

MODELLING THE IMPACTS OF URBAN UPGRADING ONTO POPULATION DYNAMICS IN INFORMAL SETTLEMENTS

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ABSTRACT:

Nowadays the biggest part of urbanization is taking place in cities of the global south, where urban development often occurs as informal settlements. Thus, it is crucial to envision possible urban futures for these highly dynamic urban areas. Urban upgrading is discussed and already implemented in order to improve livelihood conditions in these areas. However, urban upgrading might lead to unexpected effects such as increased segregation. Therefore, it is necessary to understand the effects of improved infrastructure provision onto residential mobility and resulting spatial patterns of population distribution. For a better understanding of the on-going urbanization processes and for informing local policy makers, suitable modelling tools that make use of up to date spatial information are needed. In the paper, a spatially explicit agent-based model (ABM) for simulating the development of informal settlements will be presented. The ABM is being developed for the context of Sub-Saharan Africa, which shows both the highest annual urban growth rate and the highest slum growth rate in the world (UN Habitat 2006). It will be used to derive policy scenarios for urban upgrading in informal settlements.

KEY WORDS

Urban upgrading; Informal settlement; Agent-based model, Sub-Saharan Africa, urban development

INTRODUCTION

Nowadays the biggest part of urbanization is taking place in cities of the global south, where urban development often occurs as informal settlements (Martinez et al., 2008, UN Habitat, 2009). These areas often face high and still increasing population density and non-existing or low-quality public infrastructure, leading to severe public health problems and low quality of life for their inhabitants. Thus, it is crucial to envision possible urban futures for these highly dynamic urban areas.

Urban upgrading is discussed and implemented in order to improve livelihood conditions in these areas (Satterthwaite, 2012). However, urban upgrading sometimes leads to unintended negative effects such as increased segregation or rising living costs. It might even create a vicious cycle of higher attractiveness of upgraded settlements, increased in-migration into these settlements and thus even worse living conditions (Abbott, 2002, Minnery et al., 2013). Therefore, it is necessary to understand the effects of improved infrastructure provision onto residential mobility and resulting spatial patterns of population distribution for informing local policy makers.

Using suitable modelling tools is one way of analysing the effects of urban upgrading. Only a modelling study allows for analysing the impacts of different set-ups of upgrading programmes in a comparable way while avoiding the ethical dimensions of real-world experiments. Agent-based models (ABMs) are a helpful approach to simulate the effects of urban upgrading onto the behaviour of residents: In ABMs, individual entities (“agents”) take decisions while considering both their environment and their interactions with other agents (Parker et al, 2003). Using this modelling technique, residents of the city can be represented with their individual decisions and their interactions with other residents and their surroundings.

The aim of this conference paper is to introduce InformalCity, an ABM that simulates the effects of urban upgrading onto the behaviour of residents of an artificial city. InformalCity has been developed for the context of urban informal growth in Sub-Saharan Africa. The remainder of this paper is organised as follows: In the next section, we introduce the context of informal settlements in Sub-Saharan Africa. This is followed by a description of the InformalCity model, including the household agents and the urban upgrading options. Preliminary simulation results are given. The paper closes with a discussion of the results and conclusions.

URBAN INFORMAL GROWTH IN SUB-SAHARAN AFRICA

The Sub-Saharan African region has been experiencing an unprecedented urbanization process over the last 40 years as a result of inherent demographic processes of natural population growth and rural-urban migration. Prolonged declining of economic performance, political instability and a weak statutory planning system have exacerbated associated problems of rapid urbanization in the region (Kombe & Kreibich, 2000). This has led the majority of the urban population, especially the urban poor, to live in a condition of informality. It is estimated that about 70% of the urban population lives in informal settlements. Main reasons for the massive occurrence of informal settlements are next to high urbanization rates also slow economic growth rates and generally weak institutional frameworks.

Urban informal settlements in Sub-Saharan Africa can be defined by two basic characteristics: the housing is illegally built and/or few services and community facilities are built in the immediate

neighbourhood (Sheuya 2009). Sliuzas (2004) describes the growth process of these settlements as a gradual incremental process of individual land transactions between traditional (rural) land owners and households seeking to build a new house in the city or in the urban fringe. Though the resulting urban patterns often seem to be very spontaneously developed and disordered, they are influenced by a number of physical, economic, and cultural factors (Sliuzas 1988), which can form the basis for a modelling approach.

