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Urban shrinkage: a vicious circle for residents and infrastructure? - Coupling agent-based models on residential location choice and urban infrastructure development

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Abstract: One of the challenges of simulating urban regions in Europe is urban shrinkage, where de-industrialisation, massive population losses and ageing cause housing vacancies in cities. These vacancies decrease efficiency in urban infrastructure and result in problems related to under-utilisation. Investigating the relationship between residential location choice and infrastructure-related decisions can foster urban planning related to shrinkage. This paper presents a coupled simulation of two agent-based models: a) Resident agents belong to different household types. They decide upon their location and move to existing flats or houses. For this, they consider aspects such as their preference for certain urban structural types and urban infrastructure. b) Infrastructure agents represent providers of roads, public transport and schools, as these infrastructure types are likely to influence residential choice. Infrastructure agents change urban land use by altering infrastructure. They take into account the efficiency of the infrastructure. The simulation focuses on the mutual interactions between residents and infrastructure. The main exchanges of information relate to spatially explicit distribution of population and of infrastructure. The decisions of one agent rely upon the output of the other and vice versa. It will be investigated which circumstances lead to a scattered shrinkage all over the city and which ones stimulate a decline of single urban districts.

Keywords: *agent-based model; urban shrinkage; Europe.*

Please note: In this short version of the paper, only the concepts of both models are described. During the session, simulation results will also be shown.

1. INTRODUCTION

1.1 Urban shrinkage as interplay of residents and infrastructure

Although industrialised countries have been characterised by sprawling cities over recent decades (Kasanko et al., 2006), urban shrinkage receives more and more attention in Europe as well as the US and Japan (Rieniets, 2009). "Urban shrinkage" is used for a variety of aspects, like decreasing population in the whole city, receding economic activities, perforation and decline of inner-cities, and the like. In this paper, we focus on urban shrinkage as a decline of population (according to Oswalt and Rieniets, 2006). This trend is likely to continue due to further economic stagnation, financial crisis and demographic decline leading to decreasing population numbers (Couch et al., 2005; Turok and Mykhnenko, 2007). Total settlement area does not decrease in shrinking regions. Rather, sub-urbanization processes still go on, leading to sealing in the periphery of a city (Nuissl and Rink, 2005). This phenomenon is due to the preferences of residents who demand for more single family houses in the suburbs rather than multi-storey buildings without individual gardens (Kasanko et al., 2006). The (at least temporary) result is a pattern of newly built-up area in rather close vicinity to vacant, older housing. City intervention programs finally lead to the partial demolition of the vacant housing stock and to land use perforation (Haase et al., 2007).

This pattern of vacant, demolished and new housing poses challenges for urban infrastructure provision. This is obvious for network-dependent infrastructure, like water, sewage or electricity: Vacant houses no longer need supply of water or electricity or a transport for waste water, so that the pipes and cables leading to this house are no longer used. In an area with a larger proportion of vacant houses, under-utilisation can pose severe problems for maintenance of the service for the whole area (Moss, 2008). However, social urban infrastructure like schools, kindergartens or roads and public transport also are influenced by vacancy. All of these infrastructures are optimised for a certain demand structure in an area, usually determined by population density and commercial or industrial activity. At least, efficiency decreases in areas with higher rates of vacancy (Blanco et al., 2009; Schiller & Siedentop, 2005). At the worst, an area might enter a vicious cycle of declining population, under-utilised and then dismantled infrastructure, so that the area gets less attractive. Thus even more residents relocate to another area in the city (Figure 1).

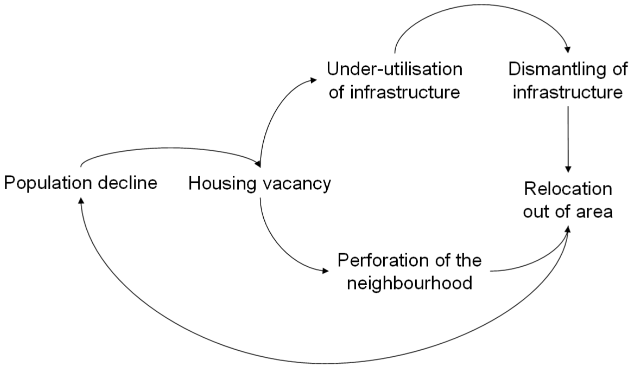

Figure 1. Possible vicious cycle for a single area in a shrinking city.

