled and vacant) flats and demolished houses. The simulation is based on iteration, assuming one year in reality for each time step.

A simulation is initiated by the determination of an initial distribution of households in the region, based on the real household distributions (Buzar et al., 2007). It is followed by the determination of attractiveness of a site $(\vec{x})$ for each household type H_j according to Eq. (3). The difference in attractiveness for a given pair of locations $(\vec{x};\vec{y})$ for all households H is then calculated. For each household, the individual preference to stay or to move to a more preferred location is calculated; from this, the number of all households H that intend to move can be determined using Eq. (4). Migration of all households is then instantiated as far as new housing space is available or can be built up. In one iteration step, the spatial distribution of households changes as new vacancies are created or houses are demolished, which may impact the suitability of housing for the next time step.

4.2. The test site-specific implementation

Leipzig is characterized by an urban core of old, built-up tenement blocks with patches of 1920s–1930s buildings (local municipal districts of Südvorstadt, Neustadt-Neuschönefeld and Alt-Lindenau), multi-story houses and comfortable villas. During the GDR era, these housing estates were occupied by better-off families with above-average educations. In the eastern and western parts of the city, we find mixed-area residential and 19th century industrial areas. Adjacent to the old town center and to large GDR-era prefabricated estates such as Grünau in the west, Lößnig in the southeast and Paunsdorf in the east, a peri-urban ring of single and semi-detached houses such as Meusdorf is present (see Fig. 3). Residential vacancies are primarily concentrated in the old built-up areas (up to 50%; average ≈25%) and, secondarily, in the prefabricated newly built-up areas (≈20%).

A land use vector map (Haase and Nuissl, 2007) and the city's cadastral database are used to define residential land use and urban

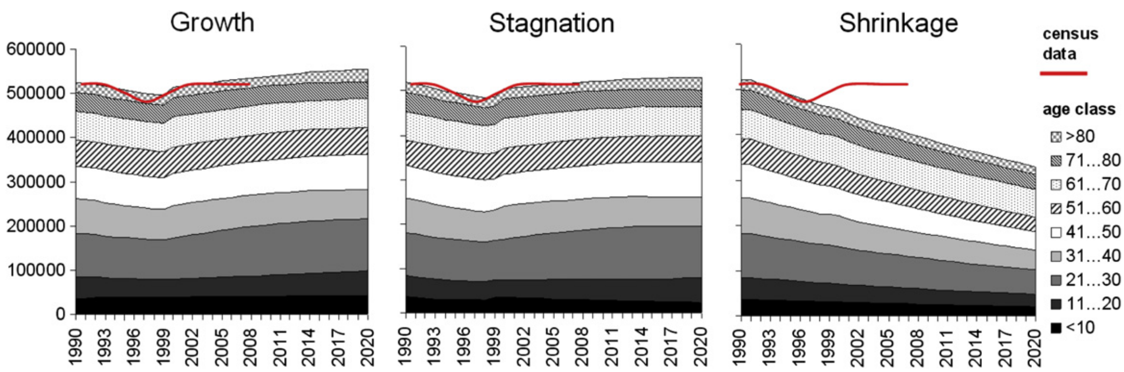


Fig. 4. Simulated total population and age class (<10 … >80 years) development for 1990–2020 for the *stagnation*, the *growth* and the *shrinkage* scenarios. In both the *stagnation* and the *growth* scenarios, in-migration leads to an increase of the young adults, whereas the number of children remains low in all three scenarios, particularly for *shrinkage*. Aging – that is, the relative increase of the elderly population – can be found in all three scenarios. For comparison, the population development in Leipzig from 1990 to 2008 is shown in red (data: Census by Municipal Agency for Statistics and Elections). The census data show the decrease of the total population after the German reunification, the increase in 1999 due to the enlargement of the admisitrative area of Leipzig and the slow but steady increase of the total population after 2000 (which could be replicated in the simulation results of the *stagnation* and *growth* scenarios). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

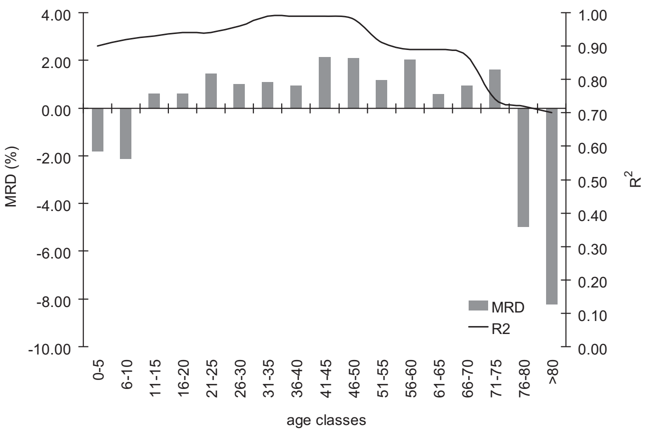


Fig. 5. Assessment of the simulated age class values versus the observed values provided by municipal census data for 1990–2005 using a bivariate regression (R^2) and the MRD (%). The very young age classes (0…5, 6…10), as well as the old age classes (76…80, >80), are underestimated in total numbers by the model, whereas all other age classes are slightly overestimated.

green spaces. The latter is then incorporated into the model for use in determining the overall accessibility (distance in meters) of urban greenery (parks, sportsgrounds, forest, etc.) for any given location. Distance functions calculating the accessibility to transport, shopping and educational infrastructure are derived using vector data of road networks and the locations of schools and supermarkets.

