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The Individual Agent Makes a Difference in Segregation Simulation

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***Abstract*–Urban social segregation modeling from the bottom up attempts at understanding the processes which take place when residents look for a new home. This micro-scale perspective thus requires implementing actual individual agents instead of socially unified communities with similar or identical behavior. Complementary, meso- and macro-scale determinants such as housing markets, estate agencies, urban planning institutions, and societal life-style preferences must be incorporated in order to comprehensively and adequately simulate residential mobility. The paper presents an attempt to simulate urban socio-spatial segregation for the city of Salzburg, Austria, by consistently taking the individual household scale into account. We first apply the beneficial features of a Schelling-style simulation model by also taking macro-social regularities into account. This is followed by a description of an adapted segregation model that includes the mentioned requirements. The paper concludes with an extensive presentation and discussion of the model results achieved so far.**

I. Introduction

The distribution of households in urban space, its underlying mechanisms, processes and spatiotemporal structures, is a complex phenomenon (see, for instance, [1], [2] as references for complexity science). The social and spatial patterns which arise and – subtly and dynamically – change over time, such as segregation, residential up- and down-grading, gentrification, places of inclusion and exclusion, are significantly influenced and determined by numerous rules, markets, political attitudes, and behaviors of different stakeholders. Attempts to model issues of households' location-allocation patterns and of simulating their processes have to take the three crucial domains of 'scales', 'entities', and 'interactions' explicitly into consideration to adequately analyze and evaluate how social and spatial forces are mutually linked.

The following paper presents an attempt at modeling and simulating processes of urban socio-spatial segregation by primarily focusing on the local scale of households, their interactions and decision-making when reflecting on the socio-spatial neighborhood setting compared with preferences and/or dissatisfactions. In so doing, the theoretical domain of the model's purpose is to highlight the individual acting conditions embedded into the context of intra-urban moves. An actor-centered modeling perspective appears to be important, because it makes the scope and constraints from the bottom up explicit and visible. This perspective, however, ought to be complemented by macro determinants, such as housing markets, the capitalization of these markets, Estate Agencies, urban planning strategies, as well as social norms and cultural attitudes towards life-style and neighborhood building, which affect individual decisions in a top-down manner. Putting emphasis on intra-urban moves is justified since they make up the majority of all residential mobility; for European cities, for instance, they vary between approx. 20 movers per 1,000 inhabitants in Irish cities and up to 121 in Finnish cities, per year [3, p. 252] (comparative data is from 1980). This remarkable range can be used as one indicator for the mutual relationship between the local-individual and global-social scale.

The methodological domain of the model's purpose is to comprehensively model residential agents as individual units. The Schelling-style segregation model serves thereby as a starting point and benchmark. One of the great benefits of this model type lies in its emphasis on emerging spatial patterns at the macro level which cannot be thoroughly explained by investigating the motives and interaction patterns at the micro level. The aim of this paper is to alter some of the agents' premises and neighborhood rules of evaluation and movement in order to strictly individualize the defined entity of households. The problem of many Schelling-style models is that they do not consistently account for the individual but refer only to collective acting. From the initialization of the model up to the agents' evaluation and decision to move, a homogenized rule setting procedure has been implemented.

In the remainder we first take a brief look at some of the macro-social regularities which determine the agents' power to act, followed by a discussion about the need to modify Schelling-style segregation models. An individualized model approach is then presented, describing first the agents' characteristics and then illustrating the effects by presenting some of the relevant model's results.

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II. The Macro Scale Of Segregation

The "Nature of Cities", published by Harris and Ullman in 1945, has changed economically, socially, politically, culturally, and geographically in structure, shape, meaning and function. With respect to the function of housing in general and the different socio-spatial patterns of segregation in particular several theoretical approaches have been developed putting the macro scale forces to the fore. One early but, to date, influential approach to investigate gentrification as a specific kind of segregation (which we are interested in here) is the rent gap theory [4], [5]. The core concern of this theory is a profit-driven economic explanation of the processes of social, cultural, and architectural upgrading accompanied by social homogenization of gentrified neighborhoods and the displacement of less affluent households. The emergence of a rent gap in city areas has been linked with suburbanization of urban agglomerations. "Inner-city decline and suburban expansion has therefore led to a **rent gap** – a disparity between the potential rents that could be commanded by inner-city properties and the actual rents they are commanding". [3, p. 145] Rent-gap-driven socio-spatial revaluation remains an important aspect in urban redevelopment, mainly as a consequence of the contemporary financial and economic crises. This in turn means that classical models, such as the Chicago model of urban structure are "[…] now largely redundant". [6, p. 128] On the other hand, an exclusive rent-gap perspective "[…] leaves little room for human agency or consumer preferences. Thus, by itself, the rent-gap theory cannot explain which cities, and which areas within cities, are most likely to be regenerated". [3, p. 146]