1.2 Agent-based modelling as a promising approach

Simulation models can assist urban planning and foster discussions on future developments. A variety of such simulation models have been developed in the last years (see reviews by EPA, 2000; Berling-Wolff and Wu, 2004). System dynamics, integrated land use – transport models, cellular automata and agent-based models are the main modelling approaches. They mainly focus on urban sprawl, while urban shrinkage is a phenomenon that still needs to be tackled properly by those models (Schwarz et al., 2010): System dynamics models and integrated land use – transport models provide non-spatial information, so that areas of concentrated vacancy cannot be detected; calibrating cellular automata largely depends on spatially explicit data which are scarce for vacancy (Banzhaf et al., 2007). Agent-based modelling seems to be a promising method, as it allows for spatially explicit simulations and explicitly includes decision rules of individuals (residents) or organisations (infrastructure).

1.3 Aim and structure of the Paper

The aim of this paper is to present a simulation for investigating the relationship between residential location choice and infrastructure-related decisions. The simulation consists of two coupled, agent-based models: Residents and infrastructure providers. The simulation focuses on the mutual interactions between these two agents, as the decisions of one agent rely upon the output of the other and vice versa. In the second section, the modelling concept is described, with the empirical case study (2.1), the interactions of the two agents (2.2), the resident agents (2.3), and the infrastructure agents (2.4). This modelling concept is then discussed in section 3. Modelling results will be presented in the second version of this paper.

2. MODELLING CONCEPT

2.1 Case study

For the test of the coupled model we use the case study of the city of Leipzig, Central Germany, which meets the above discussed criteria of a simultaneously growing and shrinking city. At a size of 297 km^2, the city has 515,000 inhabitants and is one core of the polycentric urban region of Leipzig-Halle. On the whole, both city and region lost inhabitants since the 1970s, this was spurred by the political change in 1990 and subsequent de-industrialisation. The locally divergent growth-shrinkage patterns are accompanied by residential, commercial and infrastructure development. While the post-socialist transformation period with heavy urban sprawl has passed, moderate development in the peri-urban continues to the present-day (Haase & Nuissl, accepted). At the same time, considerable parts of the inner city faced a population outflow followed by residential vacancy, large urban brownfields and massive under-utilisation of urban infrastructure (Haase et al., 2007). Urban planning neglected the missing interaction of major parties of the urban restructuring process so far. There is no communication between the housing companies who demolish building stock and create new ones and the municipal infrastructure providers.

2.2 Interaction of the two agent-based models

In order to investigate this obvious gap between housing vacancy and infrastructure provision, the simulation consists of two coupled, agent-based models. a) Resident agents belong to different household types. They decide upon their location and move to existing flats or houses. For this, they consider aspects such as their preference for certain urban structural types and urban infrastructure. b) Infrastructure agents represent providers of roads, public transport and schools, as these infrastructure types are likely to influence residential choice. Infrastructure agents change urban land use by altering infrastructure. They take into account the efficiency of the infrastructure. The exchanges of information relate to spatially explicit distribution of population and of infrastructure (Figure 2). Resident agents are the main drivers of the model, as they seek to optimise their location according to their preferences. Infrastructure agents are more passive in the sense that they do not change anything as long as using the infrastructure is within the limits of over- or under-usage. Land prices remain constant throughout the simulation, however, an agent-based model of a land market (Polhill et al., 2005; Filatova et al., 2009) can be included in the next step.

Resident agents decide upon relocating within the city, using the already existing building stock. At the moment, no new housing is being built during the simulation to concentrate on the effects of moving population within the existing stock. Residents use the current land use (including green spaces) as well as the availability of main roads, schools and public transport as input for their decision. Their output is the number of households of a certain type (see below) per grid cell. Infrastructure agents use the current land use as well as the number of households per cell for their decision on enlarging or dismantling infrastructure. Their output is in terms of land use change (by sealing up surfaces for new infrastructure) as well as supply of the infrastructure that is important for residential location choices (roads, public transport, schools.

