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Simulating shrinkage as shock? Insights from existing shrinkage models

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Abstract: Modellers and social scientists attempt to find better explanations of complex urban systems. Such explanations include development paths, underlying driving forces, and impacts of such systems but might also include shocks. So far, land-use research has predominantly focused on urban – means population and/or settlement – growth. However, a comparatively new challenge has arisen since urban shrinkage entered the research agenda of the land use science. Although the phenomenon of urban shrinkage has become increasingly widespread in Europe, the US and Japan, urban land use modelling has rarely addressed it neither in terms of process description and dynamics, nor in terms of being a consequence of the 1989/1990 political transition shock. Based on knowledge of social science research (Haase et al. 2012), we first identify processes related to urban shrinkage by using the concept of pattern-oriented modelling. Second, we assess the capacity and pros and cons of existing land-use modelling approaches (system dynamics, cellular automata and agent-based models) to integrate the processes and variables of shrinkage. Third, we discuss in detail examples of existing simulation models that already cover aspects of urban shrinkage. So doing, we include a discussion of urban shrinkage as a consequence of shock in the urban system.

Keywords*: urban shrinkage, pattern-oriented modelling, model, review, shock*

1 INTRODUCTION

Modellers and social scientists attempt to find better explanations of complex urban systems. Such explanations include development paths, underlying driving forces, and impacts of such systems but might also include shocks. So far, land-use research has predominantly focused on urban – means population and/or settlement – growth. However, a comparatively new challenge has arisen since urban shrinkage entered the research agenda of the land use science (Rink et al., 2009; Schwarz et al., 2010). Although the phenomenon of urban shrinkage has become increasingly widespread in Europe, the US and Japan (Haase et al., 2007; Kabisch & Haase, 2011), urban land use modelling has rarely addressed it neither in terms of process description and dynamics, nor in terms of being a shock to the urban systems or rather a consequence of a shock.

Haase et al. (2012) define a shock *"…as an event or process that produces a significant change within a system, e.g. an urban (human-environmental) system, occurring mostly but not necessarily outside of it.*" We hypothesize that the political transition of 1989/1990 is the shock. Haase et al. (2012) made clear that it might be impossible to model such shocks as post-1990 transition ex-ante themselves. However, modelling the consequences of shocks – such as shrinkage – can produce surplus knowledge for a better understanding of shrinking urban systems, support future simulations and scenario building (Schwarz et al., 2010). Moreover, modelling the effects of the post-socialist turnaround can help to improve learning about causal mechanisms and feedbacks within a shrinking urban system.

As urban systems are highly complex, functioning at various scales (from global to local) and shrinkage poses a new challenge on them, we use a concept of pattern-oriented modelling of complex systems introduced by Grimm et al. (2005) for our review of land-use models' capacity to simulate urban shrinkage.

So doing, in this paper, we first apply the concept of pattern-oriented modelling to disentangle the empirically observed spatio-temporal patterns of urban shrinkage from their underlying processes (section 2). Having identified typical processes and patterns that characterise urban shrinkage, we look for the capacity of existing land-use modelling approaches and applications to represent/integrate this knowledge in form of model components (section 3). We thereby focus on three major model types which are predominantly used to simulate urban systems: system dynamics (SD), cellular automata (CA) and agent-based models (ABM). We discuss the pros and cons of each of these modelling approaches to incorporate and to represent the processes and patterns discussed in section 2 as well as show examples of existing realisations of models encompassing urban shrinkage (section 3).

2 PATTERNS AND PROCESSES OF URBAN SHRINKAGE

Modellers of complex systems always face the challenge of how to deal with the complexity of the system. Individuals perform different actions, such as out-migrating, choosing a new home or having a baby. These actions lead to emergent properties on aggregate system levels, such as population losses, suburbanisation or changing fertility rates. For individual-based, bottom-up models, the concept of pattern-oriented modelling was developed to facilitate the modelling process by finding a suitable model structure. Pattern-oriented modelling asks the question: "What observed patterns seem to characterize the system and its dynamics, and what variables and processes must be in the model so that these patterns could, in principle, emerge?" (Grimm et al., 2005, p. 987).

In this paper, we use the concept of pattern-oriented modelling to disentangle the empirically observed spatio-temporal patterns of urban shrinkage from their underlying processes (Figure 1, see section 1 and Haase et al. (2012) for a more detailed description of the processes). Those processes (Figure 1: B – E) lead to model components (Figure 1: F – I) that are needed to simulate urban shrinkage. The necessary model components are used to assess the capability of different modelling approaches to simulate urban shrinkage (see section 3).

