Computers, Environment and Urban Systems xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Computers, Environment and Urban Systems

journal homepage: www.elsevier.com/locate/ceus

A multi-scaled agent-based model of residential segregation applied to a real metropolitan area

Babak Mahdavi Adrestani[a,*], David O'Sullivan[b], Peter Davis[c]

[a] Research and Innovation/ School of Business, Law and Communications, Southampton Solent University, United Kingdom
[b] Department of Geography, University of California, Berkeley, USA
[c] Centre of Methods and Policy Application in the Social Sciences, The University of Auckland, New Zealand

ARTICLE INFO

Keywords:
Agent-based modelling
Multi-scaled modelling
Complex urban system
Residential segregation
Plurality index
Housing vacancy dynamics

ABSTRACT

Residential segregation influences many aspects of urban life. It affects people's access to centres of education, healthcare, business and determines the composition of our neighbourhoods, thereby impacting our social network and urban structure. In order to understand the potential impact of policies on residential segregation and complex urban system, a dynamic modelling support tool would be essential. This research article presents a multi-scaled agent-based model capable of simulating the relocation of residents of a representative population of a large urban area in a realistic environment for investigating the dynamics of residential segregation. Using an experiment, we show that this data-driven model can replicate plausible residential distribution and segregation patterns observed in the Auckland region (New Zealand's metropolis). Simulation outcomes are promising, demonstrating the potential of the model for investigating practical policy-relevant questions and acquiring valuable insights into the future state of the urban mosaic landscape and causes behind residential segregation dynamics.

1. Introduction

As segregation has become an important feature of a modern city (Batty, 2010), our understanding of its causes, role and impact on the social and urban fabric of our societies remain relatively limited (Bruch & Mare, 2006). Yet, our ability to accurately model, measure, understand and anticipate segregation would be essential in having a more equitable distribution of public services and better social cohesion in the society.

The pioneering work of Thomas Schelling (1969, 1971) was an important milestone in investigating this multifaceted phenomenon (Clark, 1991). It built the foundation for an individually-based modelling (Crooks & Heppenstall, 2012) investigation focusing on the actions of *agents* (persons/ household embodiments) who made choices regarding where to relocate and live in the simulated world. Although many of these *abstract* models help us think about the "real world" (Fossett, 2011), the unrealistic and simplistic nature of artificial worlds in Schelling-style models has prompted "questions about how well they portray the neighbourhood dynamics of real cities" (O'Sullivan, 2009, p. 507). As a result, there are indications in the recent years that residential mobility and segregation modelling development point towards more realistic trends and their applicability to real urban areas.

This more realistic modelling approach is often comprised of four key dimensions: 1) more representative spatial characteristics; 2) use of real/empirical data; 3) more consistent and reliable evaluation (e.g. calibration and validation) against empirical benchmarks; 4) broader *explanatory factors* (determinants).

A model with more realistic characteristics has several advantages. Since "the outcomes of residential segregation models may strongly depend on the way that neighbourhoods are conceptualized and represented" (O'Sullivan, 2009, p. 508), it would be more consistent to use/ integrate real-world data which correspond to the same administrative spatial boundaries based on which data are collected (Rolfe, 2014).

Subsequently, the combination of "real data along their spatial characteristics is the ultimate form of model validation" (Stanilov, 2012, p. 258), as the evaluation of the model would naturally become more intuitive and reliable. Furthermore, inclusion of more explanatory factors in the model would enhance the overall realistic trait of the model, not the least because of the possibility of comparing the effects of the implemented mechanisms on the empirical and historical benchmarks. Overall, a more realistic model has higher potential to communicate its insights more effectively and engage easier with policy-makers (Stanilov, 2012).

* Corresponding author.
E-mail address: babak.mahdavi@mail.mcgill.ca (B. Mahdavi Adrestani).

https://doi.org/10.1016/j.compenvurbsys.2017.11.002
Received 28 April 2017; Received in revised form 3 November 2017; Accepted 9 November 2017