A different but closely related macro-scale approach, highlighting the processes of residential mobility and neighborhood change, is the concept of invasion-succession-cycles [7]. It describes the invasion of low-income households, referred to as pioneers (e.g. students, artists, alternative life-style people), into obsolescent city areas. During this phase a cultural revaluation, by establishing new and alternative stores (e.g., ethnic food restaurants) and services (e.g., galleries), and a modest architectural revaluation, the so called incumbent upgrading, takes place. A second cycle is being initiated by the invasion of gentrifiers who prefer the cultural atmosphere but dislike the built environment. Due to large-scale and costly architectural revaluation, often realized by large property development companies, housing becomes significantly more expensive, resulting in extensive displacement of less affluent households, including the pioneers of the first phase. Although this theory represents a socio-spatial generalization of city development which is often triggered by urban planning strategies and political desires of urban uniqueness under conditions of global competitiveness, it is simultaneously understood as a bottom-up approach to explaining individual preferences. It is, however, not a strict and pervasive individual perspective, but one that takes into account communities (milieus, life-styles) as more or less homogenous entities into [8, p. 66].

A further determinant influencing individual decision-making and agency is given with institutional stakeholders. [9]-[10], among others, claims an integrative approach for a theory of segregation by including a theory of social inequality, a theory of spatial inequality, and a theory of allocation of living space and city districts to households and social aggregates. Apart from builders, developers, mortgage lenders, and government agencies it is the Estate Agents who do play a crucial role within the network of mediators between sellers and buyers or landlords and tenants. Residential property management, insurance, data collection and analysis, and financing are only a few of the tasks they undertake and contribute to housing market mechanisms. "They are not simply passive brokers in these transactions, however; they influence the social production of the built environment in several ways. In addition to the bias introduced in their role as mediators of information, some estate agents introduce a *deliberate* bias by *steering* households into, or away from, a specific neighborhood in order to maintain what they regard as optimal market conditions. […] Thus the safest response for realtors is to keep like with like and to deter persons from moving to areas occupied by persons 'unlike' themselves". [3, p. 143] Though real estate agents complexify segregation processes one should keep in mind that simplified decentralized bilateral trading mechanisms, too, can exhibit remarkable complexity at the individual level, as is shown by [11].

There are undoubtedly several more approaches which deal with macro implications of segregation. One may think of the theory of fragmenting development which links global trends of economic and political developments to locally fragmented but homogenous processes of residential structuring [12]; other determinants are social housing policies, the public housing sector, or the creation of large housing complexes that give rise to influences on the individual scale of households. Though all these criteria are relevant to understanding segregation in a comprehensive way, it is usually difficult to represent them adequately. Apart from data availability at fine resolution and the necessity to suitably translate them into procedural code, it is sometimes hard to connect the (potential) knowledge to a valid synoptic unity (e.g., how do you weigh all the information properly?). The following model incorporates the above mentioned determinants in a fuzzy and approximate way by using rent price as a cumulative indicator which has been disaggregated by statistical techniques. This appears to be justified by the model's purpose, because it has its thematic priority in a comprehensive individualization of agents' agency.

III. With Schelling Beyond Schelling: Individualization of Agents

Urban segregation appears to be an amalgamation of smaller-scale intra-urban moves and larger-scale in- and out-migration. [3] refers to empirical results of intra-urban mobility which allow for some generalization in the search for regularities of social homogenization at the neighborhood scale. We refer to these regularities as a coarse framing of agents' social and spatial evaluation and decision-making behavior, in addition to the macro-social influential forces mentioned above. "The most significant regularities in intra-urban movement patterns […] relate to the relative *socioeconomic status* of origin and destination areas. The vast majority of moves […] take place within census tracts of similar socioeconomic characteristics". [3, p. 254] This result correlates closely with the distance of moves which have been found to be comparatively short, however, varying by income, tenure, ethnic belonging and suchlike. Another determinant is the distinction between voluntary and involuntary moves, which are not recognized as a sharp dichotomy in the following model (and voluntary moves are in themselves different, which causes ongoing discourses on the evaluation of 'voluntary' moves; see, e.g., [13, p. 36].

The search for a new home is commonly biased, too. Criteria such as living-space, tenure, dwelling preferences, built environment, and social neighborhood all need to be considered. In addition, the search space is strongly correlated with local knowledge about urban districts, influenced by spatial activity patterns and information sources (e.g., media, friends). "It follows that different subgroups of households, with distinctive activity spaces and mental maps, will tend to exhibit an equally distinctive spatial bias in their search behaviour". (ibid., p. 262) For the following model it is assumed that agents are flexible in their search space, being able to get information about living costs (the spatial rent domain) and the social status of neighbors (the social attitude domain) [14, p. 101].

Against this background the benefit of Schelling-style segregation models lies in its explicit focus on local circumstances as reasons for processes of socio-spatial homogenization. The model's purpose is directed towards the micro-macro link of individual agency [15], [16, p. 83]. The phenomenon that, if agents act according to their subjective aspirations of residing in close proximity to other agents with equal social characteristics, a global pattern arises which cannot be derived from these aspirations straightforwardly, is one of the most important results of Schelling's model approach. The detection of emerging segregation to a much stronger extent than individually anticipated and intended is, on the other hand, a result of a standardization of the individual agent.

