THE AGENT-BASED MODELLING AS A DECISION SUPPORT TOOL FOR BROWNFIELD REDEVELOPMENT

UDC 711.168

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Abstract. *In recent history of urban studies there is a focus on sustainable urban development and long-term strategies. Dealing with brownfield redevelopment is of vital importance for the prosperous practice of urban planning. The current decision-making methods for brownfield redevelopment are mainly used for evaluating on-site situation, but not for future development plans. The purpose of this paper is to consider potential uses of agent-based modelling (ABM) in brownfield redevelopment decision support practice. In these models, agents are assigned with certain rules of behaviour that define their mutual interactions and allow simulations in a previously defined spatial framework. These collective behaviours influence the spatial patterns through interactions of individuals, which is reflected in the fact that the actions of the agents do not simply sum to the activity of the whole. This tool provides us with opportunity of observing possible scenarios of future brownfield development and making adequate decisions and strategies accordingly.*

Key words: *brownfield, agent-based modelling, decision support system, urban development, research tool*

1. INTRODUCTION

The improvement in brownfield sites planning has been recognized as an important issue in a considerable number of studies of sustainable urban development. There is a wide agreement that brownfield regeneration is a key element of urban development and as such has been the subject of research for many authors (Beames et al., 2018; Ferber et al., 2006; Perovic and Kurtovic Folic, 2012; Petríková and Finka, 2006; Rizzo et al., 2015; Schädler et al., 2011; Schädler et al., 2012; Schädler, et al., 2013; Wedding and Crawford-Brown, 2007).

The term "brownfield" can be defined and translated into many languages in many different ways. In the United States, a brownfield represents a property on which expansion, redevelopment, or reuse can be complicated by the presence, or perceived presence, of contamination (EPA, 2006). In Canada, it is defined as a property, often a former industrial site left underused due to environmental contamination concerns (CREA, 2007). The European perception treats brownfield land as derelict, underutilized or vacant land; these lands may have environmental damage or not, on which previous use has ceased or subsided and which the market could not adequately reuse without some kind of an intervention (Ferber et al., 2006).

Redevelopments of brownfield sites became more frequent in the first decade of the 21st century. The increasing number of brownfields in cities around the world has conditioned the need for strategic actions directed toward sustainable regeneration and sustainable development (Perovic and Kurtovic Folic, 2012). Depending on the socio-political context in which brownfield sites are located, discourses to support brownfield redevelopment are various. In some countries this issue is addressed by massive national programs, supporting national and regional investment. The planning system in many European countries has supported brownfield redevelopment as an alternative to greenfield development. Furthermore, the reuse of brownfield land with taking advantage of existing urban infrastructure contributes to the reduction of urban sprawl (Petríková and Finka, 2006). All things considered, it is generally accepted that the reuse of brownfields provides many environmental, economic and community benefits, which made a large number of countries all over the world aware that investment in brownfields can pay off in many ways.

Although they include many challenges, brownfield sites at the same time represent a great potential for developers. The scale of brownfield sites in urban areas and the prospective benefit of using these places underline the necessity of providing decision support systems for their redevelopment.

The aim of this paper is to explore potential uses of agent-based modelling (ABM) in brownfield redevelopment decision support practice. According to Lawlor and McGirr (2017), agent-based modelling is a system science method to simplify and simulate complex phenomena. It is an increasingly usable simulation modelling tool that has aroused great interest in the past decade. The ABM framework allows one to simulate the individual actions of diverse agents, quantifying the resulting system behaviour and the complex characteristics of their outcomes over time. Agent-based models with their focal point on individual actions of agents have potential to be of benefit given that they potentially do not share the theoretical weaknesses of conventional models. In this paper, the use of ABM has been considered and evaluated with regard to other currently prevailing methods for brownfield development.

