Barcelona: Autonoma University of Barcelona, 2014, DDD repository <http://ddd.uab.cat/record/125597>

A theory driven, spatially explicit agent-based simulation to model the economic and social implications of urban regeneration

Stefano Picascia
Centre for Policy Modelling
Manchester Metropolitan University
All Saints Campus, Oxford road
Manchester M15 6BH
Email: stefano.picascia@stu.mmu.ac.uk

***Abstract*—We model the economic mechanics of housing regeneration employing the rent-gap theory proposed by Neil Smith in 1979. We discuss the conditions for successful regeneration in theory, using an abstract representation of a city, then try and evaluate the possible outcomes of an actual regeneration programme in Salford, England in terms of property prices and area social composition.**

I. Introduction

The present work suggests a possible agent-based approach for capturing and making sense of the economic mechanics of urban regeneration programmes and their possible social outcomes.

Urban research is one of the fields where the tools of complexity science and the modelling approach have most convincingly penetrated. Micromodelling and agent-based modelling have been challenging linear regression models in representing urban dynamics and are making their way as standard planning tools, as Giffinger and Seidl (2013) suggest. In the last two decades agent based models have been extensively used to reproduce the evolution of the urban form (Stanilov and Batty, 2011), to model the urban dynamics typical of western cities - such as segregation (from the work of Schelling (1971) onward) and gentrification (the recent work of Jackson et al. (2008); Semboloni; Giffinger and Seidl (2013); Torrens and NARA (2007) among the others) - as well as some typical of the megacities of the developing world, such as the emergence and evolution of informal settlements (Patel et al., 2012; Feitosa et al., 2011). Recently, there have been fruitful attempts at employing agent-based models to evaluate urban regeneration policies. Jordan and Birkin (2011) focused on the residential mobility processes of households to predict the social composition of a regenerated area in Leeds, Malleson et al. (2013) concentrated on the effects of regeneration on criminal networks.

The preferred approach in most residential mobility models (for an exhaustive review see Huang et al. (2014)) is to centre on individual or household-level agents as the main actors and describe emerging patterns as purely bottom-up outcomes of the interaction of such agents. Also models that include economic constraints on individual residential mobility tend to implement price formation in the form of localised bidding mechanisms on land and property(Magliocca et al., 2011; Filatova et al., 2009). This approach poses a risk, in our view, of underestimating the broader economic processes that impact the urban form and constrain individual behaviour. A traditional line of research in human geography that has seen recent revival (Harvey, 2012; Smith, 1996), sees the socio-spatial phenomena that shape contemporary cities - suburban sprawl, income segregation, gentrification - as consequences of the varying influx of capital towards urban systems, as opposed to strictly originating from individual-based residential choices.

We constructed a model inspired by this approach, derived from the rent-gap theory (RGT) - a specific economic hypotheses on the dynamics of investment in housing - in an effort to integrate structural, supra-individual factors that affect the residential process and explore their effect on cultural and economic diversity of urban areas. In a previous paper we discussed a preliminary exploration of the model - we looked at the price dynamics triggered by different levels of capital flowing in a city and the patterns of spatial inequality that may emerge (Picascia et al., 2014). We now use the framework of the RGT to implement a conceptual representation of housing regeneration, centred on the economic aspect and mechanics of urban renewal. We then apply such model to a real world regeneration programme taking place in Salford, England and monitor the possible outcomes of the plan in terms of house price and social composition of the area. A description of the theoretical base and the model implementation are provided in section II and III. Section IV explores the dynamics of housing regeneration in the theoretical framework of the RGT and section V reports on our attempt to apply the model on a real world regeneration programme.

II. The "rent-gap theory" and its computational implementations

The *rent-gap theory* (RGT) is a supply-side approach to housing investment proposed by the late Neil Smith Smith

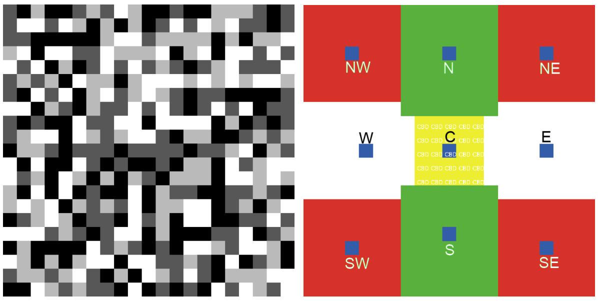
(1987), specifically for the study of the phenomenon of gentrification. In Smith's terms the rent-gap is

> the difference between the actual economic return from the rights to use the land that is captured given the present land use and the maximum economic return that can be captured if the land is put to its highest and best use

The gap between *actual* and *potential* economic return is due to progressive decline in maintenance which properties undergo, together with changes in technologies which render dwellings obsolete. Restoration or rebuilding increases the economic return that a portion of land or a dwelling generates, bringing it to the maximum possible. The locations with the highest difference between *actual* and *potential* economic return will be the ones more likely to attract investment capital and be put to "highest and best use". Although the rent gap theory was proposed to explain a specific phenomenon, gentrification, in our view it can serve as a good conceptualisation of general housing investment behaviour, suitable for a broad exploration and not incompatible with other approaches, including standard economic theory, as pointed out by Bourassa (1993). There have been a number of agent-based models inspired to the rent-gap theory in which the problem of identifying the *highest and best use* has been addressed by employing the notion of *neighbourhood effect*. Here, the highest possible revenue achievable by a given property after redevelopment is bounded by the average (or maximum, in some implementations) price charged in the vicinity of the redeveloped property, so that, irrespective of the state of the property, the maximum obtainable rent or sale price is practically determined by the overall state of the neighbourhood. This intuition embeds the principle that the state of the surroundings strongly affects a property and builds in the model the "*location! location! location!*" mantra that is familiar to property investors. Such interpretation was proposed by Wu (2003) and later O'Sullivan (2002) in his abstract, pure cellular automation model of gentrification. Subsequent work of Diappi and Bolchi (2008); Diappi (2006) concentrated implemented the RGT with a finer grained set of agents (property units, owner-occupiers, landlords, tenants and developers) and modelled investment capital as an exogenous factor. The authors tested different levels of capital and observed variations in the average price of properties and the share of under maintained properties in the city. This model is to date the most complete implementation of the mechanics of the RGT, although it lacks any consideration of the demand-side of the housing market.