EXISTING ABMS FOR INFORMAL SETTLEMENTS

Compared with the diversity of ABMs for urban sprawl in the developed world (Schwarz et al. 2010), only few models exist on simulating informal settlements or slum formation in developing countries. These are grouped in two categories: empirical or theoretical ABMs. Empirical ABMs focus on one specific case study and aim at mimicking (mostly spatial) details of that specific case study as precise as possible. Empirical studies differ with respect to spatial scale: Some authors focus on single settlements within the city. For example, Augustijn-Beckers et al. (2011) simulate the spatial location of individual houses in the Manzese settlement in Dar es Salaam, Tanzania, while Young and Flacke (2010) focus on the settlement Hanna Nassif in the same city. Others simulate the whole city: Feitosa et al. (2010) use their simulation model to explain patterns of income segregation, using the example of Sao Jose dos Campos, Brazil. Hosseinali et al. (2013) analyse the growth of Qazvin city, Iran. Finally, Xie et al. (2005) investigate the effects of rural population changing their lifestyles in the city of Wuxian, China.

Theoretical models aim at explaining general patterns of development without referring to a specific case study. Garcia-Diaz & Moreno-Monroy (2012) simulate rural-urban migration in developing countries by explicitly analysing the effects of the informal employment sector and social influences. Patel et al. (2012) model slum development in inner-city areas and the periphery as the interplay of households, developers and politicians. Barros (2003) as well as Sobreira (2005) investigate the development of spontaneous settlements at the city-level, while the latter author also analyses the spatially explicit location of dwellings in non-occupied land in such settlements.

None of the ABMs found during the literature review explicitly tackles the effects of urban upgrading onto urban development. Therefore, InformalCity is a first step towards filling this highly policy-relevant research gap. The ABM shall help investigating general effects that different urban upgrading strategies might have on both the built environment and the population distribution. For this reason, InformalCity was developed as a theoretical ABM without referring to a specific case study. However, model rules were included with the background of urban development in Sub-Saharan Africa.

MODEL DESCRIPTION

OVERVIEW OF THE MODEL

The current version of InformalCity simulates an artificial city and does not represent a specific case study, even though empirical data have been used to inform the model setup (Young & Flacke, 2010, Sheuya, 2004, Sliuzas, 2004). This artificial city is assumed to be on a plain with a total of 25 districts spread over a quadratic grid of five by five districts. The CBD is located in the centre of the districts.

Each district consists of 100 plots of land of 250 m² size each. At the beginning of the simulation, the city is initialised with agents representing households. These households settle on a plot in one of the districts and can move to other plots in other districts in the consecutive time steps. Each time step represents one year.

When starting the simulation, users can set a number of parameters. On the one hand, these parameters refer to the initial household number and the annual population growth. On the other hand, users can choose if they want to include urban upgrading in the simulation and select from options such as timing of the upgrading and selection of target districts (see section on urban upgrading for details). During runtime, users can inspect the simulation results in the format of time series and grids or analyse the results stored on disk. The model is implemented in Repast Symphony Java 2.0.