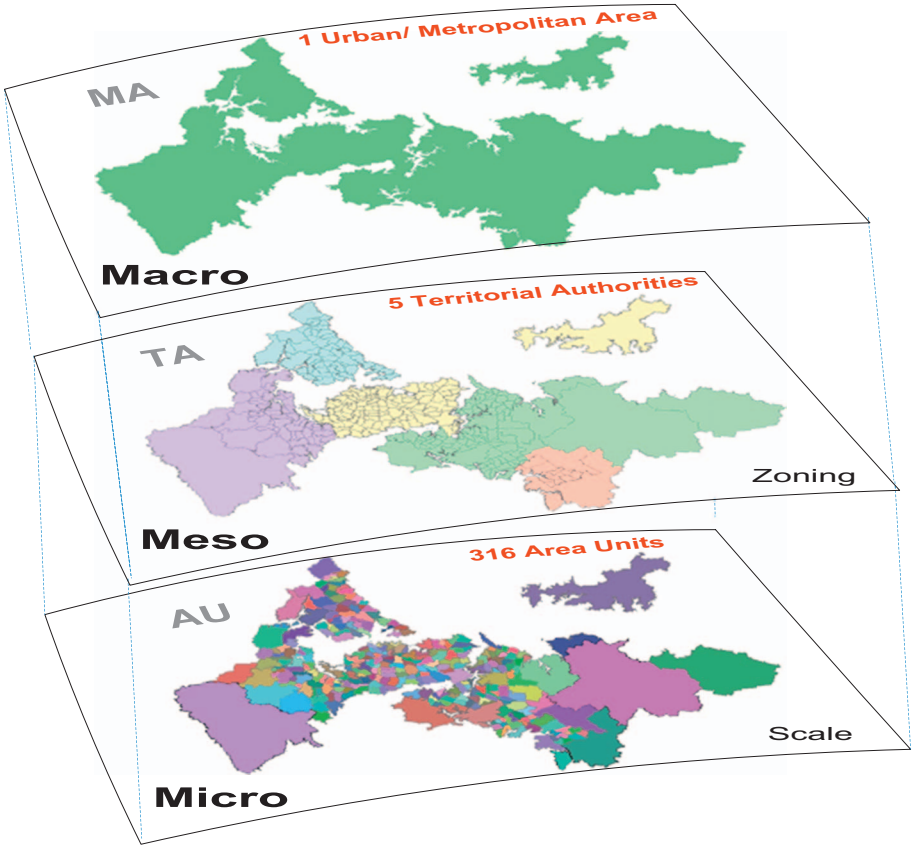

Fig. 1. Multi-scaled modelling approach

Among agent-based models (ABM) in the residential segregation sphere, the pioneering work of Benenson, Omer, and Hatna (2002) has set a high standard for subsequent work (Bruch, 2014; Crooks, 2010; Feitosa, Le, & Vlek, 2011; Yin, 2009).

However, a comprehensive assessment of changing patterns of residential segregation should preferably allow a thorough examination at different *inter* and *intra* levels of spatially nested entities (Parisi, Lichter, & Taquino, 2011). The geographical scale (e.g. divisions of a subdivided metropolitan area) can portray distinct dimensions of residential segregation (Reardon et al., 2009). A model with multi-scaled capability (illustrated in Fig. 1) will allow the investigation of segregation patterns on both *macro-segregation* (e.g. Metropolitan Area) and *meso-segregation* (e.g. Territorial Authority), based on their encompassed micro-spatial units' subdivisions (e.g. Area Units).

Similarly, the interpretation of shifting patterns of residential segregation and its social implications based on a single measure can be considered incomplete. Since there exist various paradigms and interpretations of segregation (Simpson, 2006), it is desirable to measure several dimensions of segregation (Massey & Denton, 1988; Reardon & O'Sullivan, 2004) in order to acquire more comprehensive portraits of the ethnic mosaic state in the *meso* and macro geographical entities of the urban area.

This research article presents an agent-based model of residential segregation which contributes to the same realistic modelling direction for analysing the effect of residential location decision of individual residents (agents) on the spatial ethnic mosaic pattern of the central Auckland region (New Zealand metropolis).

The following lists original features of the model. Firstly, the model deals with the entire population sizes based on census values, although only the relocating agents (informed by census mobility values for each ethnic group) are stochastically instantiated and make decisions about their residential location. Secondly, the model dynamic of residential location choice comprise of the main contextual mechanisms, including group and personal preferences (e.g. behaviours conditioned by *bounded rationality*), empirical vacancy rates (as proxy for combination of real estate market condition and (local) government policies related to new housing development), as well as economic conditions (by empirically informed proxy of residents' economic circumstances to relocate locally or globally). Thirdly, while *intra*-urban migration (movements by existing population within the boundaries of the urban/ metropolitan area and evidently its smaller spatial nested entities) takes place indigenously, *inter*-urban migration (movements between population of an external urban area and the simulated metropolitan area) has exogenous effect on the simulation dynamic, exhibiting an open urban system. Lastly, the effects of simulating residential decision-making of four major ethnic groups on various dimensions of segregation are measured and calibrated against their equivalent census-based benchmarks, before the simulations are projected into the future using Statistics New Zealand population growth projection estimates at meso-geographical scale as the base of segregation forecasting scenarios.

Thereby, the model is able to simulate future scenarios depending on changes in overall and ethnic-based population growth conditions and their distributions, including factors which are more susceptible to be influenced by macro (state, institutional) actors (such as control of international immigration, population birth rate, housing development/ vacancy rates), as well as micro (individual) actors (such as changing preferences of relocating residents).

In this article, we focus on presenting the following experiments and results. First, we show that the model is capable of generating patterns that are fairly comparable to the empirical benchmarks built from the application of multiple measures of residential segregation on several quinquennial periods of census data, notwithstanding detailed mechanisms regarding residential decision making are not fully present (implemented). Then, we use various experiments with the model to show that 1) higher population growth (and immigration) does not necessarily (automatically) exacerbate the intensity of residential