4.3. Empirical database and derivation of preference descriptor weights

The model is based on a large set of quantitative empirical data stemming from several questionnaire surveys on housing preferences conducted in Leipzig as well as in other European cities of comparable size and structure (Buzar et al., 2005, 2007; Kabisch, 2005). The data are available as an SPSS database. Overall, only attributes ranking higher than rank 20 in the importance scale of the questionnaire surveys were used to derive values for the model. To derive preference weights for the different housing attractiveness descriptors, respective data attributes were dedicated to the descriptor (e.g., the answers given to the question "How important is surrounding green space for you?"). A qualitative Likert-scale was used to determine the weights for the descriptors parks, open land and cemeteries.

4.4. Scenarios for model analysis

Three scenarios are used to analyze the model. In these scenarios, agents and their behaviors (e.g., household distribution and decision-making) remain constant; only population dynamics and migration pattern are varied. In this way, we are able to assess the impact of agent-based decision-making on the land use change pattern of the study region. Additionally, these scenario assumptions are of interest to decision makers such as local planners. Table 4 summarizes the scenarios and respective parameter assumptions, which can be described as follows:

1. The current situation of population development in Leipzig is represented in the *stagnation* scenario: fertility and in/out-migration as in 1999–2005,
2. the *growth* case assumes a positive fertility and stronger in-migration and
3. the *shrinkage* scenario considers a demographic decline with negative trends in both fertility and net migration.

5. Results

5.1. Population dynamics

The model outputs show three different paths leading to future population development in Leipzig. The real population growth between 1990 and 2008 (from 450,000 in the mid 1990s to about 510,000 in 2008; red graph in Fig. 4) is replicated by the model under the *growth* and the *stagnation* scenarios. In the *stagnation* scenario, we find almost no future population growth; the *growth* scenario shows a moderate population growth such that the total population is about 540,000 in 2020 (Fig. 4). In comparison, the *shrinkage* scenario projects a steady population decline from >500,000 inhabitants in 1990 to <400,000 in 2020.

Age structure in both the *stagnation* and *shrinkage* scenarios shows a decrease in newly- born children due to the low TFR. Under all three scenarios, the model computes a smooth decrease in the teenage population (11–20 years) from 1990 to 2000, following which this age class again increases under the *growth* and *stagnation* scenarios. Due to an increase in (an assumed) influx of students, the model predicts an increase in the young age classes (ages 20–30) for both the *growth* and the *stagnation* scenarios. All three scenarios result in a moderate increase in the elderly classes aged >60 years, which means that the population of Leipzig is aging regardless of its actual growth or shrinkage.

An assessment of the population model quality can be performed using the municipal census data available for 1990–2005.