2. CONVENTIONAL DECISION SUPPORT SYSTEMS FOR BROWNFIELD REDEVELOPMENT

Decision support systems for brownfield redevelopment are classified into two wide categories: indicator based multi-criteria analysis (MCA) tools and stakeholder participation frameworks (Beames et al., 2018). MCA is tasked with evaluating and choosing among alternatives based on multiple criteria using systematic analysis that overcomes the limitations of unstructured individual or group decision making (Belton and Stewart, 2002; Munaretto et al. 2014). Beames et al. (2018) make further division of indicator based

MCA tools into two categories: tools that include spatially explicit indicators and those that do not. The use of spatially explicit indicators provides the opportunity to operate with spatial data on specific locations by relying on automated computational processes. Contrary to that, stakeholder participation is the process of involving people who may be affected by the decisions which will be made, or who are able to influence the realization of these decisions. Stakeholder engagement methods and techniques most often refer to focus groups, workshops and questionnaires (Rizzo et al., 2015). In this paper we analyzed and compared seven decision-making methods for brownfield redevelopment, six of which belong to the MCA tools and one to the stakeholder participation frameworks.

The Sustainable Brownfields Redevelopment (SBR) Tool and SIPRIUS indicator system were designed to compare alternative redevelopment scenarios in hindsight (Wedding and Crawford-Brown, 2007; Laprise et al., 2015). Although they are primarily post-completion assessment tools, they can aid in the design of a project to some extent. SBR is a retrospective tool for evaluating the success of completed brownfield redevelopments, based on 40 indicators (grouped into 4 categories: environment-health, finance, livability, and social-economic) which are normalized to a percentage by assigning the indicator values for the redeveloped site by the values of the site before the renewal (Wedding and Crawford-Brown, 2007). Further evaluation of the results is carried out using an analytical hierarchy process (AHP). SIPRIUS is a digital monitoring tool composed of 21 criteria assessed by 42 indicators (Laprise et al., 2015). They are divided into two groups: context criteria (such as: mobility, proximity of commercial facilities, job, population etc.) and project criteria (such as: land, well-being, diversity etc.). Corresponding indicators are assigned to each of these criteria. For example, the diversity is assessed through three indicators: degree of functional mix, potential of social diversity and degree of universal access. Each of these indicators are compared to a scale of reference and the results are evaluated individually. Thus, contrary to normalizing and aggregating the results, it is avoided losing the sense of absolute scale.

The approach developed by Michael R. Thomas (2002) deals with the question of optimizing brownfield redevelopments regarding land-use siting decisions. The approach is supported by a geographical information system (GIS) tool called Smart Places and determines the optimal land-use for unused brownfield sites based on 30 indicators. Indicators are grouped into 5 categories: land resource base, social/cultural, economics/finance, environmental quality and infrastructure (energy and resources). The indicators include: adequate land area, education levels, land values, proximity to utility services, willing neighbors etc. Each site is evaluated through these indicators after mapping brownfields using Smart Places.

An assessment suitability method for land redevelopment from the aspect of sustainability was originally developed by Stadtregion (2010) as part of the research project SINBRA (Bartke and Schwarze, 2015). The SINBRA sustainability assessment tool (SINBRA-SAT) was then developed further by Schädler et al. (2011, 2012, 2013). SINBRA-SAT determines optimal brownfield redevelopment scenario design for the specific considered site (Schädler et al., 2011, 2012, 2013). This method uses an algorithm which generates all the possible combinations of three land-use types and then evaluates each according to a set of 23 Boolean indicators such as: residential areas in the surrounding area, commercial areas within walking distance, good supply and disposal infrastructure, site suitable for innovative industries and others.

The LEED rating system for neighborhood development (LEED-ND) is developed as a method to identify eligible locations for urban redevelopment (Talen et al., 2013). The system is based on a checklist of 56 indicators that can help communities to prioritize suitable sites within a city or urban centre. Indicators are organized into three main groups: smart location and linkage (SLL), neighborhood pattern and design, and green infrastructure and buildings. The approach of Talen et al. (2013) is developed as an effort to extend the green building principles to the scale of neighbourhoods.