III. Abstract model

Our implementation of the rent-gap theory follows the intuition of the aforementioned works, although we try to move away from the purely supply-side approach of Smith and add some demand-side considerations. We model a city in its entirety, divided in multiple districts (figure 1). The entities represented in the model are: (a) individual locations (residential properties), defined by their value and repair state; (b)



(a) (b)

Figure 1: The city is composed of 441 residential locations, each with a maintenance level and an economic value, divided in nine neighbourhoods. The colour shade of locations represents maintenance state from white (best condition) to black (worst). Depicted in (a) is the typical model initialisation with random values assigned. The nine neighbourhoods (C, N, NW, NE, E, W, S, SE, SW) have a local centre (b). The district boundaries are "soft", they do not constrain the agents' behaviour. Only when an *allure* emerges (see III-A) a district is represented as a recognisable entity in the agents' residential decision process.

individual agents that represent households, characterised by an income, mobility propensity and cultural configuration; (c) economic forces, represented in the form of exogenous "capital" level, aiming at profiting from redevelopment/restoration of residential locations.

We represent a city as a 21x21 square grid of 441 residential locations (Figure 1a) characterised by a value V and a maintenance level, or repair state, r, grouped in 9 districts (Figure 1b). r is initially set at random in the 0-1 range and V is set at $V = r + 0.15$. Dwellings progressively decay in their condition by a factor $d = 0.0012$ meaning that, if completely unmaintained, a location goes from 1 to 0 in 70 years (1 simulation step = 1 month). The value of the dwelling is assumed to follow the price curve theorised by Smith and shown in figure 2. For the first five years after renovation the price doesn't change, for the subsequent 50 years it is assumed to depreciate by a factor of 0.02 / year. In case of prolonged emptiness of the dwelling (>6 steps) both decay and depreciation factors are increased by 20%.

The model represents investment in housing renovation/redevelopment as the fundamental economic force operating in the city. This is implemented by the "Capital" parameter,K, which represents the maximum number of locations that can be redeveloped in the current economic climate, expressed as a fraction of the total number of residential locations of the city, similarly to the approach proposed in Diappi (2006). For example, $K = 0.02$ means that every 12 steps $441 * 0.02 = 8$ locations are redeveloped. A high level of K represents a large inflow of investment in the housing market which results in more locations being redeveloped and gaining value. The selection of the locations where the

Miguel, Amblard, Barceló & Madella (eds.) Advances in Computational Social Science and Social Simulation
Barcelona: Autònoma University of Barcelona, 2014, DDD repository <http://ddd.uab.cat/record/125597>

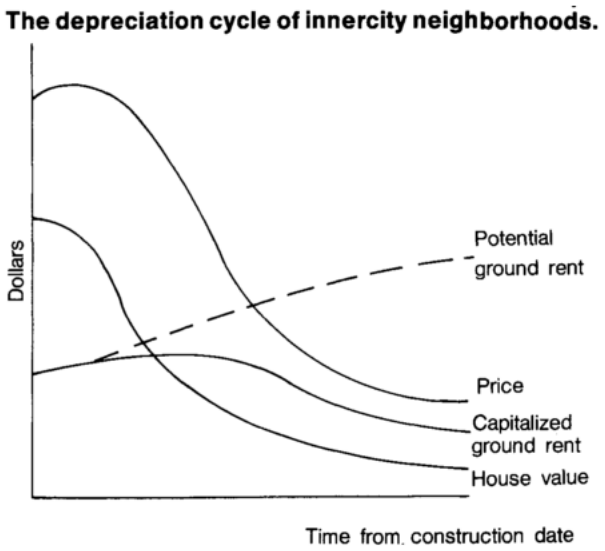


Figure 2: The depreciation cycle in inner city neighbourhoods (Smith, 1987)

Table I: Location variables

Name	Type/Range	Description
r	float, {0,1}	Maintenance state
V	float, {0,1}	Value
G	float, {0,1}	Value-gap: difference with neighbourhood value
d	integer	Distance from the neighbourhood centre
te	integer	Time empty
o	boolean	Occupied?

Table II: Agent variables

Name	Type/Range	Description
m	float, {0,1}	mobility propensity
c	list t=10,v=4	culture: memetic code
i	float, {0,1}	Income level
d	float, {0,1}	Cognitive dissonance level
th	integer	Time here: steps spent in the current location

investment lands is carried out deterministically, based on the value-gap of a location with the neighbouring properties, in accordance with previous implementations of the RGT. The relevant value gaps are determined in accordance with the *neighbourhood effect*, the principle that the amount of rent or the sale value attainable by a given location is always bounded by the characteristics and the desirability of the area where the property is located. When investment lands on a certain property p we assume that the new value nV after redevelopment will be the neighbourhood average, plus a maximum of 25% (representing a premium for a newly restored property) as in equation 1. In order to model the possible varieties of neighbourhood effect, we also consider a vicinity to be either the Moore neighbourhood of a location or the entire district that the location falls in, *whichever is bearing the highest values* and therefore grants the highest return for an investment.

$$nV_p = 1.25 * max\left(avg(V_{moore}), avg(V_{district})\right) \quad (1)$$

The value gap for location p will be $G_p = nV_p - (V_p + C)$, or 0 if $G_p < 0$. Here C is the cost of removing the present resident if the location is occupied. Once a location is selected for investment its value is set at nV_p and its repair state is set at $r = 0.95$. Table I summarises the variables associated with location.