For the development of a conceptual segregation model the difficulty is to combine methodologically true individual entities with socially similar characteristics and behavior. This challenge is framed by complex empirical knowledge. Just to give an example about the intentionality of contributing to socially homogenous neighborhoods: [17, p. 89], by highlighting a continuum of nearness and distance as a determinant for social relations, argues: "Therefore, for extensive co-residing as in modern cities, individuals have also developed subtle, complex and sometimes partially unconscious and unintended ways of dissociating from and discriminating against others". Contrary to this 'unconscious' and 'unintended' behavior effect, [18, p. 48] stresses an explicit desire "[…] for coherence, for structured exclusion and internal sameness […]", which in turn seems to be in contradiction with contemporary aims of living in vivid mutual supportive communities: "Innate to the process of forming a coherent image of community is the desire to avoid actual participation. Feeling common bonds without common experience occurs in the first place because men are afraid of participation, afraid of the dangers and the challenges of it, afraid of its pain". [18, p. 42] Both facets can be observed empirically, the latter, for instance, in gated communities and (partly) gentrified neighborhoods, while the former is more common in organically grown, multi-cultural urban neighborhoods.

A reliable conflation of individual agency (subjective opportunities for freedom with respect to aspirations, preferences, but also constraints) and social influences (power relations, cultural bias, or recognition of capabilities) in segregation modeling is justified by empirical experience and progressive debates on modifications and alterations of Schelling-like models [19]-[23]; for a review of these studies see [16, p. 83-87], [17, p. 88-97]. [17, p. 96] draws the conclusion "[…] that if individual preferences and perceived differences between groups refer just to one characteristic, such as ethnicity, religion or political position, and decision is binary, segregation is unavoidable and social integration is impossible". From a modeling perspective the unrealistic determination is due to the univariate reference and the binary decision scheme. Moreover, relaxing the causal link between the decision-threshold of (dis-)satisfaction and corresponding action should surmount the seeming inevitability of segregation.

Furthermore, the individual-community link complexifies the discussion about segregation when taking majority-minority relationships into consideration. In this case processes of inclusion and social cohesion can conflate with displacement, and political claims of integration and neighborhood diversity converge or diverge scale-dependently by quite similar transformations. From a model perspective it is very hard (or even impossible) to reasonably disentangle the bundle of interwoven processes and relations. "The language of 'preference' and 'tolerance' surrounding the Schelling model can give the appearance that such claims are being made. It is important to keep in mind that we could just as easily interpret the movement of minority households into friendly neighborhoods as arising from an inability to access neighborhoods with a high presence of the majority, a reading that would make the driving mechanism not preference but discrimination. Such debates are not about the model's outcomes but about its interpretation and what can be inferred from it". [16, p. 85]

To sum up: the consequent disaggregation of agents' characteristics and behavior towards the individual level is an attempt to avoid homogenous community building that derives deterministically from an *a priori* standardized setting of attributes which leaves agents indistinguishable. The inherent sameness of agents at the group level in the original model contains segregation within itself as a predictable outcome to some degree. Truly distinguishable agents do recognize social conditions, nonetheless, but they do it differently. We put the emphasis on similar agents acting similarly with regard to similar decision-making.

IV. The Segregation Model

The current version of the segregation model is a conceptual simulation model which serves predominantly as an instance to verify the model's purpose. It has been built to simulate intra-urban residential mobility in the city of Salzburg, Austria, by highlighting emerging patterns of socio-spatial cohesion. A quantity of census data from 2001 has been used to carry out a factor analysis followed by a cluster analysis. The data is applied to initialize spatial raster cell characteristics on an approximate empirical basis. The model will be further developed as soon as census data from 2011 are available (which is expected in July 2014). It is intended then to transform raster cell resolution to a 250 by 250 meter scale in accordance with the officially available data provided by the Austrian Statistics Authority [24]. A validation of segregation processes over the period of one decade will then be possible.

A. *Agents' Properties*

The entire agent population is subdivided into four different subgroups, representing cluster characteristics which have been derived from a factor analysis with 14 socio-demographic variables (e.g., education, age cohorts, religion, household size, nationality). Clusters represent demographic characteristics of the city of Salzburg at district level and have been disaggregated randomly at cell level.

The realization of creating individual agents refers to agents' characteristics and decisions as well as executed actions. With respect to characteristics, 'income' is used as a prototypical randomized variable using a normal distribution function with a small standard deviation to individualize an agent's economic situation. In addition to the variation of income within the four subgroups a variation between them has been applied. This is to vary the economic wealth of agents at the collective scale, representing social status.

Due to the normal distribution of income values there is no sharp distinction between agents as economically defined entities. In so doing, we included a second variable, 'attitude', which represents agents' social preferences (or disaffirmations) in a qualitatively generalized way; an agent's 'attitude' is represented by color. This is according to the idea mentioned above. The fluent transition of economic property (income) correlates with a clear distinction of the social characteristic (attitude) and allows for a reasonable diversity of agents; for instance, two red agents share the same attitude but differ in income, and a red and blue agent may have similar income, but differ in their attitudes.

The reference variable for every agent to derive its initial income is given with the 'rent' value of the cell (patch) in which an agent is situated initially. Thus, a valid relationship of agent-location interaction is achieved.