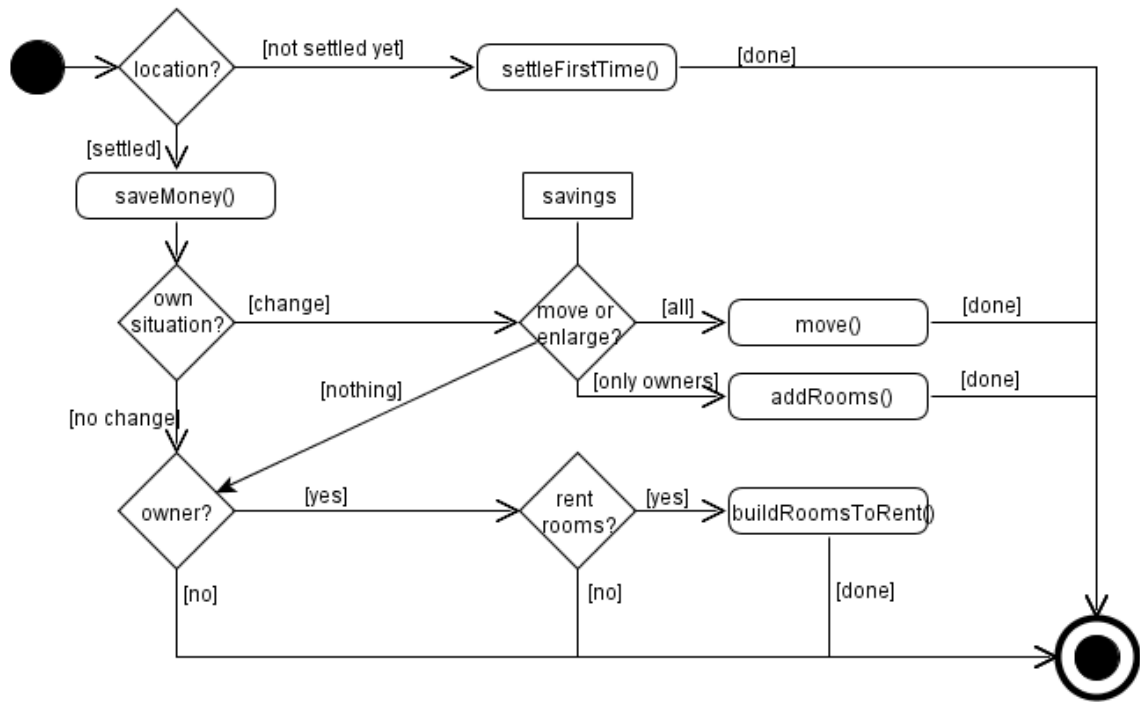
HOUSEHOLD AGENTS

The agents in InformalCity represent households. The initial number of households as well as the population growth rate is set by the user. The population growth rate currently represents both immigration and natural population growth and is meant as the annual increase in household numbers.

Households are either owners of houses or tenants, new households start as tenants and can later become owners (see below). Household agents have the following attributes: tenure status (owner / tenant), income level (low / medium / high), savings, preferences regarding their location choice (quality of public infrastructure, attractiveness of central business district - CBD), plot id of own home, number of occupied rooms, if also landlord: list of rented plots.

Once tenants are settled in a room for rent, they can move to another empty room for rent or move to an empty plot to build their own house. House owners have the options to a) add rooms for their own purposes, b) add rooms to rent them or c) move to another empty plot to build a new house. Both tenants and owners can also decide to stay in their current room / on their current plot. The decision making for one household agent in one time step is sketched in the flow diagram of [fig.1]. If agents are newly created, they settle for the first time: If they find a room to rent, they do so. Otherwise, they become owners and build a house (even without having enough savings), occupying one to three rooms. In the following time steps, agents save money by adding their income to their savings. If they own rooms that are rented to tenants, they further increase their savings. In the next stage of the time step, agents consider their own situation randomly: With 10% chance, they enter a decision making process, representing e.g. the arrival of new family members that can no longer be accommodated in the current location:

- If agents want to move and are owners, they move if they have enough savings to build in another district and have found a district that fits better to their needs than the current one. They can also enlarge their house to accommodate more family members.
- If agents want to move and are tenants, they become owners if they have enough savings to build in a district and have found a district that better fits to their needs. The latter is the case if a district has empty plots and has the highest utility (quality of infrastructure, distance to CBD) compared with the current one. If agents have too little savings, they stay tenants and move as a tenant to a new, more suitable district.
- If agents do not want to move, they can enlarge their house to rent out rooms if they are owners.
- Tenants who do not move do nothing else.



[fig. 1] Flow-diagram of agents' decision making

Agents choose districts by maximising the utility derived from them. The utility function combines infrastructure quality and distance to CBD in a multiplicative Cobb-Douglas function:

$$utility(x,k) = \sum_{i=0}^n preference(n,k) \times value(n,x)$$

with n: preference factor (quality of infrastructure, distance to CBD); x: district under consideration; k: agent. A decision tree is used to filter the districts that have empty plots / rooms and are affordable before entering the utility maximisation.

URBAN UPGRADING

In InformalCity, infrastructure quality depends on housing density. It is assumed that the relationship between infrastructure quality and density is asymptotic, thus being first robust against increasing density, but then decreasing rapidly with growing household numbers. In the model, infrastructure quality is computed per district, using the following formula:

$$infrastructure\ quality = \left(-\frac{1}{\pi}\right) \arctan(density - threshold) + 0.5$$

The critical threshold for a decline of infrastructure quality is an initial parameter which is tested during the sensitivity analysis (see results section). If maintenance of urban upgrading programmes is included, infrastructure quality is preserved in districts where upgrading has been implemented previously.