The "premium for newly restored property" is assumed to be variable and depends on the density of neighbourhood. Investing upon a property in a very densely populated area (i.e. a neighbourhood with more than 80% of locations occupied) will grant the whole 25% premium over the neighbourhood average, as we consider density as a proxy for desirability. Similarly, if the occupancy rate is less than 50%, restoring a property will only attain the neighbourhood average.

A. Agent model: cultural exchange and residential mobility

Agents in the model represent individuals or households. They are endowed with an income level, i a mobility propensity m and a numeric string that represents their cultural configuration (table II). The agent's income level is set at random, normalised to the interval $\{0, 1\}$ and represents the highest price that the agent is able to pay for the right of residing in a property. The model, ultimately, implements a pure rental market. The agent's culture is modelled as a n-dimensional multi-value string of *traits*, inspired by Robert Axelrod's classic agent-based model of cultural interaction described in Axelrod (1997) and originally applied to the urban context in Benenson (1998). The string represents an individual's "memetic code", or "cultural code": an array of t cultural traits, each of which can assume v variations, giving rise to v^t possible individual combinations. In our model each trait is susceptible to change under the influence of other agents. Cultural influence is localised: agents that have been neighbours for more than 6 consecutive steps are likely to interact and exchange traits, thus rendering the respective cultural strings more similar. At the same time a cultural "cognitive dissonance" effect is at work, implementing a concept proposed by Portugali (2004, 2011) under the label of *spatial cognitive dissonance*: this is, roughly, the frustration of being surrounded by too many culturally distant agents. Similarity between two agents is the proportion of traits they share:

$$sim_{ab} = \frac{\sum_{i=1}^{t} xor(index(i, agent_a),\, index(i, agent_b))}{t} \quad (2)$$

Agents who spend more than six months surrounded by neighbours with few common traits ($sim < 0.3$) increase their mobility propensity each subsequent time step. The mobility propensity attribute represents the probability that an agent

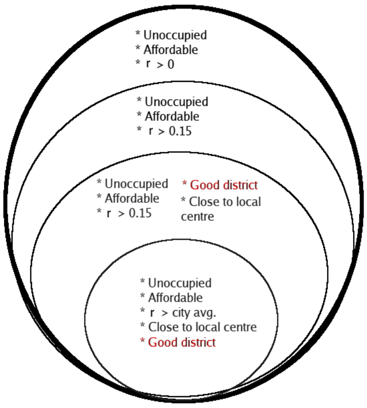


Figure 3: The residential choice process. A dwelling has to be affordable, free and habitable ($r > 0$) for an agent to consider moving into it. If these requirements are met, other characteristics are considered. If any district has developed an allure, agents who are relocating consider whether it suits them, based on a homophily preference. When no dwelling meets the out most requirements the agent leaves the city.

will abandon the currently occupied location in the subsequent time step. This parameter is set at a low level in the beginning of the simulation, drawn from a Poisson distribution centred at $m = 0.0016$, meaning that, on average, agents have a 2% chance of moving each year. Mobility propensity is affected by the conditions of the currently occupied dwelling and the aforementioned cognitive dissonance level. One agent's m is increased as follows: $m_{t+1} = 1.5m_t$ in the following circumstances:

- After 6 consecutive steps (months) in a dwelling with $r < 0.15$ (excessive time is spent in a dwelling in excessively bad condition)
- the cultural dissonance level exceeds a threshold for a period of 6 consecutive steps.

A special circumstance is when the price of the dwelling currently occupied exceeds the agent's income. In such case the agent is automatically put in "*seek new place*" mode. This represents an excessive rent increase, unsustainable by the agent. The process of finding a new location is bounded by the agent's income: a new dwelling has to be affordable ($V \leq i$), in relatively good condition, and as close as possible to the centre of the district which contains it. The selection process is represented in Figure 3. If no affordable and free location is to be found, the agent is forced to leave the city. As figure 3 shows, in certain cases the residential choice process of an agent includes the cultural configuration of the district as a factor. A special district-level variable called *allure* is set when the degree of cultural uniformity within a district exceeds a threshold, thus making the area recognisable for some of the features of its inhabitants. We measure cultural uniformity, u, as the average distance in terms of cultural traits (t) between the x agents residing in a certain neighbourhood.