The evaluation procedure of an agent's neighborhood embraces the affordability of the current location and the (dis-)satisfaction with its neighborhood. Whilst in the first case agents must move if their income is less than the costs for housing, in the latter they are equipped with some flexibility when gauging neighbors' characteristics of income and attitude. The common approach in agent-based segregation modeling is a single unified threshold value which will be applied to all agents. In contrast to this approach we, first, use two thresholds (for income and attitude, separately) and, secondly, vary the values of income by applying a range of values around the mean income (the qualitative indicator of 'attitude' remains as a binary variable). The income threshold which, as mentioned earlier, represents the socio-economic status of an agent approximately, is then transformed by a normal distribution function in order to individualize the decision-making process for residential moves.

In addition, and different from traditional segregation modeling, we have inserted two more modifications. First, not all agents move even if they fulfill the condition of being dissatisfied. The reason for this can be justified with empirical observations: residential relocation is a complex fact involving lots of criteria which must be pondered deliberately and diligently (which is represented here quite inaccurate by just two dimensions). The desire of retaining social ties developed over a long period or the established familiarity of every-day activities may represent reasons which imply some inertial behavior though dissatisfaction is a significant counter force [3, p. 253]. Furthermore, even if one feels dissatisfied with one's current social and spatial neighborhood situation, relocation is not the one and only obligatory response to it. One may think of political activism or community engagement in order to improve local social well-being.

Secondly, and contrary to the first modification, agents may wish to move even though they might be satisfied with their current neighborhood. Reasons for such a decision might be the inheritance of a house or apartment, change of work place, family situation, life-style changes, or simply the search for the perfect home.

Agents who are economically not able to find an affordable dwelling in the city of Salzburg within a certain period of time are forced to move to the suburban region. In turn, agents with sufficient income can either return to the city or immigrate for the first time. With this procedure we have included migration in addition to intra-urban mobility.

B. Spatial Entities' Properties

Spatial entities (patches) represent housing costs as scaled values derived from cluster data. The scaling of values is based initially on a normal distribution and then adapted to the cluster characteristics. The data used represent a coarse approximation of the socio-demographic situation at census district level and is disaggregated statistically, but verified as a proven approximation by experts from city authorities.

C. General Model Issues

The model has been implemented in NetLogo 5.0.4 [25] and will be made public at the author's homepage (http://www.socialgeography.at) and OpenABM (http://www.openabm.org). The parameters 'income' of agents and 'housing costs' of spatial entities increase marginally per time step, i.e. there is an interaction pattern not only among agents, but also between them (the social domain) and the cells (the spatial domain). The latter type of interaction is currently implemented in an abstract way, because only a global trend of housing costs is included due to data availability restrictions. There is, however, no local modification of this global trend at the moment. One may think, for instance, of a higher/lower dynamic in areas of high/low status neighborhoods. What has been implemented, however, is an accidental above-average increase and decrease, respectively, of housing costs, whereby 5% of all patches are then affected by an increase and 3% by a decrease. The extent can be altered interactively, for the subsequent model results the increase is set to 20% and the decrease to 10%.

V. Selected Model Results

The resolution of the city is set to approx. 15,000 spatial entities inhabited by 150,000 citizens. A number of 6,000 agents is selected as potential intra-urban movers which is a conservative estimation of 4% of the total population. Initially, agents of all four subgroups are randomly distributed over the urban space, according to the price per patch, i.e., initially, every agent can afford the dwelling she/he is living in. Census districts are colored according to the cluster they belong to, representing housing costs which vary from cheap to expensive in the following sequence: brown-orange-blue-pink-green-yellow.

The standard model has the following settings: the proportion of each subgroup is the same (25%), the preferences of similarity for each group is 25% for 'income similarity' and 20% for 'attitude similarity'. Income and housing price growth rates are set equal to 0.5% per time step. 70% of actually dissatisfied agents actually move, but also 5% of actually satisfied agents do so. Two remarkable results are noteworthy: (1) Compared with a Schelling-type model, segregation is no longer a common phenomenon, being distributed evenly over the urban space (see Fig. 1).