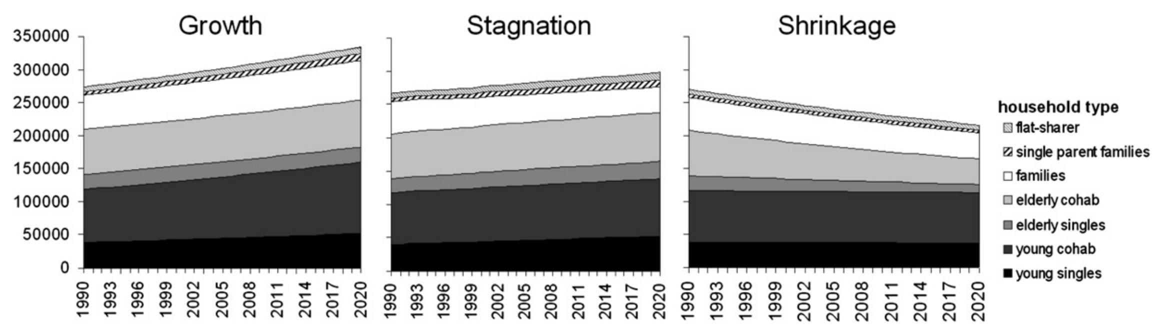
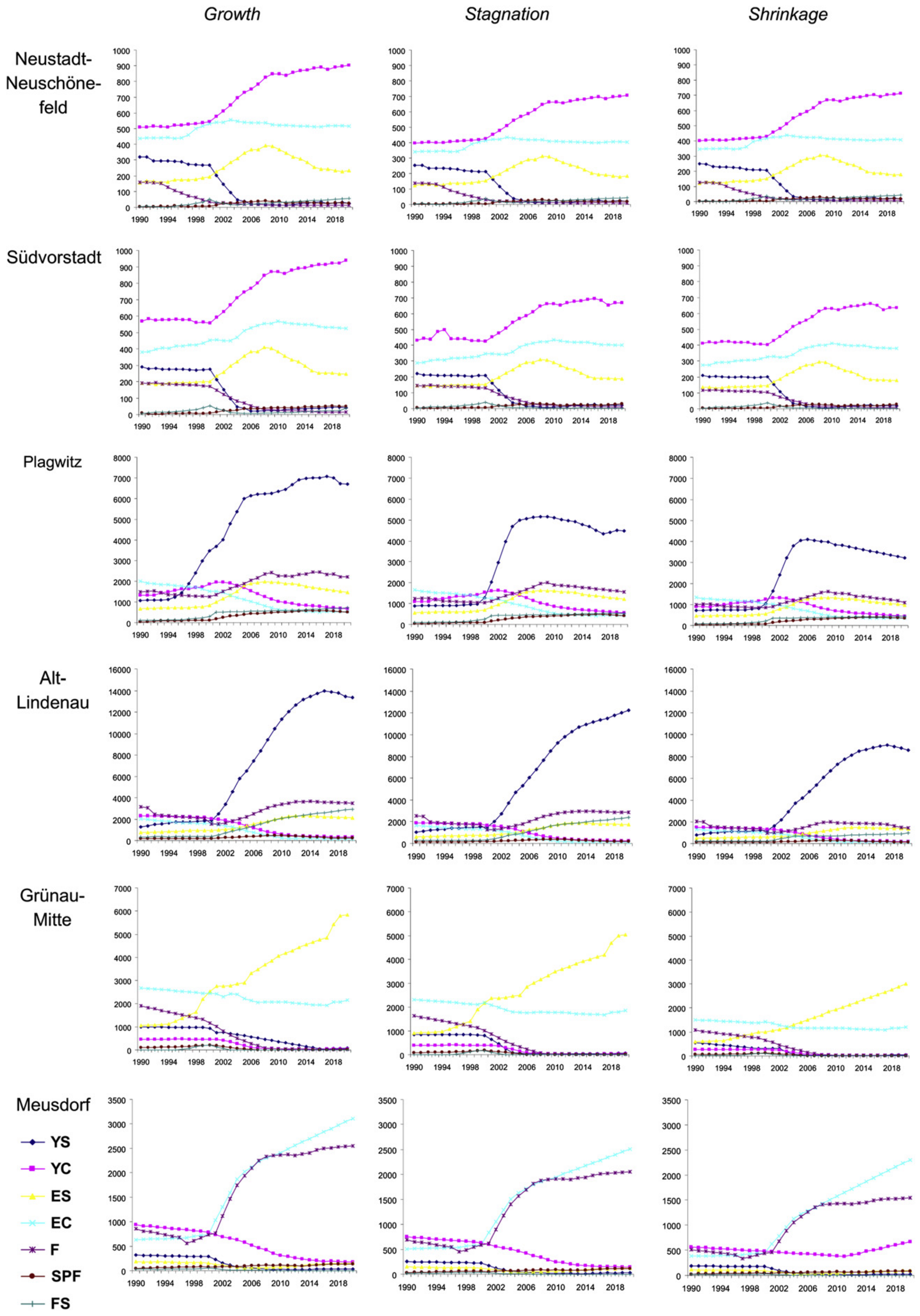


Fig. 6. Simulated number of the seven different household types used in RESMOB*city* for the *growth*, *stagnation* and *shrinkage* scenarios for 1990–2020. In each of the scenarios, we find an increase in young households, both single and cohabitation. In accordance with this finding, we find in the *growth* and *stagnation* scenarios a non-growth of the family households, while in the *shrinkage* scenario, the number of family households considerably decreases. By comparison, the number of single parent families increases regardless of the growth or decline of the total population.

Fig. 7. Probability values of the spatial distribution of young single households, elderly cohabitation households and family households in Leipzig for the three time steps of 1990, 2000 and 2020 (*stagnation* scenario). We find an increasing concentration of young singles in the inner part of the city; this reflects their preference for being highly mobile and well-connected to the public transport, as well as the positive image of the old built-up type of residential housing located there. Elderly couples, by comparison, are preferentially located in the outer parts of the old and pre-WW II built-up part of the town, which is cheaper but has longer travel distances to the city center. Families tend to move to the peri-urban parts of the town, where mostly single house areas are situated.

In performing this assessment, we applied a bivariate regression for analyzing the relationship between the dependent variable (simulated) and the independent (observed) variable; we also used the mean relative deviation (MRD in %) to show how close the simulation results are to the independent census data by predicted-observed plots (Fig. 5). The latter method expresses accuracy as a percentage but not in absolute terms, which is suitable for our purpose because we want to show and discuss the polarization of the errors. We assume the population model results are plausible if $R^2 \geq 0.75$ (25 percentile; Fox, 1997) and the MRD equals $|\leq 10\%|$ (Wackernagel, 1998). Plotting the model age classes of the *stagnation* scenario against independent statistical data, we achieve R^2 greater than 0.75 for all age classes except the >70 year-old class. Using the MRD, we see that the model


Growth
Stagnation
Shrinkage
Neustadt-Neuschöne-feld
Südvorstadt
Plagwitz
Alt-Lindenau
Grünau-Mitte
Meusdorf
YS
YC
ES
EC
F
SPF
FS

