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An easy-to-use spatial simulation for urban planning in smaller municipalities

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ABSTRACT

In order to produce precise outcomes, most spatial simulations require great volumes of data input, intensive data preparation or programming skills. Consequently, high quality spatial simulations are usually not applied in practice in municipalities of smaller size (< 25,000 citizens). This study aims to provide an easy-to-use tool for smaller urban administrations. A web application was developed which requires a minimum of manual user input for automated data preparation. Gamified elements aim to encourage the user to experience the underlying mechanisms of the system under alternating planning scenarios. These mechanisms are modelled as a combination of spatially implicit and explicit rules which can be derived from dependencies in the data itself. Spatial attractiveness was modelled as a function of accessibility of facilities, ground value, soil sealing, traffic intensity and noise pollution in a multi-variate spatial autoregressive regression analysis. A case study for the city center of Herdecke (Germany) revealed that the establishment of a new event location in the northern part of the study area was most appropriate for increasing spatial attractiveness. The presented easy-to-use tool is suitable for practical application in everyday administrative processes of smaller municipalities and thereby contributes to more applied sustainable urban planning.

1. Introduction

In the 21st century, urban decision makers find themselves simultaneously faced with a plethora of interconnected societal and ecological challenges. These challenges comprise, for instance, consequences of demographic change (Champion, 2001; Danielzyk, Meyer, & Grüber-Töpfer, 2010), demand-adapted local supply with basic services (Libbe, Köhler, & Beckmann, 2010), progressive soil sealing and its multi-scale effects on urban heat islands and heavy rains (Arnfield, 2003; Oke, 1973; Tyrna & Hochschild, 2010). Spatial decision support tools can provide informative assistance for urban planners and policy makers in order to meet the interconnected challenges of complex urban systems and to estimate consequences of specific planning strategies. In the last 70 years, various spatial simulations were created within the fields of system dynamics and agent-based modeling.

The former dates back to the 1960s, when it was founded by Forrester (1969) at the Massachusetts Institute of Technology. It models circular causalities with reinforcing or extenuating feedback loops, which are usually spatially implicit (Scholl, 2001). Examples for system dynamics modeling platforms include Vensim (Ventana Systems, 2015), Powersim (Powersim Software, 2017) and Stella (isee systems, 2017).

Agent-based models (ABM), also called individual-based or multi-agent models, represent the second large research strain regarding system simulations. It dates back to the first cellular automata (CA) in the 1940s which – after the astonishing results of the game of life CA - experienced a renaissance in the 1970s when it was used in many disciplines (Gardner, 1970; Janssen, 2005). In recent years, CA models have been applied in various research fields such as savanna fire propagation (Berjak & Hearne, 2002), vegetation distribution and desertification (Kéfi et al., 2007), land cover and land use changes (Verstegen, Karssenberg, van der Hilst, & Faaij, 2014) and urban development (Batty, 2005; White & Engelen, 1993). Recent developments in this field of research include, for instance, CA models with varying cell shapes (Pinto, Antunes, & Roca, 2017), considering modeling uncertainties (Şalap-Ayça, Jankowski, Clarke, Kyriakidis, & Nara, 2018), patched-based logistic regression (Chen, Li, Liu, & Ai, 2014) and Bayesian CA approaches (Verstegen et al., 2014; Verstegen, Karssenberg, van der Hilst, & Faaij, 2016). "Agent-based models consist of a space, framework, or environment in which interactions take place and a number of agents whose behavior in this space is defined by a basic set of rules and by characteristic parameters" (Scholl, 2001, p. 2). Reynolds (1999, on his web page) further sets out that "there is an

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overlap between individual-based models and cellular automata" and that "cellular automata are similar to spatially-explicit, grid-based, immobile individual-based models". In these models, the overall systemic patterns emerge from behavior of individual agents. This behavior is usually defined by a simple set of rules which, in most cases, is probabilistic and spatially explicit. Agent-based models have recently been applied to model, for instance, pedestrian movements in urban contexts (Omer & Kaplan, 2017), movements of individuals during an evacuation scenario (Tan, Wu, & Lin, 2015) and tenants' choice of residence within a city (Shirzadi Babakan & Alimohammadi, 2016). Examples of platforms for modeling ABMs include RePast (Collier, 2003), SWARM (Minar, Burkhart, Langton, & Askenazi, 1996), Echo (Forrest & Jones, 1995), Boids (Reynolds, 2001), CORMAS (Bommel, Becu, Le Page, & Bousquet, 2016) and MASON (Luke, Balan, Sullivan, & Panait, 2015).

As research in the fields of system dynamics and agent-based models was strikingly isolated from each other until the early 2000s, there was a general call for mixed models in order to exploit the advantages of both modeling approaches (Macal, 2010; Nava Guerrero, Schwarz, & Slinger, 2016; Scholl, 2001). Since then, various mixed models, which are also called multimethod models, have been presented, such as MASGISmo (Gebetsroither, 2010) NetLogo (Uri Wilensky, 2016), AnyLogic (AnyLogic, 2014), Nova (Salter, 2013) and an intercity transport model (Lewe, Hivin, & Mavris, 2014). All of these modeling platforms, however, require great volumes of data input, intensive data preparation, programming, modeling, analysis, GIS or other specialized technical skills (Nava Guerrero et al., 2016).