InformalCity allows for a detailed configuration of urban upgrading programmes in the city. Five different aspects can be considered by the user: timing of the upgrading, distribution of the upgrading, selection of target districts, maintenance and cost coverage.

- Timing of the upgrading refers to the start of the urban upgrading in the city: Is it implemented as soon as low infrastructure quality is detected or only if the majority of districts are affected?
- Distribution of upgrading relates to the way limited financial resources are spread over the city: Are upgrading efforts concentrated on few districts while aiming at high infrastructure quality, or are funds spread over a large number of districts while only slightly increasing infrastructure quality per district?
- Selection of target districts offers the possibility to steer the way districts are chosen for upgrading: Are target districts selected randomly or are low-quality districts upgraded with higher priority?
- Maintenance covers the aspect of stability of infrastructure quality after upgrading: Is the infrastructure quality acquired by urban upgrading preserved or can it decline again due to over-use?
- Cost coverage by residents, finally, relates to the question if residents of upgraded districts should be asked to financially contribute to the upgrading: Do residents in upgraded districts have to pay a fee for the enhanced infrastructure or not?

Table 1 summarises these aspects, the available options to choose from and their implementation.

[Tab. 1] Options of urban upgrading

Aspects of upgrading	Options	Implementation
Timing of upgrading	early	as soon as first district has infrastructure quality of less than 50%
	late	as soon as 50% of inhabited districts have less than 50% infrastructure quality
Distribution of upgrading	many districts with low quality	80% of districts → quality + 20%
	few districts with high quality	10% of districts → quality = 100%
Selection of target districts	randomly	random selection of target districts
	districts with lowest infrastructure quality	districts with lowest quality first
Maintenance	yes	infrastructure quality is preserved after upgrading
	no	-
Cost coverage by residents	yes	decrease savings of inhabitants by 1
	no	-

PRELIMINARY RESULTS

DYNAMICS OF URBAN DEVELOPMENT

The first part of the simulation runs focuses on a sensitivity analysis of the model. The aim of the sensitivity analysis is to check the plausibility of the modelling results and the sensitivity of the results to the initial parameter settings. Consequently, the initial parameters of the model were systematically varied for their influence on the model results. Tested parameters were the initial number of agents, the costs for building three rooms, the threshold for decreasing infrastructure quality, and the annual population growth rate. The range of tested parameter settings is given in Table 2. All possible combinations of parameters were analysed and repeated 10 times, leading to a total of 2880 simulation runs. For the sensitivity analysis, no upgrading programmes were included. For all runs, income is drawn from a normal distribution with mean 0.5, standard deviation of 0.25 and lower and upper limits of 0 and 1, respectively. Income classes of low, medium and high are assigned for thresholds of <0.25, <0.75 and 1, respectively.

[Tab. 2] Range of parameter values tested in the sensitivity analysis

Parameter	Values tested
Initial household number	1000; 1250; 1500; 1750
Costs for building three rooms	5; 10; 15; 20; 25; 30
Threshold for decreasing infrastructure quality [households per hectare]	10; 40; 70; 100
Annual population growth rate [%]	0; 5; 10