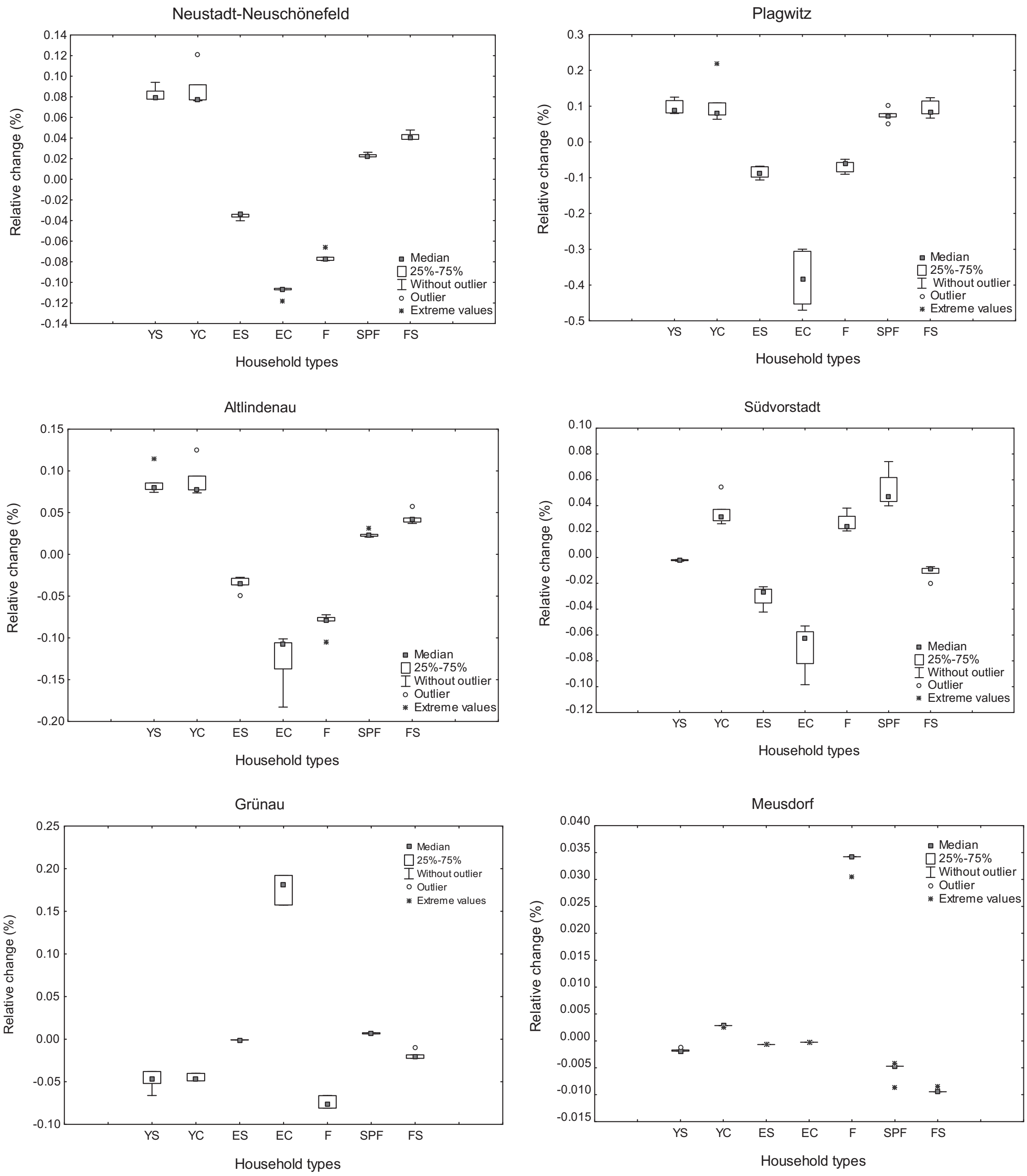


Fig. 9. Relative change rates across all three scenarios 1990–2020 of household types *1…m.* where YS is a young single household, YC a young cohabitation household, ES an elderly single household, EC an elderly cohabitation household, F a family household, SPF a single parent family household and FS a flat-sharer household (see Table 1) in 6 selected municipal local districts of Leipzig: the old built-up "low-image" district of Neustadt-Neuschönefeld, the old built-up "high-image" district of Südvorstadt and the socialist pre-fabricated housing estates of Leipzig-Grünau. The size of the boxes reflect parts of the uncertainties of the age/class simulation, particularly in the family and elderly single and cohabitation households.

systematically underestimates both the very young age classes (0…5, 6…10) and the old age classes (76…80, >80) by a small amount compared to the census data. All other age classes are slightly overestimated (Fig. 5). The reason for the underestimation of the very young and the old age classes might be that we assume average fertility and mortality rates for all residents regardless of their gender or ethnicity and regardless of the effects of these factors on longevity. Because we do not feed a specific share of gender and ethnicity within the annual in-migration into the model but instead use average data here, we underestimate particularly the aged. Despite these minor deviations from the census data, the population model results meet the quality criteria defined above.

Fig. 8. Scenarios of household pattern (distribution of household types *1 … m* where YS is a young single household, YC a young cohabitation household, ES an elderly single household, EC an elderly cohabitation household, F a family household, SPF a single parent family household and FS a flat-sharer household, see Table 1), aggregated age class distribution (children, working age, pensioners) and trend of the average age of selected local municipal districts of Leipzig 1990–2020. The districts include the old built-up districts of Neustadt-Neuschönefeld, Südvorstadt, Plagwitz and Alt-Lindenau, the GDR-era prefabricated multi-story district of Grünau and the peri-urban single house area of Meusdorf in the peri-urban part of the city.