Table III: District-level variables

Name	Type/range	Description
u	float,{0,1}	Cultural uniformity
a	list	Allure (cultural makeup)

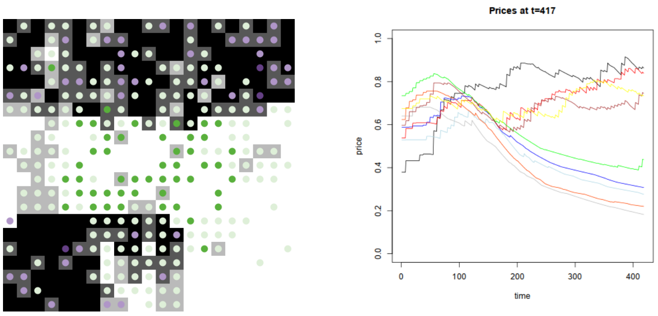
$$pairs = \frac{x(x-1)}{2}$$

$$u = \frac{\sum_{i=1}^{x}\sum_{j=1}^{x-1} sim(agent_i, agent_j)}{t * pairs}$$

The allure of a district is represented as a string of cultural features, similar to that of individuals, where each element of the string is the most common value for that trait in the district population. A district's allure is therefore an emergent feature of the model, which may or may not appear. This reflects the fact that not every neighbourhood has a special connotation visible to agents, but only those with a recognisable population do. The allure attribute can be thought of as the *reputation* of a neighbourhood in the eyes of agents. The attribute is sticky, after its emergence it is updated seldom and doesn't necessarily reflect the current composition of a district, representing the fact that reputation is a nearly permanent feature, difficult to eradicate or to replace Conte and Paolucci (2002), a characteristic that applies to places' as well as humans' reputation. Once a district's allure has emerged, agents include it in their residential decision under a homophily constraint: the agent will seek to move to a district with an allure similar to her culture string.

IV. The economics of housing regeneration

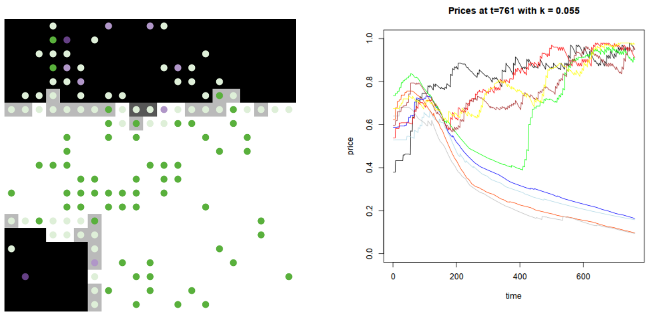
In a previous exploration of the model dynamics (Picascia et al., 2014) we described the spatial dynamics emerging from different levels of capital invested in the city and different methods of computing the rent-gaps. Starting from a random situation such as that in figure 1a, the model highlighted the tendency of capital to spatially concentrate and subsequently "move" in waves around the city in pursuit of the highest profit, producing enduring inequalities in investment and therefore in maintenance state, between areas. Prices across the city reproduced the oscillations theorised by Smith. In cases of low inflow of capital the model showed certain areas of the city suffering permanent under maintenance, because the rent-gaps that develop in such areas are too narrow to guarantee a profit. It is the situation depicted in figure 4, which represents the city at t=417 with k=0.035. That of figure 4 is the typical situation that calls for a urban regeneration programme: an under maintained area with very low property values and ongoing de-population. We take that as a starting point to simulate the regeneration of a run-down area under the theoretical constraints that we assumed.



(a) t=417

(b) Evolution of price levels from t=0 to t=417

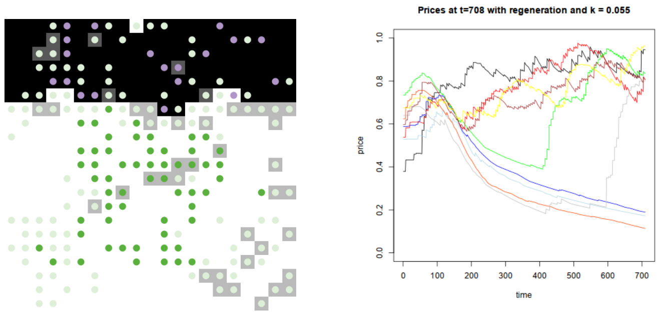
Figure 4: k=0.035. Neighbourhoods C,E,W and SE capture all the investment capital available, achieving high maintenance and high prices. Neighbourhoods N, NE, NW and SW (bottom grey line) see prices and maintenance condition decline and progressive depopulation, as agents leave undermaintained properties.



(a) City situation at t=761

(b) Price levels across the simulation. SW is the grey curve

Figure 6: Capital increase without regeneration t=761 - k=0.055



(a) t=664

(b)

Figure 7: Regeneration, plus capital increase at t=664. In this case we regenerate 9 locations in SW and set k=0.055. The white area spreads to all the declining neighbourhood and prices rise very quickly, as capital has moved in.

Urban regeneration in neoliberal economies

Broadly, urban regeneration is usually described as a set of policies and interventions aimed at the improvement of neglected urban areas, with the intent to revitalise deprived communities, renovate the housing stock, varying the social composition and, ultimately, rendering the area more palatable for private sector investment. Urban regeneration takes often the form of mixed public and private partnerships, a formula known in the UK as “private finance initiative”, or PFI, whereby the government invest public money in buying properties in decaying areas from private owners and hand them to developers for very little o no price, for restoration or rebuilding (Blackley and Evans, 2013). The effect is that an area incapable of attracting investment is suddenly *kick-started:* the properties are upgraded, the prices generally increase, the social composition changes and sometimes the effect reverberates on neighbouring areas.

Within our conceptualisation of the city and its economic dynamic, we could conceive publicly funded regeneration programmes as having the ultimate effect of *artificially* raising the prices of near zero-value areas - such as run down parts of a town, or brownfield - outside of the normal private investment mechanic described in section III, with the effect of generating rent-gaps where there are none, in the hope that private capital will move in to close them and, as a consequence, bring a wider area to higher maintenance conditions and economic value. To represent such an intervention in the model we raise the level of maintenance of a decayed area - the 9 contiguous locations with the lowest value and maintenance level of the city - to $r = 0.95$ and bring the price of such area to the city average. In the case in question the locations with the lowest value and maintenance level fall all in neighbourhood SW, the bottom left quadrant of figure 4a.