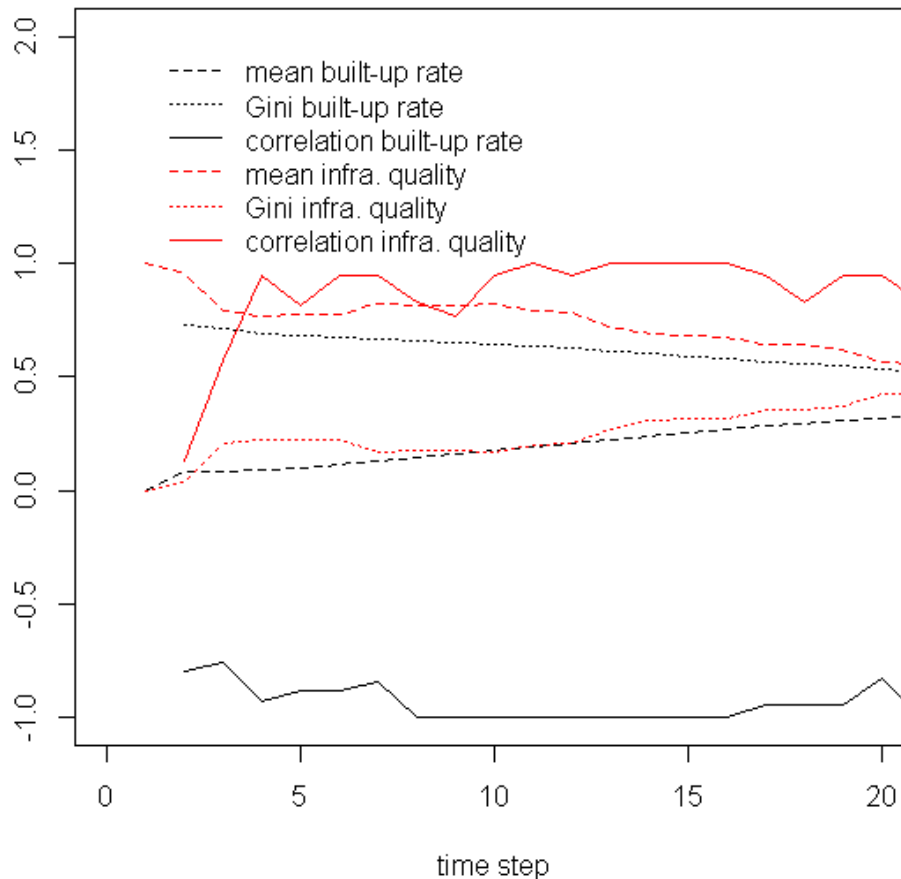
The results over 20 simulation steps for one example run are given in Figure 2. The sensitivity analysis was focused on a comparison of simulation runs after 20 simulation steps, and the runs were analysed regarding a) built-up rates and b) infrastructure quality.

a. The mean built-up area per district varies between 12 and 65 % and increases with the initial number of agents and population growth rate, while higher costs for building three rooms have a decreasing effect. The infrastructure quality-threshold has no effect on the mean built-up rate. In order to describe the spatial pattern of built-up areas in the city, the correlation between the built-up rate and the distance of a district to the CBD was computed. Negative correlations between -0.71 and -1.0 were found, indicating that built-up rates decrease with the distance from the city centre. The initial parameter settings had no impact on these correlations. Finally, the Gini-coefficient was computed for the built-up rate per district in order to describe spatial (in-)equalities between districts. The Gini-coefficient has a theoretical range of 0 to 1, with 0 indicating an equal distribution. The Gini-coefficient for built-up rates ranges between 0.07 and 0.77 in the sensitivity analysis. Increasing the number of agents, increasing population growth rate and increasing the costs lead to more equal distributions of built-up rates, while a higher threshold for infrastructure quality slightly decreases equality of built-up rates.

b. Mean infrastructure quality (ranging from 0.003 to 1.0) is influenced by all initial parameter settings: A higher number of agents and a higher population growth rate lead to lower mean infrastructure quality, while higher costs for building three rooms and a higher threshold of infrastructure decrease both increase infrastructure quality. The correlation between infrastructure

quality and distance to the CBD is positive, indicating lower infrastructure quality in the city centre, with a range of 0.09 to 1.0 independent of the initial parameter settings. Finally, the Gini-coefficient for infrastructure quality ranges from 0.0001 to 0.88. Inequality in the spatial distribution of infrastructure quality is increased by higher population growth rates, while higher costs for building three rooms and a higher threshold for infrastructure quality lower inequality.

[fig. 2] Overview of the results of one example run over time.



Parameter settings of this example run were: initial number of agents: 1250, costs for building three rooms: 10, threshold for decreasing infrastructure quality: 70 households per hectare, annual population growth rate: 5%.

To sum up, the results of the sensitivity analysis show plausible results for the model behaviour dependent on initial parameter settings. Spatial patterns such as decreasing built-up rates and increasing infrastructure quality from the city centre outwards are robust against changes in the initial parameter settings, while the dependence of mean built-up rate and mean infrastructure quality on the initial settings for household numbers and population growth is expected. Thus, the model seems useful to simulate basic patterns of urban development and can be tested for different urban upgrading options.

SCENARIOS OF URBAN UPGRADING

The second part of the simulation runs investigates the effects of urban upgrading programmes. The scenario runs were conducted with constant values for the initial number of agents (1250), costs for building three rooms (10), the threshold for decreasing infrastructure quality (70 households per

hectare) and an annual population growth rate of 5%. All urban upgrading options as described above were included in the scenario runs. All combinations of options were run 10 times.