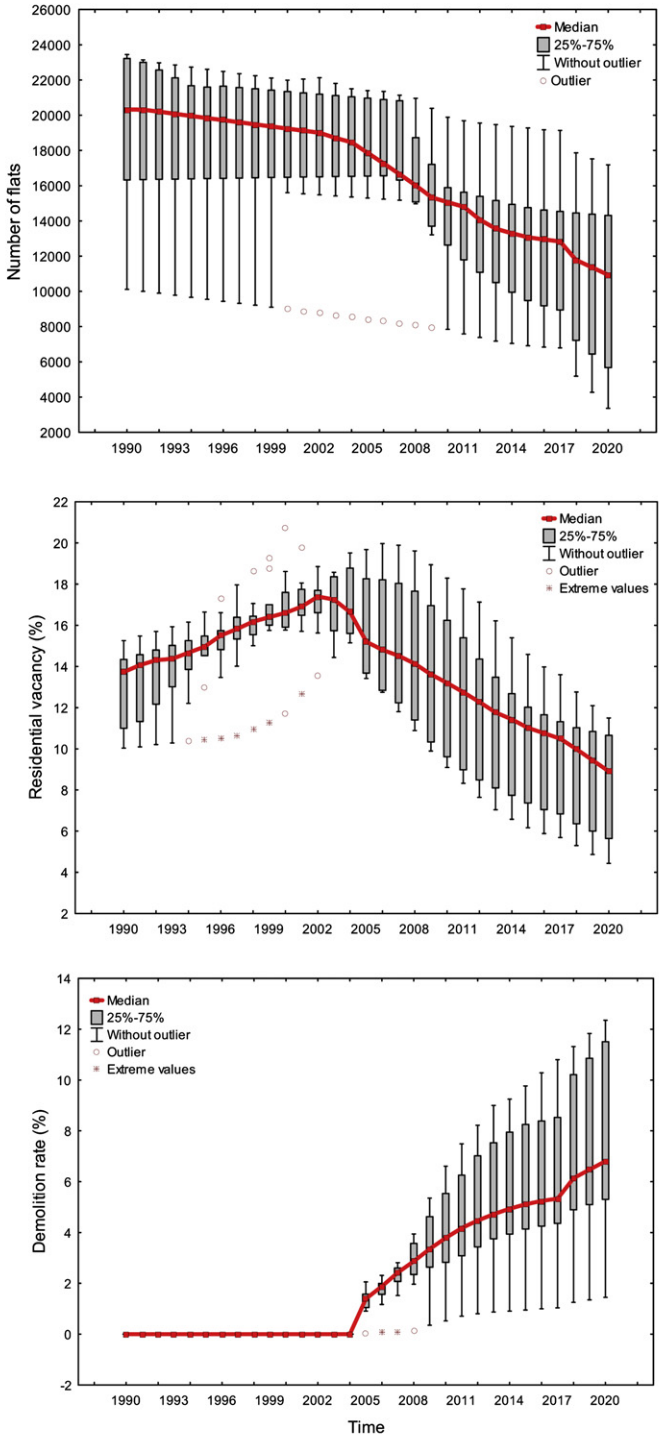


Fig. 10. Simulation of the past and future development of the residential land use of the city of Leipzig across all three scenarios using the model variables of the number of flats, the share of residential vacancy and the related demolition rate at the municipal district level for the period 1990–2020.

5.2. Household dynamics

The household simulation results show that the number of non-traditional young and elderly single households, as well as the number of young cohabitation and flat-sharer households, increases regardless of population growth or shrinkage (Fig. 6). The model well reflects theoretical considerations of an increasing individualization formulated by Giddens and the SDT or a regaining

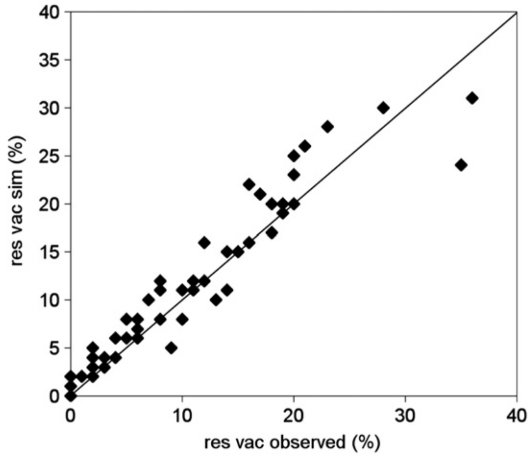


Fig. 11. Simulated residential vacancy (%) versus measured residential vacancy (%) for all 63 municipal districts of Leipzig for 2004 for the *stagnation* scenario (the only reliable available estimation of existing housing vacancy).

of attractiveness of the inner city (Burton, 2000, 2003) for young professionals. The results of the household simulations are also in accord with empirical findings on other European cities such as Paris, Bologna and León (cf. data published in Buzar et al., 2007; Ogden and Hall, 2000). 'Accord' means here that both development trend (positive, negative) and share (relative percentage of the total population) of the respective household types are similar to survey and literature findings. Next to young households, elderly ones contribute most to the increase in single and cohabitation households in the inner city; they rise in terms of their total numbers and particularly their share per local municipal district. Conversely, the number of families, which still represents the highest number of residents due to its household size of 3–5 persons, decreases, at least in the *stagnation* and *shrinkage* scenarios (Fig. 6). Single parent families, by contrast, increase.