The simulation is implemented using the *ABMland* framework (http://www.ufz.de/index.php?en=17776). It is programmed in Java and builds upon Repast Simphony. Its main feature is the possibility to include different agents involved in urban land use changes into the model and to ensure valid communication between them. Communication exchanges are defined by specifying mandatory information import and exports with units as well as upper and lower boundaries. Interactions between agents as well as between agents and land surface are spatially explicit. During runtime, resident and infrastructure agents are scheduled in parallel. Accordingly, their interaction is delayed, because each agent can only read in data in time step t that has been produced by another agent in t-1.

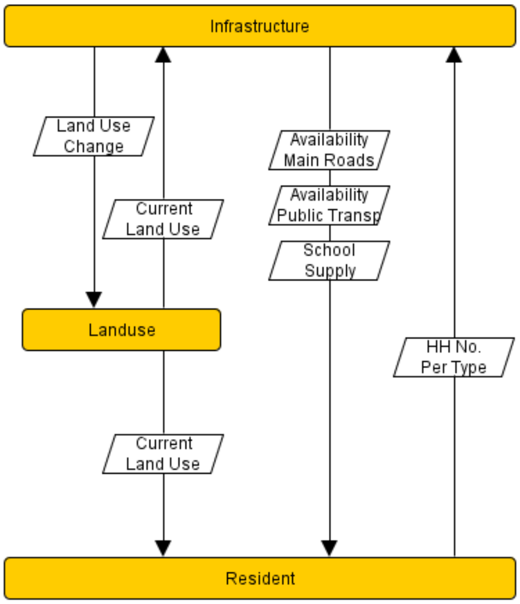

Figure 2. Data exchanges between resident and infrastructure agents.

2.3 Resident agents

Resident agents belong to different household types. They decide upon their location and move to existing flats or houses. For this, they consider aspects such as their preference for certain urban structural types and urban infrastructure. Residents are created by a population model (births, deaths, net-migration). For the implementation of the household type concept defined (partially stochastic) parts of each age-class is sorted into household types (resident agents) with specific the properties (Haase et al., accepted). Resident agents are divided into land owners and non land-owners and into seven household types (which are assumed to make a choice for a flat/house): young singles and young cohabitation households, elderly singles and elderly cohabitation households, families with dependent children and single parent families and flat sharer communities (Haase et al., accepted). Agent types differ with respect to certain parameters like amount of settlement area needed for an individual (in m^2 per capita), tolerance for other household types, housing preferences – among them infrastructure provision, persistence times within one flat and adaptation mechanisms. Furthermore, they differ in terms of their decision making scope. During the simulation, 14 agents are created to represent each of the household types separated into land owners and non land-owners. Each agent represents all households of its type in the city, and it computes all its decisions on a cell-by-cell basis. The resident agents are scheduled in random order within each time step, as the computation order at least theoretically influences simulation results: Each agent might “fill up” (or: “open up”) existing (or: new) empty flats that can be used (or: are no longer available) in the same time step for subsequent agents.

Residents have two options of decision-making: (1) looking for a new (already existing) house or flat or (2) stay within the flat at time t+1 (figure 3). In case of the first option, households migrate if a place is more attractive than their own location and, further, when they exceeded their temporal limit for persisting in one flat using a rational choice algorithm and a maximum utility of the place. Neighbourhood indicators were used to estimate household preferences behind the choice algorithm in an attractiveness matrix (Haase et al., in press). The indicators represent the socio-demographic (household patterns in the neighborhood), the economic (costs, flat and house prices), spatial (accessibility, distances) and recreational (greenery, waters) environment of the resident agents. The empirical foundation of the housing preference indicators is represented by a range of questionnaire surveys and household interviews conducted in Leipzig during the last 10 years (Haase & Haase, 2007): The indicators influencing the housing choice are the result of a systematic variable ranking and respective relative importance the respondents in the survey assigned to the indicators. The weights w for each indicator were 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 (Haase et al., in press).