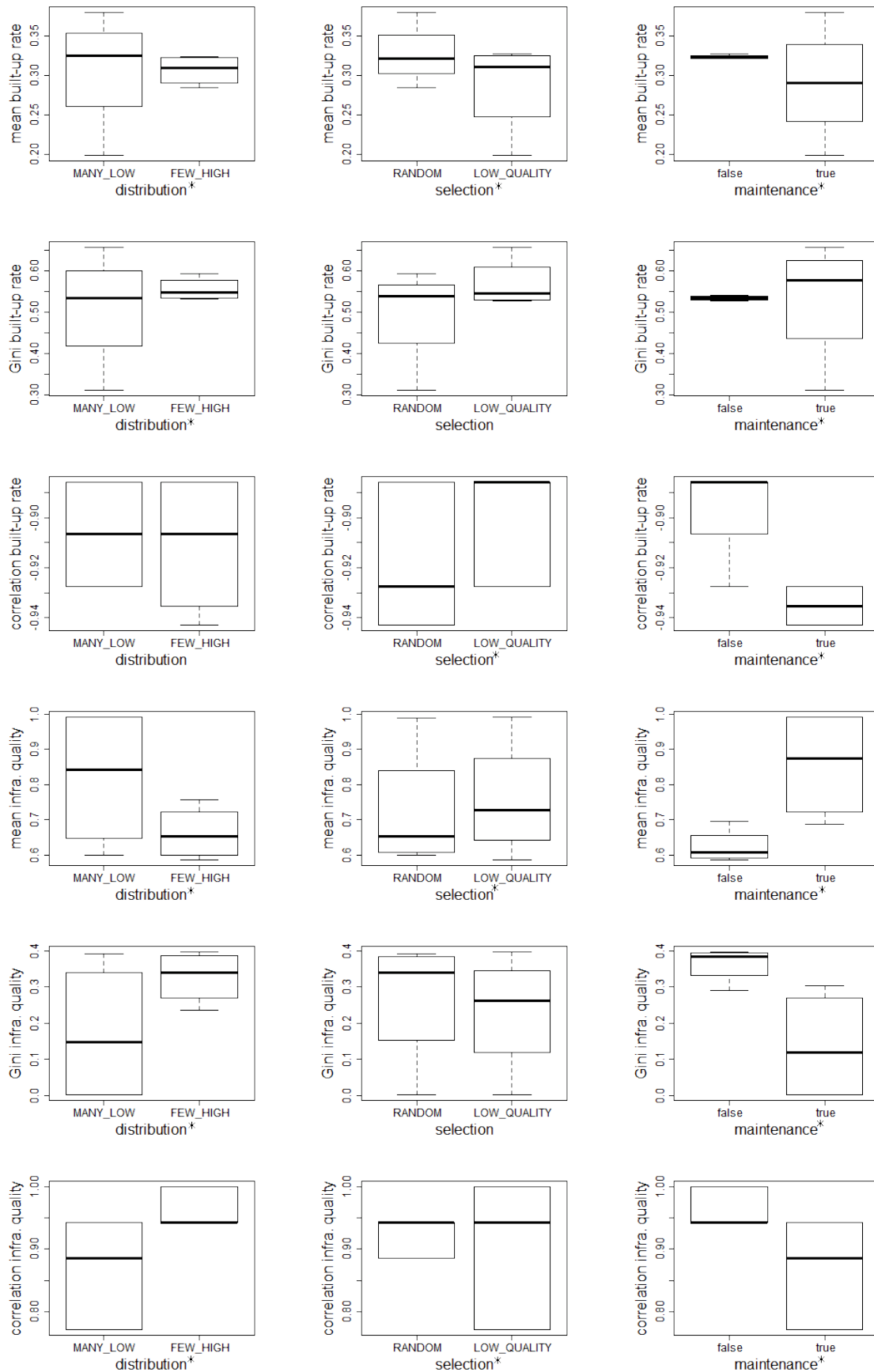
In order to analyse the effect of the upgrading options onto scenario results, statistical tests were performed to check for significant differences in the scenario outcomes. Wilcoxon rank-sum tests were used as the simulation results were not normally distributed. Figure 3 shows the boxplots for the main scenario results differentiated by the urban upgrading options and gives the results of the statistical tests. The different options regarding timing of urban upgrading and cost coverage did not have a significant influence on the results, thus boxplots are not given in Figure 3.