The spatial household patterns simulated by RESMOB*city* are, in part, the result of spatial interactions between the agents ("like my neighbor") but may also be the result of relatively simple factors such as distance or accessibility to social or transport infrastructure. The relative importance of these factors cannot so far be explained by the model. Because no observed spatial data for household distribution in Leipzig are available, a map comparison, as suggested for assessing spatially explicit land use change models (Pontius and Petrova, 2010), is not feasible.

Fig. 7 gives an idea of the spatial change in probability of the concentration of young singles, elderly cohabitations and family households in Leipzig from 1990 to 2020 using a range of values from 0…1. Compared to a more equal spread in 1990, in 2020 young singles will primarily reside in old 19th century built-up districts of the inner city, along with a simultaneous decrease in their residence in the 1920s to 1930s, 1960s and GDR-era prefabricated housing estates. The model thus predicts a concentration of young people in the inner city, likely because it is close to the city center and provides better access to public transport facilities, labor and other socio-cultural facilities. This mode behavior is supported by recent empirical research on inner city reurbanization processes in Leipzig, in which an increasing influx of young (<45 years old) and mobile households to the inner city since 1995 was found (Kabisch et al., 2009).

By comparison, elderly cohabitation households assemble in either the 1920s to 1930s, the 1960s or the GDR-era prefabricated housing estates because, for them, lower rents and housing costs are more important than high accessibility values. The families meanwhile concentrate in the single house areas in both the inner and outer parts of the city. Overall, RESMOB*city* simulates an

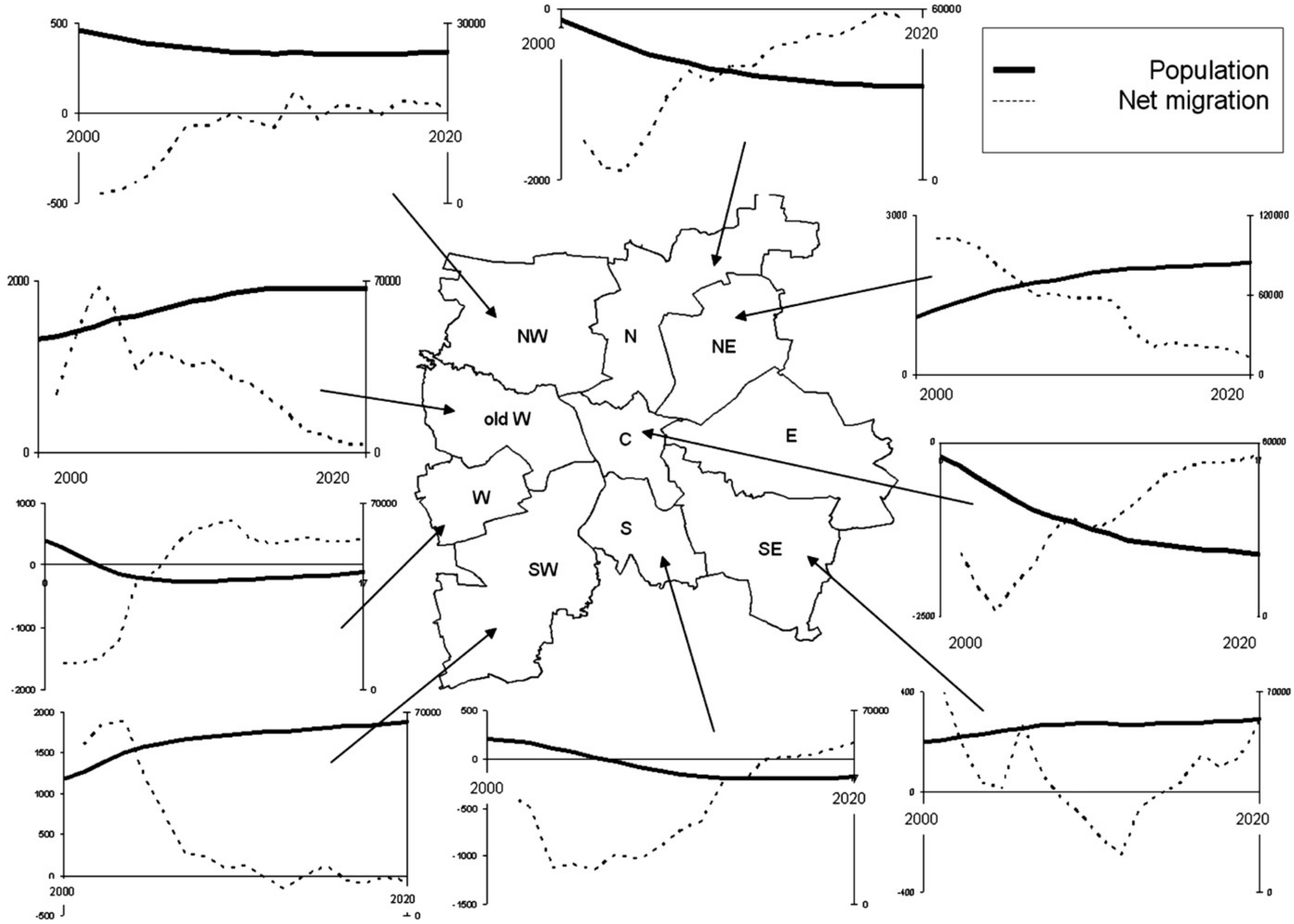


Fig. 12. Summary of trajectories of population growth and net migration at the municipal district level of the entire study area of Leipzig for 2000–2025 for the *stagnation* scenario (based on the smaller local municipal districts; the larger municipal districts are summarized and labeled by cardinal points here. C denotes the Central district).

increasing segregation of the different household types in Leipzig. Based on these findings, we hypothesize that after a phase of relative mixture during socialist times, the reverse process of increasing social segregation carries more and more significance.