The effects of such measure vary depending on the level of decline of the affected area. In the example provided, regeneration alone proved insufficient to trigger a renaissance of the area. In most cases, as figure 5 shows, the regenerated area couldn’t sustain the new price and maintenance levels and ended in decay. A level of investments that has not guaranteed development across the whole city, in this model, cannot be overturned by simply restoring an area. The reverse is also true. A substantial increase in the capital available is also not enough to rescue a neighbourhood that has reached the lowest level of price and maintenance, because if the area is not capable to attain lucrative rent-gaps, the higher capital level will have the effect of ending up elsewhere in the city, raising the prices there. Figure 6 shows this circumstance. Capital has been raised to k=0.055 at t=418, the effect is prices going up in the already well developed districts of the city and falling further in SW. However, we found that the combined influx of capital and regeneration has the effect of bringing a completely declined district back into the investment cycles in most runs (figure 7).

Miguel, Amblard, Barceló & Madella (eds.) Advances in Computational Social Science and Social Simulation
Barcelona: Autònoma University of Barcelona, 2014, DDD repository <http://ddd.uab.cat/record/125597>

(a) t=418 - The 9 location at the top of the SW quadrant become white (well maintained)

(b) t=692 - The regeneration hasn't had a beneficial effect on the rest of the SW area, which stayed in bad repair (black) and the locations restored are declining again (they are now grey).

(c) Price levels in the 9 neighbourhoods across the simulation. SW is the grey curve. An increase is visible at the time of the regeneration, but in the longer term the prices continue their decline

Figure 5: Regeneration without capital increase - Increasing price and maintenance level for 9 locations in neighbourhood SW at t=417. This intervention has a marginal effect, limited to the interested area, nine locations at the top of the SW quadrant, which turn white (=well maintained) and attract new residents, but decline in the long term.

V. Modelling Pendleton(One), Salford

PendletonOne (http://www.pendletonone.co.uk) is a vast scale regeneration project ongoing in the Pendleton area of Salford, in Greater Manchester, England. Pendleton lies 2 miles west of Manchester city centre, has a population of 18,000 and is one of the areas with the highest indices deprivation in the country. The area was entirely built in the 1960s and 70s replacing hundreds of streets of Victorian terraced housing in the extensive slum clearances that wiped out unsuitable dwellings. Today's architecture sees a variety of heights, with imposing tower blocks sitting next to maisonettes and terraced homes. Pendleton has attracted a bad reputation and, despite the proximity to MediaCity and Salford Quays, the area failed to attract the necessary investments and sits in bad conditions. The £400m redevelopment plans under way involve, again, like in the 1960s, extensive demolitions which will change again the face of the area, along with refurbishment of existing dwellings and building of new housing. The new builds expected to complete by next year range from a price of £115,000 to £155,000. What could be the effect of such an intervention in 10 years time? Will the price levels substantially increase and sustain the new level? What will be the social composition of the area?

A. *GIS model and data sources*

We constructed a GIS model of the whole Manchester urban area, embedding vector data on house prices, average household income, ethnicity and religion of the inhabitants employing data gathered from the various sources shown in table IV. The data were integrated in the shapefiles of the Manchester area provided by the Ordinance Survey, which were then imported in Netlogo Wilensky (1999) via the GIS extension, generating the initial situation shown in figure 8. The modelled city is composed of 5,583 locations, all of which assumed to be residential, endowed with a maintenance state and a price and grouped in 44 districts. The study area interested by the PendletonOne regeneration is marked in green and consists of 20 locations. The initial population is of 4300 agents with an income derived from the census and a cultural string of 10 dimensions, the first two of which map ethnicity and religion derived from the 2011 census. The first two features are fixed and the remaining eight are susceptible to change as a consequence of interaction with neighbours, as in the abstract model. We also built a reserve population matching the ethnic composition and income structure of the Uk at large in order to simulate a plausible immigrant population. Population growth is set at 0.7% per year, as in the actual Manchester area. For the time being we assume a maximum of one agent per location, therefore assuming equal density for all the areas. Another crucial assumption is that we consider a location affordable if the price is less or equal to 6 times the annual income of an agent. This parameter will have to be explored further, especially in the light of the government encouraging the substantial expansion of credit to new homeowners.

B. *Results*

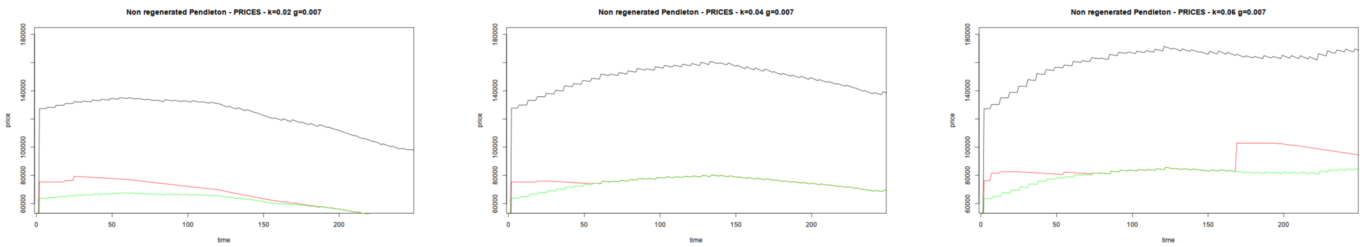
We run the model described in section IV on the Manchester urban area. Being able to represent the whole city is crucial to model the assumptions of the RGT: capital will flow where it is profitable, and in our model, as in reality, Pendleton is in competition with the rest of Manchester to attract investment. We modelled the regeneration process by replacing 50% of the existing dwellings with restored housing (i.e. housing with condition m = 0.95) and a price range determined stochastically in the range prospected by the developer (115,000 - 155,000 GBP). The regeneration happens at time step 24 and we monitored the evolution of prices for the subsequent 20 years (480 time steps) in the PendletonOne area and in the surrounding locations in radius 10. We compare the evolution

Table IV: Data sources. LSOA (lower level super output area) and MSOA (medium level super output area) refer to boundaries extent in the UK census.