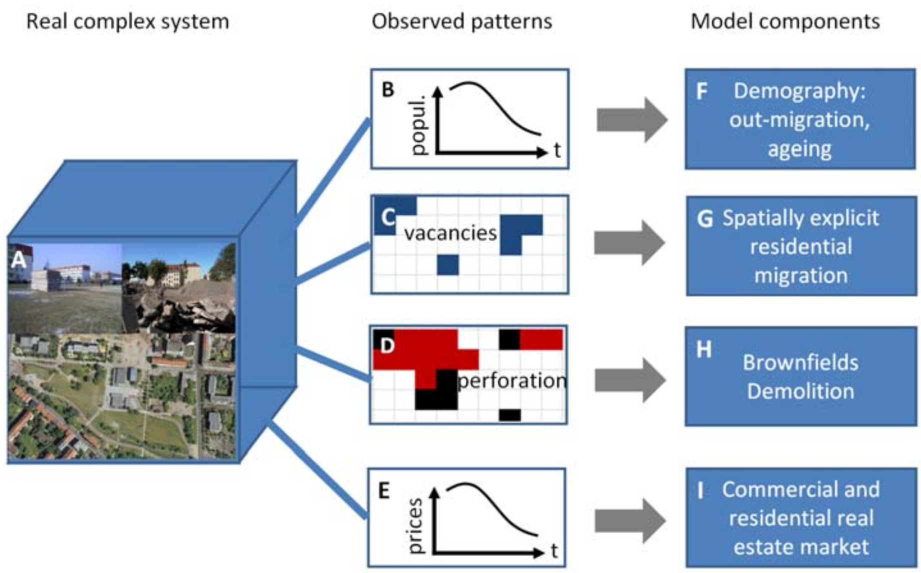

Figure 1. An application of pattern-oriented modeling to shrinking cities. Urban shrinkage (the real complex system, A) shows four empirical patterns: population losses (B), residential and commercial vacancies that may vary spatially in different neighborhoods (C), perforation of the urban fabric with brownfields (D), and decreasing real estate prices (E). These patterns can be simulated with a demography component accounting for out-migration and ageing (F), a spatially explicit representation of residential migration within the city (G), brownfields as a land cover class and the process of demolition leading to those brownfields (H), and a commercial and residential real estate market (I) (using Grimm et al., 2005, as a blueprint).

(A) Population losses are the dominant temporal pattern that can be found in shrinking cities, i.e. they are the most important variable for defining a shrinking city. To capture population losses in a simulation model, a model component is needed to simulate the demographic development. Out-migration is a very important process that needs to be tackled; assuming that mostly younger inhabitants leave a region, out-migration leads to ageing even without a general ageing population (F). A variety of drivers can be responsible (Reckien & Martinez-Fernandez, 2011). However, the post-socialist transformation is here emphasized as a shock for eastern European cities. (B) Spatial patterns of residential and commercial vacancies necessitate a spatially explicit representation of residential mobility to be included in a simulation model (G). (C) Perforation of the urban fabric with brownfields is due to the process of demolition (H). Perforation means the dissolution of the urban grid creating islands of built fabric in midst of brownfields. Furthermore, brownfields themselves need to be included in a typology of land use (as opposed to land cover), to differentiate between brownfield and urban green areas. (E) Price dynamics can be simulated with commercial and residential real estate markets (I).

The patterns B and D manifest themselves in a spatially explicit way in reality. However, their relevance for urban shrinkage is on the temporal aspects, i.e. the loss of population and the decrease of prices. Thus, these two patterns are included in a non-spatially way.

3 MODELING PROCESSES OF URBAN SHRINKAGE

In the following, we discuss the representation of the in section 2 identified processes of urban shrinkage as components in different model types:

- SD is an approach to modeling complex systems through the use of stocks and flows and by explicitly including feedback loops in the model.

- CA usually consist of a two-dimensional grid of cells, in which each cell has a finite number of states that change solely due to the state of its neighboring cells in the previous time step.
- ABMs consist of autonomous individuals (agents) who perceive their environment and interact with each other.

These three modeling approaches are included as they have already been used to model shrinkage in the past or have a high potential for modeling it (Schwarz et al., 2010). Model applications for the three different model types mentioned and discussed in sections 3.1 to 3.4 will be shown for different shrinking cities only during the oral presentation in July 2012 due to space limitations of this full paper format.