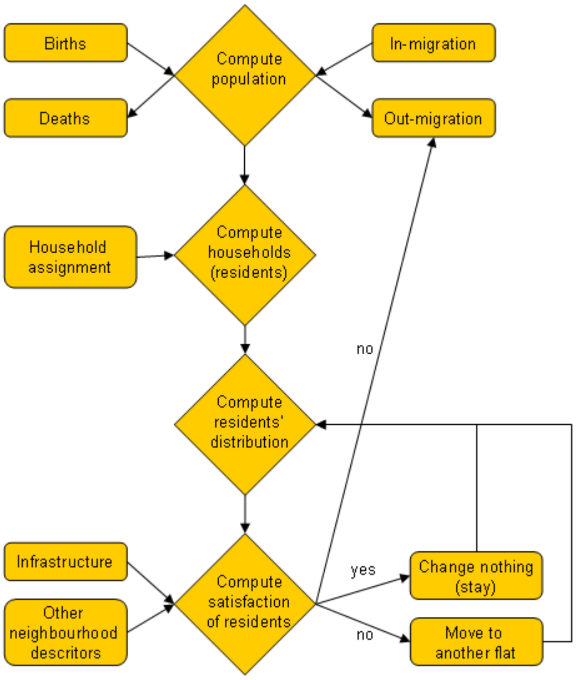

Figure 3. Decision process of resident agents for the whole area.

2.4 Infrastructure agents

As the aim of the paper is to contribute to the interactions of infrastructure and residents, the focus is on those infrastructures that are important for residential location choice. Accordingly, three agent types are distinguished:

- SchoolProvider,
- RoadProvider, and
- PublicTransportProvider.

For reasons of simplicity, only one agent instance per type is created per simulation. One key indicator for infrastructure agents is the efficiency of their infrastructure. In order to avoid the issues of costs, amortisation rates and other financial details, efficiency is included in a simple way at the moment: The share of demand / supply of a specific infrastructure is compared to an agent-specific threshold. For instance, a SchoolProvider builds a new school if the share of pupils per school (demand/supply) exceeds 350 (threshold) – a value that was approximated out of statistical data for the case study region. On the contrary, the SchoolProvider closes a school if the share of pupils per school is less than 150.

Infrastructure agents act on two spatial levels: (1) Urban area. Infrastructure agents check if action is needed (for instance if infrastructure is used inefficiently, figure 4). (2) Single cells. If action is needed, infrastructure agents select cells for enlarging or closing down infrastructure.

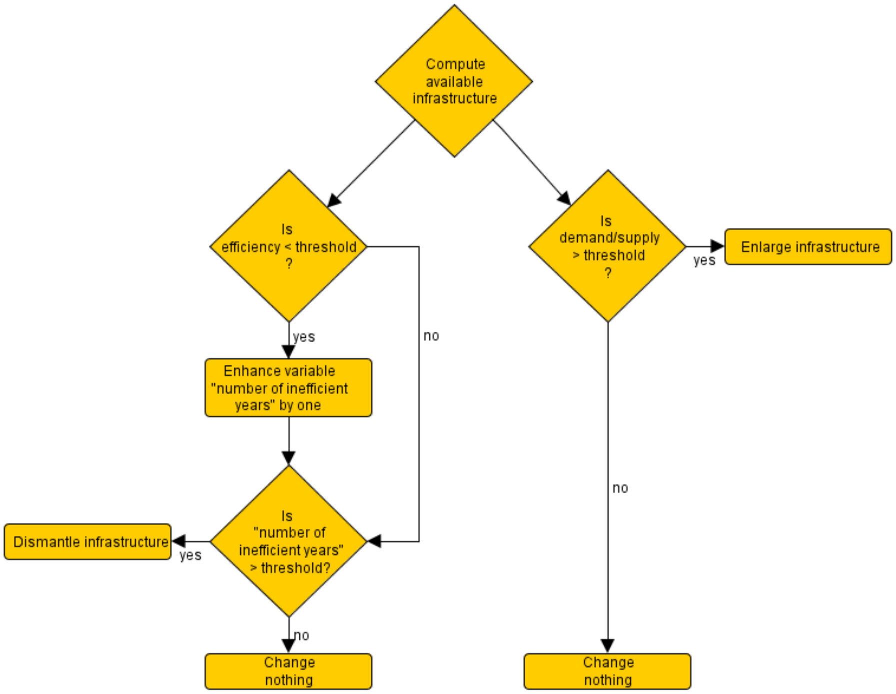

Figure 4. Decision process of infrastructure agents for the whole area.