Spatial segregation patterns of both household types and age classes offer novel and challenging insights into a future spatial housing geography of European (shrinking) cities (Figs. 8 and 9). In the old built-up local municipal districts such as Südvorstadt, where urban sociologists assume that something like gentrification is occurring, an increase in and relative gain of young single, but first and foremost, young cohabitation households is simulated. Inner city residential areas of this type, which have a positive image as well as proximity to green and other kinds of urban infrastructure, are preferred for long-term residency and during the family formation phase. We find a lower number of flat-sharers here.

In 2020, the district seems to be saturated, which explains the lowering of the influx projected at that time. By comparison, at that time other old 19th century built-up districts evidence high vacancy rates, suggesting an image of a place for the deprived class such as Plagwitz or Altlindenau. In these areas, the model simulates a high influx of mostly young single households and flat-sharers (Fig. 8), which means that shorter persistence (living-in) times dominate within one flat, resulting in a higher through-flux of households within this structure. Remaining young cohabitation (dinks[4]) and elderly households either profit from short distances and good access to social and transport services or do not want to leave their areas. In summary, we find positive relative changes of young households in these deprived old built-up districts, along with positive relative changes in the number of single parent families, whereas families leave these districts (Fig. 9).

These results are comparable to those observed in local municipal districts such as Neustadt-Neuschönefeld and Alt-Lindenau that have been found to be typical reurbanization districts; thus, data of the model prove this (Haase et al., 2008; Kabisch et al., 2009). The town center, however, faces an extreme loss of population due to a decrease in residential land use (expressed in the number of flats per land parcel) in the town center through replacement by commercial and cultural land uses.

In contrast to the old built-up areas, the local municipal district of Grünau, one of the prefabricated GDR-era housing areas, is faced with an extremely diverging household development. According to the model, elderly (single and couple) households remain or even increase, whereas young households continuously leave the district in all three scenarios. According to the shrinkage scenario, in 2020 we find nearly exclusively elderly singles and couples in Grünau, which leads us to speculate whether such districts will die out (Fig. 8). Current municipal statistics report a positive net migration of low-income single parent households to Grünau (City of Leipzig, 2006a, b, 2007), but this is not reflected in the model outputs.

[4] Short for “Double income no kids” households.

Finally, we look at the typical peri-urban single and semi-detached house areas such as Meusdorf; here, we find a concentration of young cohabitation households (before the parental phase), families and elderly cohabitation households (after the parental phase). Does this represent a future group-wise segregation pattern? The concentration of families at the periphery shows that these areas are still attractive to younger households, which supports the idea of the shrinking city with islands of inner city and suburban growth.

At present, the model does not reflect ethnic questions in the migration data. In Leipzig, we have only a limited number of foreigners from other countries, and there is only a very limited amount and quality of reliable input data related to the ethnicity of residents of the city. However, this point should be kept in mind with respect to later amplification of the model because it might be useful in another case study where ethnic issues are of more importance.

5.3. *Dynamics of residential land use*

In terms of the future housing structure and available dwellings, the following model output variables are of interest:

- the number of dwellings,
- the residential vacancy and
- derived demolition of houses (clearance of housing areas).

Fig. 10 illustrates that the number of flats remains stable until 2005; a decrease in this number is simulated between 2005 and 2008 due to high vacancy rates and related demolition measures. In the model, the latter processes depend on each other and emerge from the net migration of the household agents.

According to our model, the rate of demolition of vacant houses (or housing estates) begins to increase by 2004. This can also be deduced in reality based on the demolition rate in Leipzig East and Grünau (Schetke and Haase, 2008). Hereinafter, starting in 2008, we will find about 10% of the vacant dwellings demolished, by 2015 about 50% and by 2020 >50%. After 2010, the demolition curve slowly flattens out; it approximates 0 in 2015 due to the fact that the equilibrium is reached between houses being demolished and remaining vacant.

Residential vacancy appears more or less the same in terms of its share until 2005 (Fig. 11; it comprises also in reality 15–25%). For 2004, we plotted simulated versus observed data and compared those values with the MRD (Fig. 11; percentage values of the local statistics for 2004 represent the most recent reliable estimate of residential vacancy for the city by local authorities and the Agency for Statistics and Census; Banzhaf et al., 2007). Although the MRD is comparatively low (≤|10%|), the model systematically produces values that are too large by a small amount in cases where the share of vacancy is ≤30%, but underestimates higher shares of vacancy.

The start of demolition generated a decrease in the highest shares of residential vacancy to an average value of 20% in 2007–2008. Development since 2008 decreases residential vacancy to 15%, which fits into the long-term (until 2050) vision for Saxony that predicts 10–15% residential vacancy (Börsch-Supan et al., 2001).