Datum	Variable	Level	Source
House prices	V	Postcode	Zoopla.Com (retrieved October 2013)
House condition	r	LSOA	2011 Census - Living environment deprivation
Ethnicity	item 0 in {culture}	LSOA	2011 Census
Religion	item 1 in {culture}	LSOA	2011 Census
Share of social housing		LSOA	2011 Census - Tenure
Income	i	MSOA	2007 Estimates based on 2001 census

(a) (b)

Figure 8: The Manchester urban area represented in Netlogo. The color of the patches represent their maintenance conditions, as in the abstract model. Red patches represent social housing areas. The circles in (a) represent households, coloured according to their income levels: violet represents a below average income, green above average. The green area in (b) is the study area of PendletonOne



(a) k=0.02 (b) k=0.04 (c) k=0.06

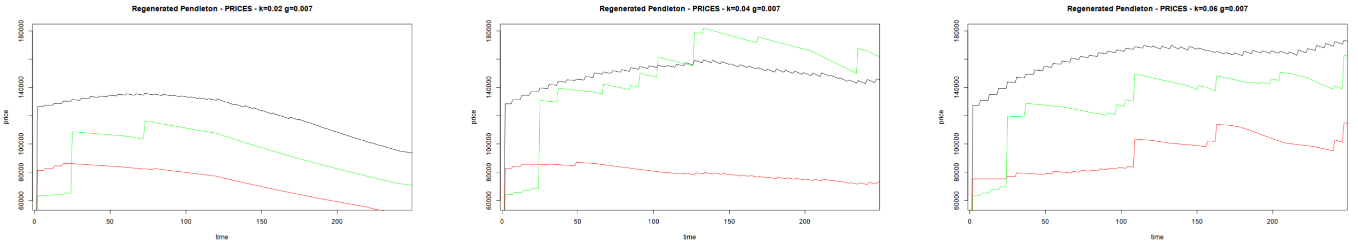
Figure 9: Median price in Manchester as a whole (black), PendletonOne (green), and PendletonOne proximity (red) in case of no regeneration taking place for three levels of capital. In absence of regeneration the amount of capital that flows into the city is irrelevant to Pendleton and its surrounding area. The profitability of these parts is too low, compared to other parts of the city, to attract any investment.

of the price dynamics in the case of regeneration taking place and no regeneration happening at all and we test three levels of capital (0.2, 0.4 and 0.6).

As figure 9 shows, if no regeneration were to happen, prices in Pendleton would decline as investment would never reach the area for any of the levels of capital tested. In the case of k=0.6, after about 13 years prices would rise in the area surrounding Pendleton, sign that for that level of investment, it would take more than 10 years before investing around Pendleton will be profitable. In figure 10 we see the effects of regeneration for the same three levels of capital. In this case the outcomes differ according to the level of capital flowing into the city.

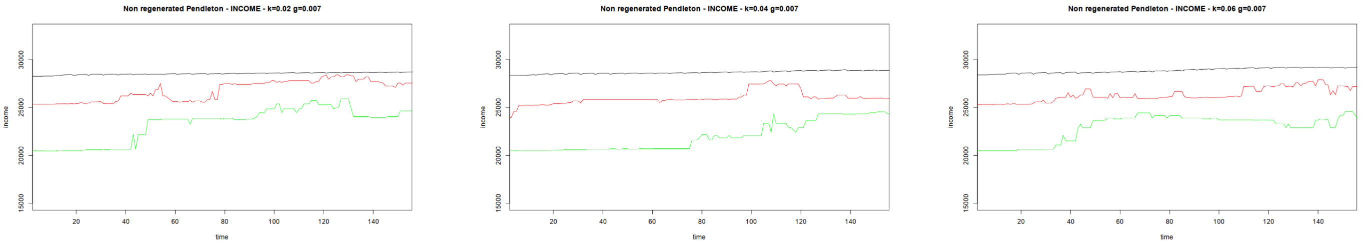
In figure 11 we take a look at the income levels of the study area. In the regeneration case, gentrification can be spotted, as the higher prices drive out some of the original population that has the lowest median income in Greater Manchester.