The decision process builds upon several attributes of the individual agents: (1) their lower limit for efficiency, (2) upper limit for efficiency for comparing demand and supply for enlarging infrastructure, and (3) their tolerance of inefficiency in number of years. The numerical values for these attributes are based upon an analysis of locally statistical or empirical (expert-opinion based) data whenever possible.

3. DISCUSSION AND OUTLOOK

3.1 Model structure

Discussing the model structure relates to three aspects of appropriateness (1) of the agents that are part of the simulation, (2) of omitting other agents, and (3) of omitting market mechanisms.

(1) The resident agents of our model follow a new household-type concept which had been developed particularly for shrinking cities under demographic change (Haase et al., accepted). The household form plays an important role here compared to the pure number of household members, their ethnicity, employment status etc. The results of the coupled model to be presented at the conference will show how appropriate this household classification is for modelling housing choices in relation to infrastructure requirements.

Up to now, modelling infrastructure as agents has been done very rarely, as urban infrastructure is mostly considered as a constant or at most reacting entity in simulation models (Schwarz et al., 2010). One exception is an agent-based model that simulates decisions on water-related infrastructure in a river catchment (Barthel et al., 2009). The approach of using decision rules rather than rational choice algorithms is similar to the one used in this paper. This approach seems more appropriate when representing processes like dismantling existing, crucial infrastructure. Such processes are often part of political discussions and less likely to be solely covered by immediate efficiency criteria. The choice of infrastructure represented here is pragmatic and focuses on the interaction with residents. Other infrastructure like water supply or sewage could be considered as new types of infrastructure agents to broaden the urban issues that are covered by the simulation. Finally, competing agents of one type could be included into the model, for instance for providers of public transport. This could lead to a Tiebout model (Kollman et al., 1997), where entities compete for citizens and influence their location choice.

(2) To cover urban issues in a more comprehensive way, other agents should be included. Actually, this is already part of the work in the EU-funded project PLUREL, by which the work presented here is funded. In the overall model called "ABM*land*", more agents are involved, such as developers, planning institutions, businesses, and lobby groups who all "negotiate" upon the housing market. However, the focus here is on the interaction between the two agents as described above.

(3) Including a land market (Polhill et al., 2005; Filatova et al., 2009) would allow for changing prices for housing. Changing prices would fasten the processes of areas becoming more (un-) attractive for certain groups of residents: Declining areas become cheaper, price differences between different areas within the city increase, so that segregation is accelerated (cf. a comprehensive report by Rink et al., 2009). However, dynamic prices would not change the direction of the processes. Thus, the focus is here on segregation as a phenomenon of affinity to social groups rather than prices. Nevertheless, some empirical data on the housing market is available for municipal districts in Leipzig, so that an integration of flat or house affordability is possible for the future.

3.2 Empirical foundation

Calibration and validation of the agent-based models are both challenging, because no data is readily available for this, especially for feeding the decision rules. Data availability is better for residents, where housing preferences are represented by a range of questionnaire surveys and household interviews on housing satisfaction and migration desires conducted in Leipzig during the last 10 years. Moreover, more general information about household and demographic changes is available in different European databases (Haase & Haase, 2007). This makes the approach used here transferable to other cities. For infrastructure, statistical data on length of roads, number of schools compared to number of children et cetera is locally available in time series. However, empirical information on the infrastructure-related decision processes is scarce, as decisions are taken within institutions and in political processes.

3.3 Outlook

We seek to provide simulation results with respect to (1) sensitivity analysis and (2) scenario runs. (1) A sensitivity analysis will show for each agent individually which changes occur in simulation results if agents' attributes are altered. (2) Four scenario runs are going to be compared. (a) A baseline scenario without interaction of agents, in which each agent simply carries on with its status quo. (b) A scenario of full interaction in which both agents communicate their information and react on it. (c) A scenario in which resident agents carry on with their status quo, while infrastructure agents react – here, an "optimal" adaptation of infrastructure should evolve over time. (d) A scenario in which residents react, while infrastructure agents carry on with their status quo – this scenario should show inefficiency and the need for interaction.

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