6. Discussion

The RESMOB*city* simulations computed for the 30-year period 1990–2020 show that non-traditional household types such as young singles, young cohabitation households and flat-sharers will be the primary occupants of the old and densely built-up districts with above-average (district of the Südvorstadt) and below-average (district of Neustadt-Neuschönefeld) flat costs or rents. Conversely, in the GDR-era prefabricated districts such as Grünau, the future proportion of financially deprived and medium-level income elderly couples will dramatically increase to up to 20%.

The model results for the three scenarios suggest locations in which future hot spots for urban planners might encounter recent negative developments. A cross-comparison of the findings for all local districts supports the idea of the shrinking city with islands of urban and suburban growth (Fig. 12).

The predicted increase in spatial segregation of households within the entire city also means a change of residents' demand concentration, which has further implications for the consumption of land, environmental resources and local ecosystems. A clear advantage of the model is that the household and vacancy patterns it produces are very detailed compared to the more general findings (maps, data) obtained by household and housing market prognosis for Germany (BBSR, 2009) and Europe (Council of Europe, 2004).

To test the plausibility of the presented RESMOB*city* model results, we have chosen a twofold approach in agreement with Jakeman et al. (2006) and Evans and Manson (2007). As assessment criteria for the quality of the model, we first used statistical fitness as far as independent data was available. Subsequently, we presented the simulated housing patterns to experts in the field of housing mobility and requested that they evaluate the results. In terms of the statistical evidence, the model simulates the population development in such a way that the measured R^2 between simulation and observed (=census) data are 0.70–0.99 and the MRD |≤10%|; it further simulates proportions of migration flows, required flats and resulting residential vacancy along an $x = y$ line that differ at most |≤10%| from the statistical data provided by the city. Particularly, future flows of net migration give an idea of the segregation and clustering processes in a city that holds massive residential vacancies and a rental market of low pressure and huge oversupply.

Another factor relevant to comprehensive quality assessment of our residential mobility and vacancy model is the relatively short time span since the German reunification in 1990. Following Pontius and Spencer (2005), we see a plausibility analysis as presented as the currently most effective and realizable form of model test. An interdisciplinary causal interpretation of both the temporal and the spatial model results creates credibility in both model concept and output data. In developing such an interpretation, an intensive discussion of the model results with social scientists and experts of the city planning department of Leipzig positively evaluated the model outcomes. These scientists and experts can serve as a communication platform during decision-making processes in town planning, the more so because their involvement has already been achieved when presenting the model.

Model rules are transferable to other European cities by incorporating respective local data in addition to available European data sets (Haase and Haase, 2007). Thus, RESMOB*city* can act as a tool for quantification of residential land-use scenarios of the future of both growing and shrinking cities. We further argue that, compared to simply demographically-driven, quantitative approaches, a qualitative household-choice-based ABM approach is more productive with respect to explaining the nexus between spatially selective growth, perforation and shrinkage processes, the occurrence and amount of residential vacancy, and demolition processes at both the city region and small-scale level (e.g., local municipal districts). The ABM approach enables us to shed light on the household-type-based perspective of urban dwellers concerning their housing choices and, furthermore, to gain knowledge about potential variables that influence residential and mobility behavior.

Our model does not explicitly capture the decision-making process itself, as a behavioral agent-based approach would (as stated in Parker et al., 2003). It does not explain the individual reasons for alternative choices of residential mobility; rather, it investigates the relationship between the existing housing supply and the specific demands of the agents to explain mobility decision-making and household patterns.

7. Conclusions

Using the example of the eastern German city of Leipzig, the specific local conditions (population decline over decades, high vacancy rates, and tenants' market) were set in relation to the residential preferences of empirically-based household types. The findings of our model, in the form of household patterns and trends of residential vacancy created by the model, were in plausible agreement with both measured municipal data and estimates by local experts. We were able to show that an increase in the total number of households reduces residential vacancy only in the event of a simultaneous demolition and sanitation of the housing market.

Assuming that today's residential behavior is valid for the near future, we have to expect an increase in the spatial segregation of households in the city, with youngsters and the very old concentrating in the center, whereas families still direct outward. Residential vacancy will decrease and level out at a 10% rate in 2020. It will move from the old built-up estates of the inner city to the 1920s to 1940s and 1960s housing estates, which will lose attractiveness for most of the household types.

The concept of RESMOB*city,* we believe, is a useful one in terms of evaluating demographic scenarios and their impacts on residential land use in urban regions. The model is applicable to ongoing processes in many cities in Europe. Thus, its development can be used as a tool for further analysis in other comparable regions. We were able to demonstrate how and where potential re- or de-densification of urban housing structures will most probably occur up to the year 2020. The same is true for the future allocation and concentration, or even the disappearance, of residential vacancy. We have further shown both difficulties and options related to assessment of the quality of such an ABM using empirical data, as well as in cases in which no validation is possible due to missing independent data.

Future work will focus on the incorporation of additional economic variables that consider the economic constraints of individual households and their choices concerning transport modes and travel distances, as well as scenarios of decreased or modified infrastructure supply due to shrinkage. Additional improvements will include a more detailed incorporation of the local housing market as well as contextual constraints for land use policy and planning in the form of scenario alternatives.

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