It is worth noting that, while the 6x limit may be too restrictive or unrealistic, gentrification is often a byproduct of state sponsored regeneration programmes, especially in the

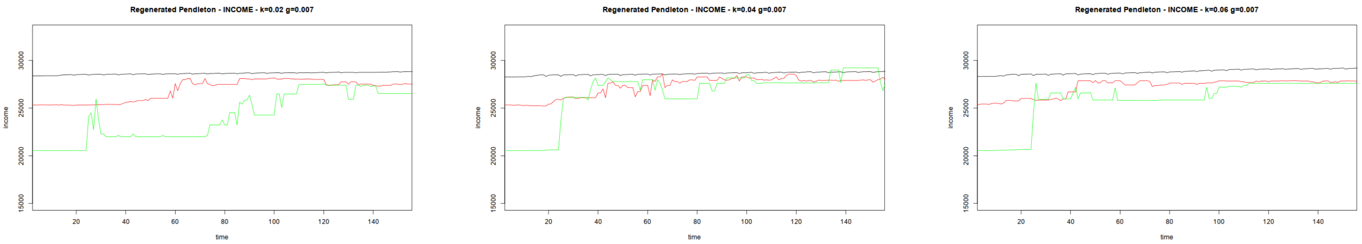


(a) k=0.02 (b) k=0.04 (c) k=0.06

Figure 10: Median price in Manchester (black), PendletonOne (green), and PendletonOne proximity (red) for three levels of capital, with regeneration taking place at step 24. At k=0.02 all prices decline and the regeneration has no long term effect. A level of k=0.04 grants higher prices for a longer term, but has no effect on the area around Pendleton; k=0.06 sustains high prices in PendletonOne and triggers investment in the surrounding area as well.



(a) (b) (c)



(d) (e) (f)

Figure 11: Median income in Manchester, PendletonOne and proximal area for three levels of capital in case of no regeneration taking place (a-c) and with regeneration taking place (d-f)

UK and in case of extensive demolition, as in Pendleton. The demolished properties are generally forcibly bought from the owners via a legal instrument called Compulsory Purchase Order for a price set by the local authority. Once the regeneration is completed, previous owners may find that no property is available in the local area for the amount they received and therefore, in order to stay in the neighbourhood, have to take up debt and many choose to move elsewhere. It is the case of many regenerations in London, notably the last Elephant and Castle, but there is evidence that this phenomenon is happening in Pendleton as well. As Allen (2008) points out, this phenomenon amounts to a form of government-driven gentrification, when not social cleansing.

VI. Conclusions, limitations, future work

The work presented here is still in progress and presents a number of obvious rough spots: the representation of the housing market is still extremely stylised, most of the model analysis and exploration is still underway - the ultimate purpose for which the model was developed is to investigate the effect of the change in prices triggered by the regeneration on the level of cultural diversity of the study area.

The role of land use change, particularly crucial in postindustrial cities, is also overlooked, not to name the lack of a systematic validation of the results, which is challenging in absence of adequately detailed historic data. Also the notion of "capital" expressed as the fraction of locations invested upon is problematic. The levels employed in the case study were derived from the exploration of the abstract model and not empirically tested (although we tend to believe that they are not completely devoid of relationship with the reality of Manchester economy: house building has been increasing the dwelling stock by 1.5%/year for all the the last decade, adding to that an estimate on restoration of existing housing easily takes us to the values of 0.02 - 0.06 that we have been testing in the model).

Nonetheless, this work serves as a demonstration of the possibility of embedding theory and data in a detailed and descriptive agent-based model, in an effort to understand and possibly predict the mechanics and outcomes of certain urban dynamics.

References

C. Allen, *Housing Market Renewal and Social Class*, ser. Housing, Planning and Design Series. Taylor & Francis, 2008. [Online]. Available: http://books.google.co.uk/books?id=4mN9AgAAQBAJ

R. Axelrod, "The Dissemination of Culture: A Model with Local Convergence and Global Polarization," *Journal of Conflict Resolution*, vol. 41, no. 2, pp. 203–226, Apr. 1997. [Online]. Available: http://dx.doi.org/10.1177/0022002797041002001

I. Benenson, "Multi-agent simulations of residential dynamics in the city," *Computers, Environment and Urban Systems*, vol. 22, no. 1, pp. 25–42, Jan. 1998. [Online]. Available: http://linkinghub.elsevier.com/retrieve/pii/S0198971598000179

G. Blackley and B. Evans, *The regeneration of East Manchester. A political analysis*. Manchester: Manchester University Press, 2013. [Online]. Available: http://www.manchesteruniversitypress.co.uk/cgi-bin/indexer?product=9780719084409

S. Bourassa, "The Rent Gap Debunked," *Urban Studies*, vol. 30, no. 10, pp. 1731–1744, Dec. 1993. [Online]. Available: http://usj.sagepub.com/cgi/doi/10.1080/00420989320081691

R. Conte and M. Paolucci, *Reputation in artificial societies: Social beliefs for social order*. Kluwer Academic Pub, 2002.

L. Diappi, "Gentrification waves in the inner-city of Milan," *Innovations in Design & Decision Support Systems in*, pp. 187–201, 2006. [Online]. Available: http://www.springerlink.com/index/g3174053k9911783.pdf

L. Diappi and P. Bolchi, "Smith's rent gap theory and local real estate dynamics: A multi-agent model," *Computers, Environment and Urban Systems*, vol. 32, no. 1, pp. 6–18, Jan. 2008. [Online]. Available: http://dx.doi.org/10.1016/j.compenvurbsys.2006.11.003

F. F. Feitosa, Q. B. Le, and P. L. Vlek, "Multi-agent simulator for urban segregation (MASUS): A tool to explore alternatives for promoting inclusive cities," *Computers, Environment and Urban Systems*, vol. 35, no. 2, pp. 104–115, Mar. 2011. [Online]. Available: http://linkinghub.elsevier.com/retrieve/pii/S0198971510000608

T. Filatova, D. Parker, and A. Van der Veen, "Agent-Based Urban Land Markets: Agent's Pricing Behavior, Land Prices and Urban Land Use Change," *Journal of Artificial Societies and Social Simulation*, vol. 12, no. 13, 2009. [Online]. Available: http://jasss.soc.surrey.ac.uk/12/1/3.html

R. Giffinger and R. Seidl, "Micro-Modelling of gentrification: a useful tool for planning?" in *Modeling and Simulating Urban Processes*. Wien: LIT Verlang, 2013, ch. 3, pp. 59–76.