The approach developed by Beames et al. (2018) focuses on spatial proximity in evaluating the potential for different redevelopment alternatives for a specific site. The proposed method is supported by a combination of GIS software platforms including the VITO GeoDynamiX Toolbox and ArcMap. Spatial proximity analysis supports efforts toward more compact urban planning. Beames et al. (2018) developed the approach with an aim to integrate both kinds of decision support systems for brownfield redevelopment. However, the social indicators of this system take into consideration only physical aspects of the built environment such as zoning, accessibility to green spaces and roads, percentage of sealed soil, historic buildings or nearby amenities in walking distance.

The RESCUE sustainability assessment tool (RESCUE-SAT) is developed in a five-year EU-funded research project (RESCUE, 2004). It is a participatory, consulting and procedural approach that highlights the role of stakeholder participation in the assessment of sustainability. RESCUE takes into consideration aspects of land quality, development planning and citizen participation in order to draw up recommendations for actors in land revitalization. This method consists of two assessment sets - by the approval body and the stakeholders. They are further merged to make an overall assessment, which is then compared to a fixed benchmark setting a minimum standard of quality. The final result represents the ground for deciding whether financing is to be granted for the project. To summarize, the RESCUE-SAT is a completely participation-based method practised to encourage the sustainable use of brownfields.

Table 1 shows an overview of all the methods described above. Existing tools are presented in the interest of demonstrating how the approach presented here contributes to the current state-of-the-practice. All considered approaches aim to facilitate decision-making process in brownfield redevelopment practice, but only few have been embraced by practitioners. When it comes to their implementation, the evaluation of their diverse qualities must be guided by the normative aspect of sustainability but at the same time be oriented toward the user's various requirements. Assessment tools for brownfield redevelopment are developed to fit a given norm-based aspect that involves selecting certain sustainability principles over others, e.g. broader participation or better practicability and flexibility or more systematic compliance with a holistic perspective (Bartke and Schwarze, 2015). In the frame of tools that include spatially explicit indicators, the SINBRA-SAT and Spatial proximity analysis are the only ones which use an automated computation process to get a result. The existing methods are generally used for evaluating on-site scenarios, but not for predictive modelling of different redevelopment scenarios. That prompted us to examine the potential use of ABM as a tool for improving current practice.

Table 1 Existing decision support systems for brownfield redevelopment

Decision support system	Method	Author	Computational tool
MCA tools	Smart places	Thomas (2002)	GIS software platforms
	SBR	Wedding and Crawford-Brown (2007)	-
	SINBRA-SAT	Schädler et al. (2011, 2012, 2013)	Visual Basic and GIS software platforms (MapWindow GIS)
	LEED-ND	Talen et al. (2013)	-
	SIPRIUS	Laprise et al. (2015)	-
MCA tools	Spatial proximity analysis	Beames et al. (2018)	GIS software platforms (VITO GeoDynamiX Toolbox)
Stakeholder participation frameworks	RESCUE-SAT (workshop, stakeholder groups)	European Commission (2004)	-

3. Theoretical Framework and Historical Background of ABM

The initial application of agent-based modelling was intended for the urban dynamics simulation on a micro-scale (Benenson, 1998). Only later the scope of its utilization was expanded. It took a long time for the ABM to emerge noticeably in social simulation and geographical information science. It happened only after Epstein and Axtell (1996) described the potential of its application to growing entire artificial cities.

Some of the first agent-based simulations used as support in making decisions in urban planning were models like UrbanSim (Waddell et al., 2003), and PUMA (Ettema, de Jong, Timmermans and Bakema, 2007). The increased presence of ABMs on an urban scale is considerably caused by the standardization of the modelling process through the ODD (overview, design concepts, and details) protocol (Grimm et al., 2010).

Agent-based models are mainly consisted of two components: the agents – implying a population of entities which are described by a set of attributes, and the environment – representing the area intended for agents' interactions (Benenson, 1998; Bonabeau, 2002). Agents interact with each other and with the environment, generating changes within the model.