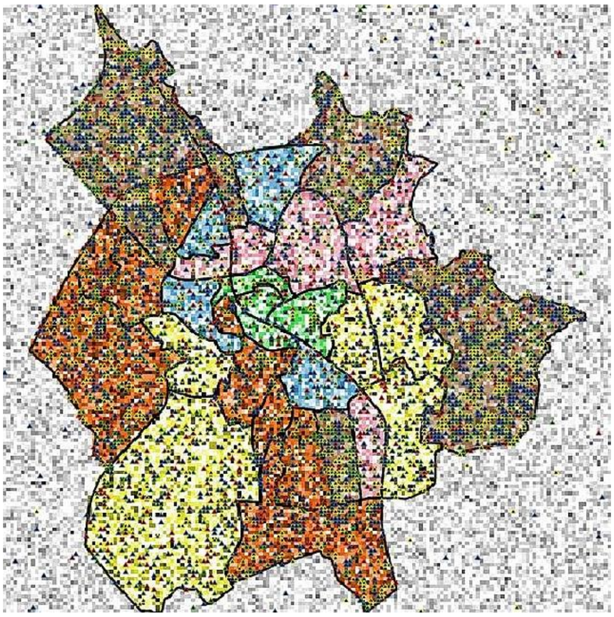

Fig. 1 spatial representation of segregation with the standard simulation model

Instead, segregation is concentrated in affordable districts (colored brown and orange), and its spatial manifestation is given at a small-scale level. In high-price districts (green and yellow) socio-spatial community building of similar agents is much harder to achieve, even for the most affluent (red agents). (2) Segregation takes place, notwithstanding. Ultimately different degrees of neighborhood evaluation, of decision-making processes and agents' as well as patches' characteristics do not avoid clustering of similar agents. The exceptional fact is the declining degree of segregation, most obvious for the least affluent (blue agents) and only very limited for the most affluent. As an attempt to interpret one might be tempted here to draw a distinction between involuntary moves, caused by displacement, and higher opportunities for freedom with respect to affordability, income and attitude preferences. For the current model there is only a qualitative statement of experts' empirical experiences, verifying the segregation clusters in the north of Salzburg, but of less scope in the eastern district. Other interesting results refer to the extent of outmigration to the suburban region, which significantly depends on the agent's income and the city's housing cost situation, and which is most problematic for the least affluent subgroup (see Fig. 2). Sudden dramatic rises of rents do affect all tenants in more or less the same way (Fig. 3).

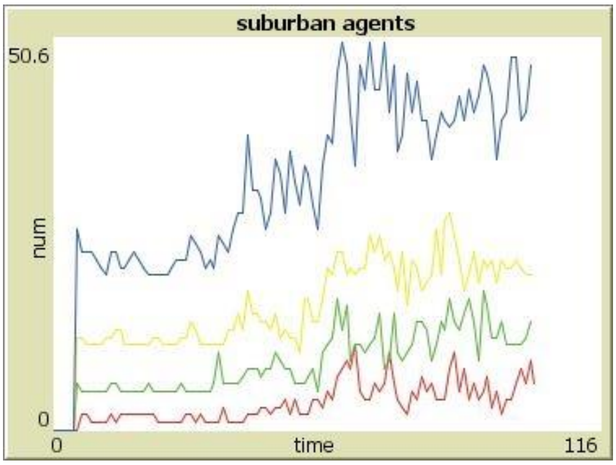

Fig. 2 number of agents expelled from the city (standard model)

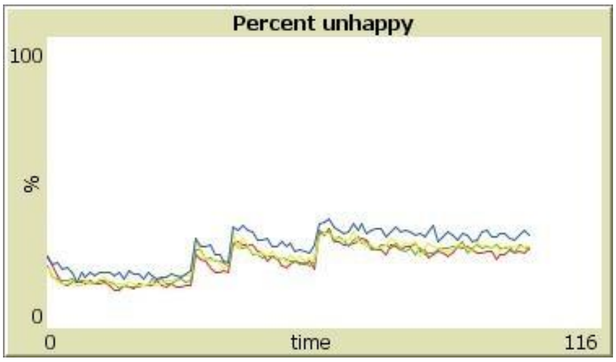

Fig. 3 proportions of agents dissatisfied and sudden increases of rent prices (standard model)

The standard segregation simulation model is provided with eleven parameters to modify and alter the behavior space of agents according to the theoretical requirements mentioned above. The behavior space, therefore, offers a wide range of opportunities for if-then-analyses and scenario building. In what follows four model variations which appear to be relevant for the (potential) emergence of segregation will be discussed briefly.

The first modification refers to the variation of the (individualized) thresholds of 'income' and 'attitude'. One hypothesis here is that the more affluent subgroups (red and green agents) appreciate higher degrees of income-similarity while the less affluent prefer higher degrees of attitude-similarity. Thus, income-similarity of red and green agents is set to 40%, and attitude-similarity to 15%. Yellow and blue agents' preferences are set to 25% for income-similarity and 45% for attitude-similarity. As Fig. 4 illustrates (with four sudden significant leaps of housing costs), a differentiation in the quality of preferences leads to two different levels of realized homogenous neighborhoods of similar agents. The trajectories of either two subgroups remain, however, relatively similar. It turns out that the emergence of neighborhoods with higher aspirations of income-similarity is less difficult to achieve than is the case for attitude-similarity. This can be explained with the continuous variance of the income variable which makes the arrangements of local co-residing much easier than for the dichotomous attitude variable, even in the case of individualized agents.