The distribution of the upgrading measures has a statistically significant impact on both built-up rates (mean and Gini coefficient) and infrastructure quality (mean, Gini coefficient, correlation with distance to CBD). Concentrating urban upgrading efforts rather in few districts, but with higher infrastructure quality, leads to an overall lower mean infrastructure quality with a higher inequality of infrastructure quality in the city compared to spreading urban upgrading over a larger number of districts, but aiming at lower infrastructure quality. Furthermore, the gradient of infrastructure quality depending on the distance to CBD is stronger, indicating a stronger contrast between inner-city districts with low infrastructure quality and peripheral districts with higher quality. Regarding built-up structures, this distribution option results in lower mean built-up rates with a higher concentration of built-up areas in the city.

Selection of target districts has a statistically significant impact on both infrastructure quality and built-up structures (for both, mean and correlation with distance to CBD are significant, differences in Gini coefficients are not). Selecting those districts with low infrastructure quality as targets for urban upgrading results in a higher mean infrastructure quality and a lower correlation with distance to CBD. This indicates that the decrease of infrastructure quality from the city centre outwards is slightly weaker. This selection option furthermore leads to lower mean built-up rates and a higher negative correlation between built-up rates and distance to CBD, showing that built-up areas are more focused on the city centre.

Maintenance has statistically significant effects on all results. Including maintenance in the urban upgrading results in higher mean infrastructure quality, a more equal distribution of infrastructure quality throughout the city and narrower gradient of infrastructure quality decrease from the city centre. Regarding built-up structures, maintenance for urban upgrading programmes leads to lower mean built-up rates and a higher concentration of built-up areas in the city centre.

[fig. 3] Boxplots for the results of the scenario runs on urban upgrading. Stars indicate statistically significant Wilcoxon rank-sum tests with $p < 0.05$.



CONCLUSIONS AND OUTLOOK

The aim of this paper was to introduce the ABM InformalCity which investigates the effects of different urban upgrading options onto the residential mobility in an artificial city. A preliminary sensitivity analysis suggests that the model produces plausible results. High household number and / or high population growth rate are drivers of increasing built-up rates and decreasing infrastructure quality. Costs to build new houses or to add rooms have the adverse effect, as higher costs lower built-up rates and increase infrastructure quality.

Further analysis of different urban upgrading options revealed that maintenance, selection of target districts and the distribution of upgrading efforts have significant impacts on both built-up rates and infrastructure quality in the artificial city. On the contrary, timing of upgrading and cost coverage had no effect on the simulation results. Explicitly differentiating these options of implementing urban upgrading will later allow for deriving recommendations for policy. For example, future simulation runs might confirm the preliminary finding that maintenance has a very clear effect on infrastructure quality and that spreading upgrading efforts over a larger number of districts increases overall infrastructure quality, but also mean built-up rates.

However, several limitations have to be mentioned for the current version of InformalCity: The model rules were developed for the context of Sub-Saharan Africa and might not be applicable to other regions. Furthermore, the current model does neither distinguish between formal and informal settlements nor does it explicitly indicate the development of informal settlements into slums. In order to do so, clear indicators on how to monitor slum development are needed. InformalCity offers variables such as household density, built-up density and infrastructure quality as variables that could be used for such an exercise. Finally, this conference paper presents only preliminary model results, while more investigations of model behaviour are needed for the next steps.

The next steps are on the one hand related to the current theoretical modelling approach of InformalCity. (1) The effects of income distribution on model results have to be included in a broader sensitivity analysis. (2) The sensitivity analysis as well as the analysis of urban upgrading strategies needs to include the effects on social segregation and population density. Both aspects are already included in the model output and need to be analysed further. (3) The scaling of model parameters (number of plots per district and initial household number) needs to be investigated to check if model results depend on the size of the city and its population. (4) The current implementation of urban upgrading options has to be re-considered. For example, cost coverage is currently implemented without any notice in advance. This means that household agents are forced to spend some of their savings for the urban upgrading and have no means to avoid the costs. In reality, households will anticipate rising costs and might choose to avoid them by moving to another district. On the other hand, it is planned to use the theoretical model also for a case study and to simulate the development of Dar es Salaam, Tanzania with empirical data.

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