3.1 Demography component accounting for out-migration and ageing

Modeling the natural population balance can be done in an aggregated way using (differential) equations with birth and death rates. However, it would also be possible to apply a bottom-up approach such as ABM with human agents deciding upon whether or not to have a family and accounting for individual fertility and death. However, to our knowledge this has not been done yet. Likewise, in- and out-migration can either be tackled with aggregated migration rates or individual decisions. The conceptual view taken here does not tackle the emergence of urban shrinkage as such, but rather the specific processes and patterns in a given shrinking region. Thus, to simulate the pattern of population loss in shrinking cities, an aggregated view is sufficient.

In the literature, demographic processes have mostly been described by SD models, also for stagnating and shrinking cities (e.g. Lauf et al., 2011, 2012). The SD model type is highly suitable for the fast computing of a set of differential equations in a non-explicit way. For calibrating and running the population model, spatially implicit initial/input data from the local census are required. The results produced by SD models are also spatially non-explicit. The clear advantage of SD models for computing population and demographics is that it reflects the need for aggregated population numbers and is both easy to understand and fast to compute. SD models are often used to compute numbers that serve as input for e.g. CA models (Van Delden et al., 2007; Van Vliet & van Delden, 2008) that have a spatial (often GIS-based or supported) $\{x,y\}$ representation for both input and output data. The Metronamica model for example uses SD components to calculate a number of new residential cells based on population growth. However, information about age-specific out-migration and ageing cannot be simply “translated” into new amounts of cell states. Lauf et al. (2011) developed a coupled SD-CA approach for the Metropolitan Region of Berlin using Simile and Metronamica where a sophisticated and household-based SD model code replaces the Metronamica-own system dynamics component in its log-file. ABMs on urban shrinkage also use SD-like components to compute the overall population dynamics of birth, death and in-/out-migration (Haase et al., 2010).

3.2 Spatially explicit representation of residential migration in the city

Simulating residential migration within the city shall implement the spatial pattern of vacancy in the building stock. The top-down approach is to first compute demand and supply of housing in an aggregated way and to impose this on a given spatial structure in the second step. The bottom-up approach is to directly simulate residential mobility on an individual level and then deduce vacancies.

In the literature, SD models have been used to compute numbers of residents or households for spatial units or urban structure types (such as old and new built dense urban fabric, single house areas etc.) (e.g. Lauf et al. 2012). However, such allocations of population in structure types cannot be allocated in a spatially explicit map. Another top-down approach is the CA model type that has also been used to model residential mobility shrinking cities (Lauf et al. 2011). This general modeling technique could in principle also model vacancies due to residential mobility, given fine-grained data to fit the CA equations in the calibration phase. As land use data are commonly used for calibrating CAs, they are currently not very suitable for modeling residential mobility under conditions of shrinkage. Here, ABMs are best suited. Haase et al. (2010) used an ABM for simulating household-based residential migration in a city with declining population under a "relaxed" housing market. The results convincingly show a further segregation of the urban residents in the shrinking city with a concentration of young single and pair households in the central part of the town and an elderly and family segregation in the outer dense built up and single house areas, respectively.

3.3 Brownfields and demolition

Empirical knowledge about decisions regarding demolition of the building stock and the resulting emergence of brownfields in urban land management and planning is available (elicited by social scientists mainly). The spatially explicit allocation of demolition and brownfields can – as for residential mobility – be modeled (1) top-down or (2) bottom-up. (1) The top-down approach has a spatial allocation procedure with neighborhood rules and distance and takes site characteristics into consideration. (2) ABMs describe the demolition action as direct consequence of an individual decision and not as a general rule applied to all vacant lots in the city. Thus, they could explicitly simulate the decision to demolish an individual building or quarter

Haase et al. (2010) and Lauf et al. (2011) identified vacancies in their models and established comparatively simple rules in the form of *demolition=f(proportion of vacancy, time of vacancy)* to create demolition and brownfield patterns. A real ABM on the perforation of the urban land use does not yet exist according to the knowledge of the authors. For a spatially explicit representation of demolition decisions – as argued a typical case for an ABM – requires a range of specific data needed to represent such a decision and thus might lead to comparatively long runtime of the model. The SD approach, finally, can compute amounts of vacancy and demolition as *f(other stocks and time)* but without spatially explicit representation; the numbers have to be translated into a cellular model as done in Lauf et al. (2011).