The main issues with which are ABMs models challenged are: the rule definition of the agents, acquiring data and the spatial implementation structure (Kocabas and Dragicevic, 2013). It is not easy to define an agent, but according to Crooks et al. (2008) their main features are autonomy and heterogeneity. This means that agents can exchange information between each other and make decisions independently as well as implement independent control of a situation. According to Hatch and Dragicevic (2018) agents are also pro-active, reactive and perceptive, goal-directed and distinguished by bounded

rationality – meaning they may be restricted to only partial access to data; and then also interactive, mobile, and adaptive.

The focus of ABM framework is on agent behaviours and dynamics in terms of agent interactions. Agents are provided with a set of rules that define their interactions both with their surrounding environment and amongst one another. There are several methods within ABM which have been used to provide simulations. Some of them are based on hypothetical datasets (Crooks et al., 2008; Ligtenberg et al., 2001; Shan and Zhu, 2007), while the others integrate real geospatial data enabling better representation of agent's reasoning (Cabrera et al., 2010; Evans and Kelley, 2004; Hatch and Dragicevic, 2018). There is a wide range of parameters that could be used to define agents' behaviour and ability of making decisions. According to Sakamoto and Ferré (2007), almost everything can be internalized as parameter.

Agent-based modelling differs from many classical approaches because the global system behaviour manifests itself as a result of interactions of many individual behaviours. There is no room to impose the behaviour of the system directly by user, thanks to the parameterization of agents' behaviour. Its ability to display realistic processes, variety, behaviours and outcomes at different scales means that ABM can provide meaningful insights where many other methods cannot.

4. APPLICABILITY OF ABM TO BROWNFIELD REDEVELOPMENT

The employment of agents provides the opportunity to apply advanced behavioural models to simulate participants' behaviour in a more realistic way. Agents can be modelled as more advanced cognitive units, which are able to show pro-active behaviour, engage in long term planning and come to know about their environment. In addition, it is possible to model interactions and feedback effects at various levels (Ettema et al. 2007).

The approach we propose in this paper is based on defining agents' behaviour in the framework of brownfield redevelopment. According to Ferber et al. (2006) there are many actors in brownfield redevelopment that can influence brownfield reuse from several different levels: personal, local, regional, national and global (Ferber et al., 2006). All these interest groups need to be active and take part in enabling sustainable brownfield solutions.

In order to precisely define types of agents it is necessary to carry out stakeholder analysis, where the first step usually consists of stakeholder identification. Depending on which level the analysed brownfield site is considered, there will be different types of stakeholders defined for different case studies.

One of the most represented methods in stakeholder analysis is the interest-influence matrix (Reed et al., 2009). This method provides a classification of stakeholders that facilitates decision-making for the inclusion in participatory processes as well as setting priorities. This method can be implemented through surveys, workshops or on the basis of the criteria defined by researchers. After the types of agents are clearly identified, it is necessary to define their behaviour. Depending on the scale at which the research is conducted, inputs for agents' behaviour will be different. If the stakeholders are institutional entities, the input data could be well known as legal outcomes, while in the case of individuals, the defining of their needs requires additional research through questionnaires, meetings, interviews or employing other methods of participation. Individuals could be set to follow certain rules of movement, such as

avoiding obstacles (buildings, roadway, urban furniture…), selecting the desired destination, avoiding crowds or staying in sunny places etc. Through such rules and interactions different aggregate patterns emerge. The observation and analysis of the resulting outcomes can help in the process of predicting and deciding on the future development of brownfield sites. In other words, the main challenge lies in specifying agents' behaviour, and particularly, in choosing the rules they use to make decisions.

The approach proposed here can be appended to existing methods or employed as a standalone tool. The MCA tools can assist in the creation of decision-making algorithms of agent reasoning within ABM. Since the influence of the brownfield site location is as important for agents as their mutual interactions, spatial parameters could be obtained from some of the existing MCA tools. For instance, GIS might be used for preparation of inputs which are then passed to the modeling system, where the results of the model after the execution could be returned to the GIS for display and analysis (Crooks, 2010).