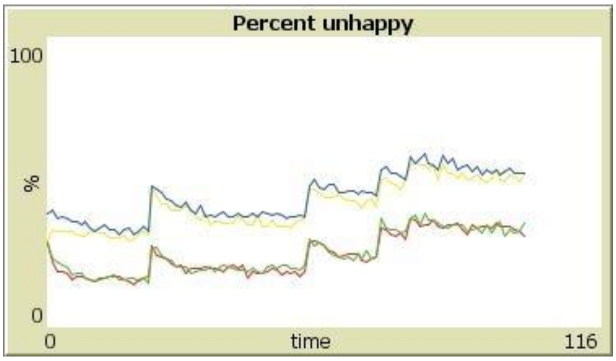

Fig. 4 proportions of agents dissatisfied and sudden increase of rent prices (change-of-preference model)

Segregation patterns are in part similar to the standard model – higher proportions of small-scale segregation have been evolved in the cheaper districts –, but are also different from that model, because red and green agents have now been more successful in the creation of homogenous neighborhoods. Finally, the effect of the cost jumps is different for the four subgroups (see Fig. 5); while for the least affluent agent population (blue) displacement is a cumulative force from the very beginning of the simulation, it is of only marginal relevance for the more and most affluent during the first half of simulation time and remains less influential in the second half.

The parameters that determine the proportion of unhappy agents who actually move and happy agents who move notwithstanding, are relatively insensitive. For the first case we varied the proportion between 60% and 90% without significant changes in the model output. The latter has been varied between 3% and 10%, again without significant changes. These results hold true if the preferences for income-similarity and/or attitude-similarity are being varied (between 20% and 40% for both kinds across agents' subgroups).

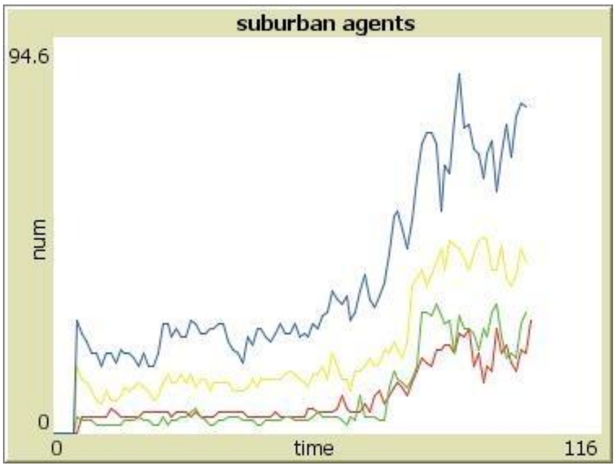

Fig. 5 number of agents expelled from the city (change-of-preference model)

A third variation of the standard simulation model considers the independent variables of 'increase of income' and 'increase of housing costs' as influential for neighborhood composition. Income-similarity and attitude-similarity is set to 35% for every subgroup. If income development is substantially higher than the development of housing costs (the subsequent model used an earnings growth of 0.7% per time step and a growth of housing costs of 0.3% per time step) then the more or less expected result is that all subgroups are able to live in the city. The differences between groups are marginal and even sudden leaps of rising prices do not affect agents' residential behavior significantly (Fig. 6).

In fact, the percentage of dissatisfied agents is decreasing slightly. Furthermore, even small clusters of homogenous neighborhoods of medium- and high-income households in more expensive districts have evolved. The situation changes with a reverse relationship, but less significant than expected. Remarkably, the four subgroups do not differ in their capability to create homogenous neighborhoods (Fig. 7). Sudden changes of housing costs do, however, influence this capability explicitly; in the simulation illustrated in Fig. 7 the percentage of unhappy agents increases from approx. 37% before up to 63% after the price jump.

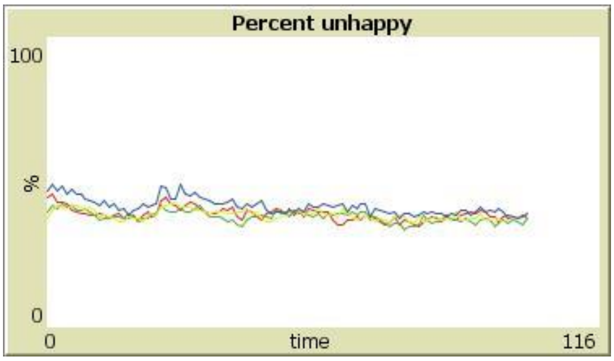

Fig. 6 proportions of agents dissatisfied and sudden increase of rent prices (change-of-income-cost relationship model), with 0.3% / 0.7% cost-income-rise relationship

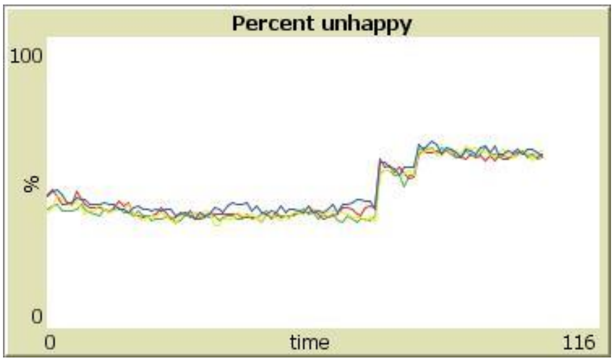

Fig. 7 proportions of agents dissatisfied and sudden increase of rent prices (change-of-income-cost relationship model), with 0.7% / 0.3% cost-income-rise relationship

The last variation takes the range of action of minorities into account. A first modification refers to the situation of having one minority in the city, starting with the least affluent subgroup (blue agents). They represent 10% of the urban population while the other three subgroups make 30% each. The poor minority wishes to live in a neighborhood of at least 50% of agents sharing a similar attitude; its aspiration towards income-similarity is comparatively low (20%). The remaining subgroups all have a relationship of 35% income-similarity and attitude-similarity, respectively.