A deficit in financial and staff resources is a universal phenomenon among small administrations (< 25,000 citizens). Consequently, spatial simulations are usually not applied in practice in municipalities of smaller size and systemic feedbacks and respective reasonable and evidence-based measures are usually not considered for planning strategies and policies in these communities (Janssen & Ostrom, 2006; Pullin & Knight, 2003; Pullin, Knight, & Watkinson, 2009; Russo, Lanzilotti, Costabile, & Pettit, 2018).

One approach to overcome these restraints of spatial simulation for the application in everyday urban panning routines is the "gamification" or "serious game" approach (Ahlqvist, Khodke, & Ramnath, 2018). It picks up findings from the field of psychology which indicate that rather than instruction, the most efficient way to comprehend complex matters is by personal experience and by evoking the learner's curiosity (Deterding, Sicart, Nacke, O'Hara, & Dixon, 2011). As games provide both, the gamification approach puts complex and serious topics into an easy-to-use and enticing game environment (Deterding et al., 2011; Ingensand et al., 2015; Prensky, 2003). The user is rewarded for appropriate action with motivational affordances, such as game scores, which aim to trigger psychological and, ultimately, behavioral outcomes (Hamari & Koivisto, 2014).

Another drawback of most decision support tools for urban planning is a predominant technical perspective rather than addressing the overall well-being of citizens which is the main objective of urban planning (Nam & Pardo, 2011; Neirotti, Marco, Cagliano, Mangano, & Scorrano, 2014). However, the level of self-perceived well-being and if citizens feel comfortable within the given space is highly subjective, individually different and geographically bound. This raises the question as to how spatial attractiveness can be quantified, compared and best integrated into an easy-to-use spatial simulation.

1.1. Objectives and structure of the paper

This present study aims to integrate geospatial methodologies for measuring spatial attractiveness (Section 2.2) with various geo data sources (Sections 2.3, 2.4) and combines gamification (Section 3.1), system dynamics (Section 3.2) and agent-based modeling (3.3) approaches in a novel, easy-to-use platform for creating spatial simulations for urban systems (SimUSys). In this context, an urban system is defined as the construct of all interconnected social, environmental and technical entities within a city which can be quantitatively expressed and for which data is provided (see Section 5 for a discussion on incorporating qualitative approaches). It aims to deploy as of yet underexploited synergies of the individual approaches from a geospatial perspective.

A web-based user interface which requires no local installation allows planners with no technical geospatial skills to simulate various planning measures such as the establishment of a new facility of basic goods and services and the resulting systemic effects for e.g. the spatial attractiveness for a city district. It thereby investigates whether the methodological synergies allow for practical application and consideration of complex systemic feedbacks in everyday planning routines. Moreover, it thereby supports knowledge transfer and mainstreaming of technical learnings. A high usability for non-technical users is accounted for by, for example, integrating methods for automated geospatial data preparation.

In accordance with the gamification approach, users get incentives to evaluate planning strategies, for example, by game scores. In addition, the model parametrization is straightforward as the rules for this mixed model can be derived automatically from influences and dependencies in the data itself using geographical regression methods. These models influence the simulations which can be created with the SimUSys platform, as they can be used to define the behavioral rules of the agents (Section 3.3).

In a case study, it is shown how SimUSys can be used to build a simulation for the identification of facilities with the highest influence on spatial attractiveness and the most suitable site for a new facility (Section 4). The SimUSys platform for creating urban simulations was set up in cooperation with city planners and its layout is applicable by administrations of smaller municipalities but in principle, it is scalable to other urban and regional planning contexts.

2. Methodology and data

A platform for creating spatial simulations was created which makes use of the gamification approach and is straightforward to access, set up and use for evaluating different planning strategies. The following sections describe how the main benchmark for this evaluation, the spatial attractiveness, was measured (Section 2.2) for a use case in Herdecke in Western Germany (Section 2.1) and how a multitude of data sets were automatically integrated (Sections 2.3, 2.4) in order to investigate influences and dependencies.

2.1. Study area

The city of Herdecke is located at the southern rim of the metropolitan Ruhr-Area in Western Germany, south of the larger cities of Bochum and Dortmund. The Ruhr-Area is an urban agglomeration of eleven metropolitan cities and four administrative districts incorporating a total of 53 communities. It covers an area of ~ 4436 km^2 and is inhabited by ~ 5 million citizens which results in a population density of about 1200 citizens per km^2 (Regionalverband Ruhr). The city of Herdecke itself covers an area of about 22 km^2 and is inhabited by ~ 25,000 people (IT.NRW, 2017), resulting in a population density of ~ 1100 citizens per km^2. The cities administration employs 265 people in total, and the department for construction and planning is run by 4 people (City of Herdecke). This number of staff is typical for a city of this size in this region and does not allow for elaborate data preparation, programming and validation of urban system simulations in everyday planning routines. SimUSys was set up in cooperation with Herdecke's city planners. Their user demands were that in order to exploit insights into system behavior for more effective and sustainable practical application, SimUSys had to be easy-to-use and its results intuitively comprehensible.