D. Harvey, *Rebel Cities: From the Right to the City to the Urban Revolution*. Verso Books, 2012. [Online]. Available: http://books.google.co.uk/books?id=s4s5f7NnaZAC

Q. Huang, D. C. Parker, T. Filatova, and S. Sun, "A review of urban residential choice models using agent-based modeling," *Environment and Planning B: Planning and Design*, vol. 40, pp. 1–29, 2014. [Online]. Available: http://www.envplan.com/abstract.cgi?id=b120043p

J. Jackson, B. Forest, and R. Sengupta, "Agent-Based Simulation of Urban Residential Dynamics and Land Rent Change in a Gentrifying Area of Boston," *Transactions in GIS*, vol. 12, no. 4, pp. 475–491, Aug. 2008. [Online]. Available: http://doi.wiley.com/10.1111/j.1467-9671.2008.01109.x

R. J. Jordan and M. Birkin, "Agent-based simulation modelling of housing choice and urban regeneration policy," *Multi-Agent-Based Simulation XI*, pp. 152–166, 2011. [Online]. Available: http://www.springerlink.com/index/V2L1907M273V095U.pdf

N. Magliocca, E. Safirova, V. McConnell, and M. Walls, "An economic agent-based model of coupled housing and land markets (CHALMS)," *Computers, Environment and Urban Systems*, vol. 35, no. 3, pp. 183–191, May 2011. [Online]. Available: http://linkinghub.elsevier.com/retrieve/pii/S0198971511000056

N. Malleson, A. Heppenstall, L. See, and A. Evans, "Using an agent-based crime simulation to predict the effects of urban regeneration on individual household burglary risk," *Environment and Planning B: Planning and Design*, vol. 40, no. 3, pp. 405–426, 2013. [Online]. Available: http://www.envplan.com/abstract.cgi?id=b38057

D. O'Sullivan, "Toward micro-scale spatial modeling of gentrification," *Journal of Geographical Systems*, vol. 4, no. 3, pp. 251–274, Oct. 2002. [Online]. Available: http://www.springerlink.com/openurl.asp?genre=article\&id=doi:10.1007/s101090200086

A. Patel, A. Crooks, and N. Koizumi, "Slumulation: An Agent-Based Modeling Approach to Slum Formations," *Journal of Artificial Societies and Social Simulation*, vol. 15, no. 4, p. 2, 2012. [Online]. Available: http://jasss.soc.surrey.ac.uk/15/4/2.html

S. Picascia, B. Edmonds, and A. Heppenstall, "Agent based exploration of urban economic and cultural dynamics under the rent-gap hypotheses," in *Multi-Agent-Based Simulation XV*, no. c, 2014.

J. Portugali, "Toward a cognitive approach to urban dynamics," *Environment and Planning B: Planning and Design*, vol. 31, no. 4, pp. 589–613, 2004. [Online]. Available: http://www.envplan.com/abstract.cgi?id=b3033

——, "Revisiting Cognitive Dissonance and Memes-Derived Urban Simulation Models," in *Complexity, Cognition and the City*, ser. Understanding Complex Systems, J. Portugali, Ed. Berlin, Heidelberg: Springer Berlin Heidelberg, 2011, ch. 17, pp. 315–334. [Online]. Available: http://www.springerlink.com/index/10.1007/978-3-642-19451-1

T. C. Schelling, "Dynamic models of segregation," *The Journal of Mathematical Sociology*, vol. 1, no. 2, pp. 143–186, Jul. 1971. [Online]. Available: http://www.tandfonline.com/doi/abs/10.1080/0022250X.1971.9989794

F. Semboloni, "Segregation and gentrification as emerging phenomena from the real estate market." [Online]. Available: http://fs.urba.arch.unifi.it/PUB/papErsaFSemb.pdf

N. Smith, "Gentrification and the Rent Gap," *Annals of the Association of American Geographers*, vol. 77, no. 3, pp. 462–465, Sep. 1987. [Online]. Available: http://dx.doi.org/10.1111/j.1467-8306.1987.tb00171.xhttp://www.tandfonline.com/doi/abs/10.1111/j.1467-8306.1987.tb00171.x

——, *The new urban frontier : gentrification and the revanchist city*. Routledge, 1996. [Online]. Available: http://www.worldcat.org/isbn/9780415132558

K. Stanilov and M. Batty, "Exploring the Historical Determinants of Urban Growth Patterns through Cellular Automata," *Transactions in GIS*, vol. 15, no. 3, pp. 253–271, Jul. 2011. [Online]. Available: http://doi.wiley.com/10.1111/j.1467-9671.2011.01254.x

P. Torrens and A. NARA, "Modeling gentrification dynamics: A hybrid approach," *Computers, Environment and Urban Systems*, vol. 31, no. 3, pp. 337–361, May 2007. [Online]. Available: http://linkinghub.elsevier.com/retrieve/pii/S0198971506000718

U. Wilensky, "NetLogo," 1999. [Online]. Available: http://ccl.northwestern.edu/netlogo/

F. Wu, "Simulating Temporal Fluctuations of Real Estate Development in a Cellular Automata City," *Transactions in GIS*, vol. 7, no. 2, pp. 193–210, Mar. 2003. [Online]. Available: http://doi.wiley.com/10.1111/1467-9671.00140