Surprisingly, the poor minority does not have completely different troubles in dealing with its preferences of co-residing (Fig. 8) though there are fewer opportunities because of the small size of this group. The size of the group might be a suitable explanation for this result since majorities – primarily the socially adjacent group of yellow agents with slightly higher income and less restrictive preferences – are more powerful competitors in the housing market. Rent gaps and public housing allocation policy, as mentioned above, may contribute to amplify or mitigate this competitive change in socio-spatial distribution. Fig. 9

confirms this thesis in part: the competition among the three relative majorities outperforms the competition between them with the minority.

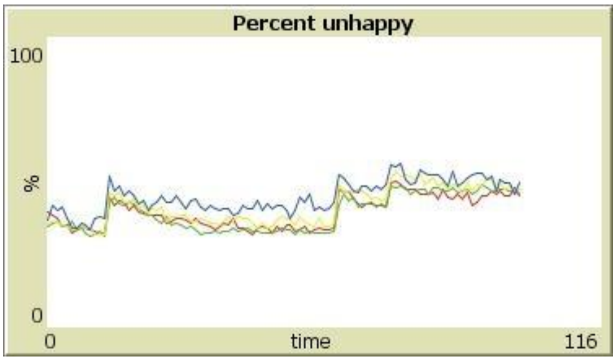

Fig. 8 proportions of agents dissatisfied (poor-minority model)

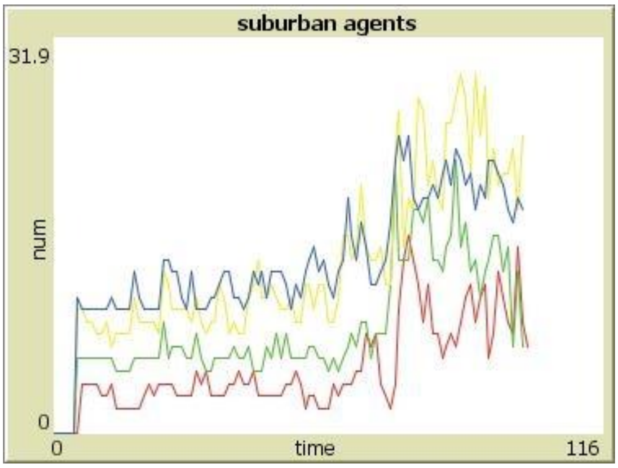

Fig. 9 number of agents expelled from the city (poor-minority model)

If the most affluent subgroup in the city is in a minority situation – and their aspirations are more directed towards income-similarity (50%) and less towards attitude-similarity (20%) – then the underlying principle does change visibly: the affluent agents do much more to achieve their preferences, and the percentage of unhappy fellows is significantly larger than it was for the poor agents (Fig. 10). Simultaneously, the least affluent agent group exhibits a contradictory fact: on the one hand it is much easier for them to segregate themselves in the affordable districts; on the other hand the number of expelled agents is much higher than it is for the other three groups (Fig. 11). One explanation might again lie in greater competition between socially and economically similar communities of the same population size.

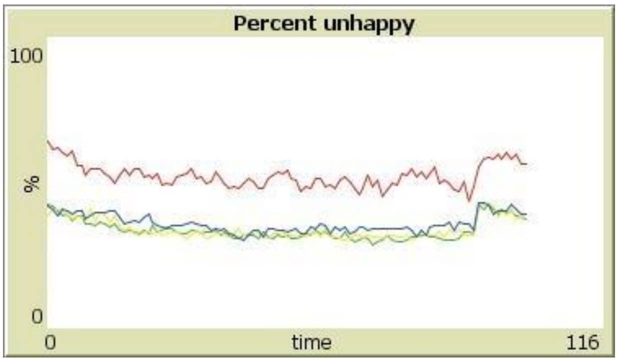

Fig. 10 proportions of agents dissatisfied (rich-minority model)

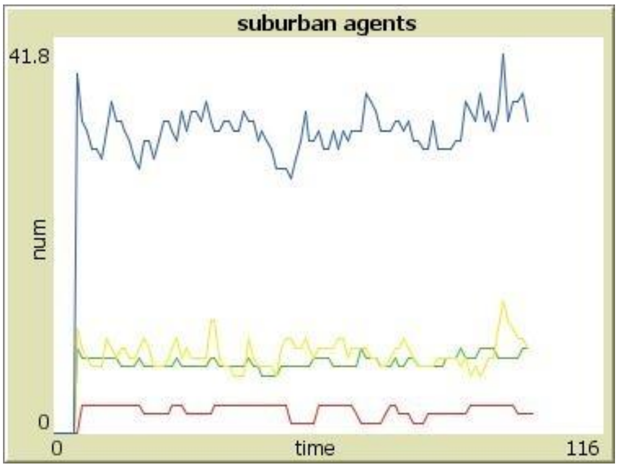

Fig. 11 number of agents expelled from the city (rich-minority model)

The second modification of majority-minority relationship investigates the constellation of two minorities. In the first scenario the most and least affluent agent groups find themselves in a minority position. While the richest agents prefer income-similarity (50% compared with 20% attitude-similarity) the poorest like it the other way round. In addition, housing costs growth is higher than income growth. Now, both minorities have significantly greater difficulties in segregating themselves (Fig. 12). They live in some kind of diaspora while the two middle-class majority populations are able to create small-scale but widespread homogenous neighborhoods. They, however, struggle most against displacement.