3.4 Commercial and residential real estate market

Similar to demographic processes, the dynamics of real estate markets and prices can be simulated in an aggregated or disaggregated way. As far as decreasing real estate values for the whole city are concerned, an aggregated view is appropriate to capture the balance of demand and supply and resulting price development. However, spatially explicit patterns of real estate prices (as captured in Alonso's model) would need either a spatial dis-aggregation or an individual-based approach.

Models that explicitly simulate shrinking cities so far do scarcely tackle the real estate market. Housing development is for instance included in the SD approach of Sanders and Sanders (2004). In other urban simulation models, real estate markets are covered in models of spatial economics, but are also underrepresented in other land use change models. In CA, housing prices are not included. However, probabilities for land-use change are sometimes regarded as bids for development or redevelopment (Landis and Zhang 1998a, b). In ABMs, real-estate markets can be explicitly modeled (e.g. Filatova et al., 2009).

3.5 Summary

The convincing representation of the above discussed processes of shrinkage logically includes the representation of their resulting patterns: population losses

(B), residential and commercial vacancies that may vary spatially in different neighborhoods (C), perforation of the urban fabric with brownfields (D) and decreasing real estate prices (E). The results of our assessment are summarized in Table 1. Our analysis indicates that no model type fulfills all prerequisites for modeling urban shrinkage and that a combination of different model types – using spatially explicit but also implicit ways – might be a good choice. However, when combining different modeling approaches, three aspects of compatibility should be considered: spatial and temporal resolution as well as congruence of model units. The costs and benefits of using a specific modeling approach should be pondered.

Table 1. A summary of the suitability of different modelling approaches to represent processes of urban shrinkage (+ = good representation, o = potential for representation, but limited, - = no representation).

Processes	SD	CA	ABM
Demography (F)	+	-	o
Residential Migration (G)	-	o	+
Brownfields, Demolition (H)	o	+	o/+
Real estate market (I)	+	-	+

4 CONCLUSIONS

We applied the concept of pattern-oriented modelling by Grimm et al. (2005) to disentangle the empirically observed spatio-temporal patterns of urban shrinkage from their underlying processes. We discussed the representation of these underlying processes as components in three different model types that are typically used and applied in an urban land-use context – SD, CA and ABM. This review-type analysis brought up that none of the three model type fulfills all prerequisites for modeling urban shrinkage. Therefore, and in accordance with the more social-science based analysis of urban shrinkage by Haase et al. (2012), we advocate a combination of model types or modelling philosophies to capture processes and patterns of urban shrinkage. To give at least two examples, one way would be the coupling of SD and CA models in the form Lauf et al. (2011) have shown. Another opportunity would be to run a spatially explicit ABM on residential migration that creates layers of used and non-used residential land and to use these layers a suitability maps in a CA model.

In terms of completing the representation of processes and patterns of shrinkage by land-use models, it needs to be added that a) the real estate market could also be represented spatially explicit (in form of an Alonso model-type grid or lattice) and b) the impacts of shrinkage on urban transport, health, education or subterranean infrastructure should be included as well. Particularly the latter are a clear effect of the observed patterns of residential migration, vacant stock and brownfields. However, an empirically proofed feedback of vacancies on any kind of infrastructure had only been scarcely found so far by the shrinkage research community (Guy et al. 2011 and Moss 2004 for Berlin). Feedbacks on vacancies in form of residential choices, in contrast, are possibly to be extracted from questionnaire surveys and/or interviews in urban areas affected by shrinkage and land-use perforation.

Haase et al. (2012) define urban shrinkage as a “transition shock”. According to our insights from existing land-use models to represent shrinkage patterns, we hypothesize that a shrinkage model will not be able to simulate systemic shocks itself but they might be able to show evidence of a kind of shock-like responses emerging from shrinkage, means from the observed patterns discussed in section 3: For example, a massive and sudden population decline might lead to a “dying” of a settlement or parts of a settlement. This settlement dying might be also a consequence of “extreme” rates of residential migration. Further, residential migration itself might lead to “extreme” forms of segregation and thus convert parts of the city into ghettos and “no-go areas” for the urban majority. But there are not only such negatively connotated impacts or “second order shocks”. Conversely, well managed brownfields (used as festival area, attractive public usable green space, recreation area, flea markets etc.) could attract new residents and investors to an area in short periods of time. Finally, the real estate and commercial market is definitely influenced by the financial situation and thus also by crises that affect the finance sector as the crisis in 2008 or the current Euro-crisis.

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