Figure 1 shows the schematic representation of possible interaction between conventional methods and the proposed approach. In order to create an agent-based model as a decision support tool for brownfield redevelopment, the following inputs are required: agents' behaviour rules, spatial brownfield framework and indicators. To define behavior rules, it is
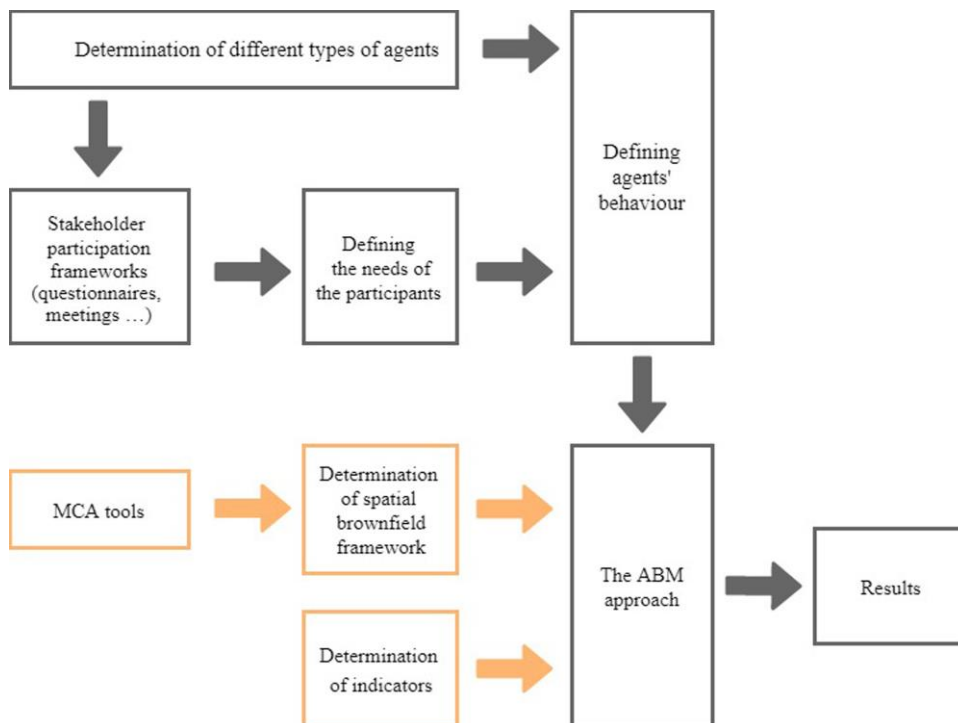

Fig. 1 Flowchart of interaction between conventional methods and the proposed approach
(Source: Authors)

first necessary to determine the groups of agents and their needs. Stakeholder participation method can be used for identifying agents' needs through questionnaires, meetings, workshops etc. On the other hand, spatial brownfield framework can be obtained with the help of MCA tools, as stated above. Indicators can also be defined separately or with the help of some already existing groups of MCA tool indicators. Since different aims of heterogeneous interest groups have to be considered in connection with different sites, their sustainability cannot be evaluated using a fixed checklist of indicators (Bartke and Schwarze, 2015). Through the direct interaction, agents exchange information which can give rise to new knowledge or ideas. This new cognition may lead to the agent reacting and pursuing a new form of behaviour to reach its goal. That implies that indicators should be determined for each project individually, depending on the types of input parameters. Such a defined approach allows generating various possible scenarios of brownfield redevelopment.

The conventional methods described in Chapter 2 are generally post-completion assessment tools and they can help in choosing alternatives but cannot generate them themselves. Only SINBRA-SAT uses an algorithm to generate possible land use combinations, but it is limited to three fixed land use types. The ABM method could use different types and different number of land use, which would be established for each project individually. Also, the proposed approach could integrate both categories of decision support systems for brownfield redevelopment (MCA tools and stakeholder participation methods and techniques), unlike most of described existing tools. Compared to the approach developed by Beames et al. (2018), the ABM method could include other aspects of social indicators in addition to the physical ones, depending on the identification of the type of participants and their needs.