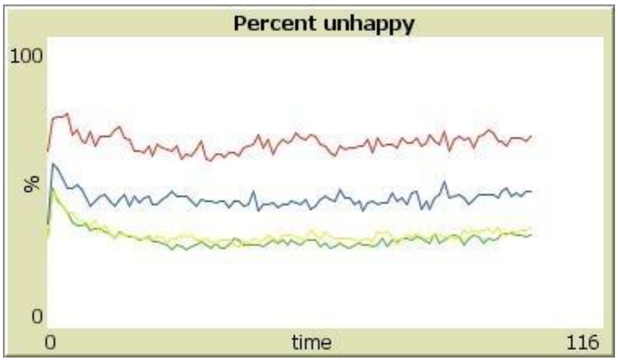

Fig. 12 proportions of agents dissatisfied (two-minorities' model)

On the assumption that social polarization took place in the city, with high proportions of most and least affluent agent groups (80%), and a strong minority of middle-classes (20%) which prefer attitude-similarity to a higher degree (50% compared with 20% of income-similarity) then, again, it becomes obvious that displacement of the poor to the affordable districts (and to the suburban region) does play a crucial role in intra-urban residential mobility (Fig. 13). On the other hand, no large-scale gentrification of the richest agents in the most expensive districts takes place. This modeling outcome is contrary to the empirical reality and thus confirms the necessity to take macro social conditions more seriously into account (thus, the failure of the model here is coherent and logical).

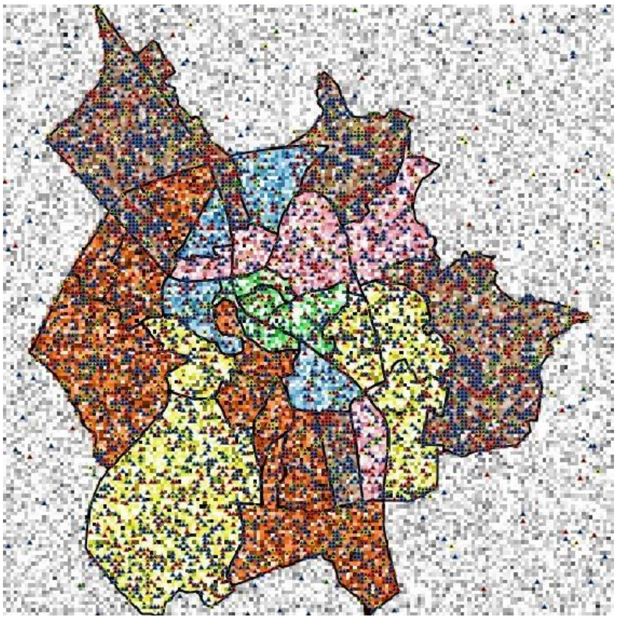

Fig. 13 spatial representation of segregation with the two minorities' simulation model

VI. Conclusion

The theoretical aim of the paper was to develop a segregation simulation model which implements a coherent individualization of agents' characteristics and behavioral settings. The model's purpose is to highlight the bottom-up processes which may help to understand better the emerging patterns of urban socio-spatial homogenization. In so doing, the social macro determinants are included as complementary, but implicit, forces of this complex phenomenon. They should be implemented in a more explicit manner in a forthcoming version of this model. The methodological aim, thus, was to verify the current conceptual simulation model. With the availability of the latest data around July 2014 this next step will be executed.

The observation of [14, p. 123], "despite the elegance of Schelling's model, empirics show neighborhoods are overall quite mixed", inspired us to use the basic ideas of this model-type in order to create true individual agents consistently. The benefit of Schelling's model approach, apart from it being the most influential approach in computational segregation research, is that it integrates a locational model and a "bounded-neighborhood model" [14]. From this starting point the results of the extended and modified simulation model presented here have demonstrated that segregation is a strong though small-scaled process when viewed from the bottom up. Even though: (1) agents individually vary in attitudes, decision-making, actions, and characteristics; (2) a universal threshold has been avoided; (3) macro social determinants have been included (with housing costs in at least an abstract manner), segregation took place.

Some empirical validation is given: while affluent households tend to exclude themselves from the rest of the society, poor households are mostly forced to segregate, although they would prefer to live in a socially mixed environment. Segregation is a controversial topic – in science, spatial planning, and politics. Among many others, one aspect has become increasingly crucial in debates on segregation: the knowledge transfer between people of different social statuses has been more and more interrupted, because of the creation of tangible and intangible borders. These borders tend to be used to make exclusion, injustice, and poverty invisible. A computational approach thus remains an important technique and provides a scientific contribution to detect the hidden mechanisms of these processes.

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