5. CONCLUSION

The greatest asset of ABM is its ability to model complex social phenomena. By generating heterogeneous individuals who can communicate with other individuals and the environment, we can monitor the emergence of new patterns or trends. This offers the possibility of creating new insights and knowledge about the direction in which the analysed model might develop in the future. Agent-based models cannot predict the future, but they can be helpful in better understanding of how a process might play out under a particular set of circumstances (Lawlor and McGirr, 2017).

In the context of brownfield redevelopment the emphasis is put on development of participative modelling as an interactive process that involves relevant stakeholders at every stage of model development. In such a model each agent ought to be able to proactively respond to changes in their environment. This flexibility is mitigated by the risks of making over-complicated models, as the final result is the product of a huge number of individual decisions. In proposed approach agents are rationally bounded, that is to say they do not have a universal knowledge but only that specific to their context. In that way it is possible to avoid too complicated models and provide only targeted outcomes. In this sense, the key task in this type of modelling is to define and manage input data appropriately. It can also be used in combination with other, conventional approaches to design the model environment.

Unlike conventional modelling approaches, there are no standard elements that can be used from the model library. Every ABM is different and the modeller must have sufficient

programming knowledge and experience. Therefore, determining the input parameters is the greatest challenge of the proposed approach since defining of indicators is also dependent on it. On the other hand, this approach provides generating a lot of different possible scenarios as well as their optimization through simulations.

There is no formal methodology for evaluating agent-based models, hence ABM results demand a comprehensive examination and represent a significant challenge for the researchers. The evaluation of specific planning strategies outcomes, performed by urban planners and policy makers, can be supported by informative assistance of geospatial simulations.

In order to evaluate the ABM model properly, it is not sufficient just to estimate the model results, but it is necessary to evaluate the behaviour of individual agents as well (Crooks Heppenstall and Malleson, 2018). The emergence of big data through sources like social media has given rise to sensitive individual-level data that offers a potential resolution to the problem of evaluation of these models. It remains to be seen whether this possibility is taken up. What is certain is that the ABM is accepted as a research tool, which provides us with new way of thinking and understanding about how urban systems have developed and what the consequences of future individual behaviours are likely to be. As such, ABM is capable to be applied to generate different solutions in the context of brownfield redevelopment at various spatial scales.

In Serbia, issues related to brownfield sites are particularly noticeable in the last two decades due to the deindustrialization caused by the privatization and followed by economic blockades and the devastation of war in the 1990s. There is still no comprehensive strategy and management platform for brownfield redevelopment at the state level. In this regard, this paper could be the basis for further research in making it easier to find a solution for the treatment of this problem.

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MODELOVANJE ZASNOVANO NA AGENTIMA KAO ALAT ZA PODRŠKU U ODLUČIVANJU U PROCESU OBNOVE BRAUNFILD LOKACIJA

U savremenim urbanističkim studijama fokus se stavlja na održivi urbani razvoj i dugoročne strategije razvoja. Rješavanje pitanja obnove braunfilda je od vitalnog značaja za prosperitetnu praksu urbanističkog planiranja. Konvencionalne metode odlučivanja u procesu obnove braunfilda uglavnom se koriste za procjenu situacije na terenu, ali ne i za buduće razvojne planove. Cilj ovog rada je da razmotri potencijalnu primjenu modelovanja zasnovanog na agentima (ABM) kao alata za podršku u odlučivanju u procesu obnove braunfild lokacija. U ovakvim modelima agentima se zadaju određena pravila ponašanja koja definišu njihove međusobne interakcije i omogućavaju simulacije u prethodno definisanom prostornom okviru. Dobijena kolektivna ponašanja utiču na prostorne obrasce kroz interakcije pojedinaca, što se ogleda u činjenici da je ponašanje agenata individualno i ne može se poistovijetiti sa krajnjim ponašanjem grupe. Ovaj alat nam pruža mogućnost sagledavanja mogućih scenarija budućeg razvoja braunfild lokacija i, shodno tome, donošenje adekvatnih odluka i strategija.

Ključne reči: *braunfild, agentno modelovanje, sistemi podrške odlučivanju, urbani razvoj*