MODELLING THE IMPACTS OF COST RECOVERY IN URBAN UPGRADING ON SEGREGATION

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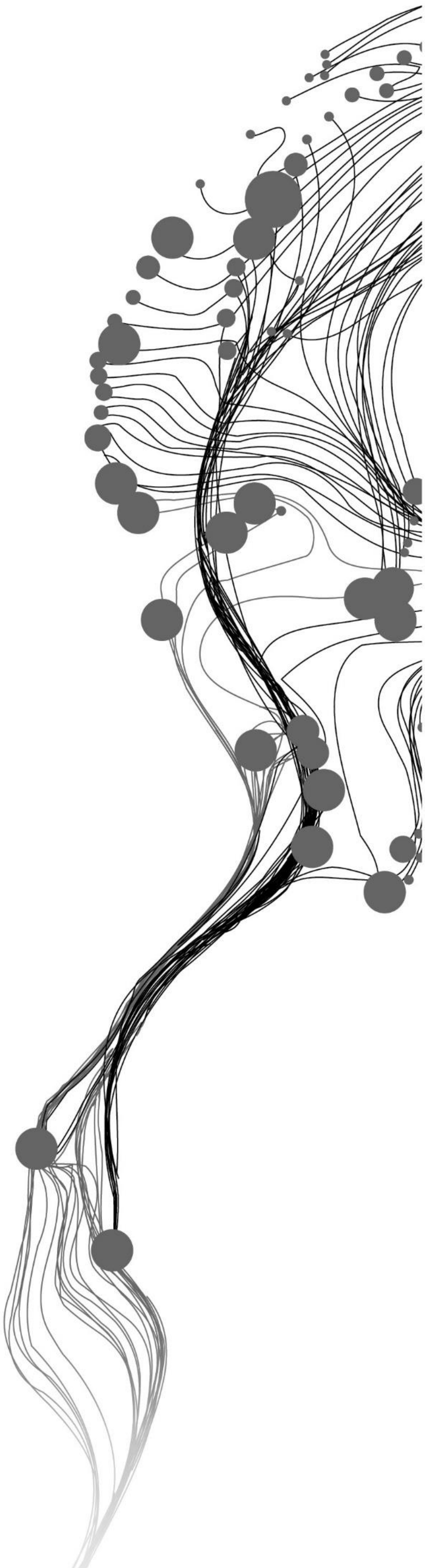

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ABSTRACT

Cost recovery in urban upgrading and income segregation in the city are two urban processes that have rarely been studied together. While a few studies show that urban upgrading can lead to income segregation, the relationship between cost recovery in urban upgrading and income segregation has been studied more rarely. This study aimed to analyse the relationship between the two. For that, InformalCity an agent-based model that simulates the process of urban upgrading in a hypothetical city was adapted. The model was introduced with options of classical upgrading, verticalisation and cost recovery whose emergent results were analysed using indicators for measuring and analysing income segregation. The results in these indicators were studied. The simulation results show that cost recovery or lack of cost recovery in an upgrading effort does not influence the Gini coefficient calculated to measure income segregation. Classical upgrading (with or without cost recovery) which is well-funded leads to higher levels of segregation in the city (measured using Gini coefficient). On the other hand, classical upgrading with insufficient funding reduce the Gini coefficient, but these efforts do not improve the mean income or share the of lower-income households in the target district which suggests that while the distribution of lower-income households improves, the target district (target of upgrading) remains dominated by lower-income households. Verticalisation (with no cost recovery) has a reducing effect on the income-segregation (measured by Gini coefficient) in the city. Along with that the share of lower-income households in target districts also decreases suggesting that households from different income groups occupy districts that were before verticalisation predominantly lower-income districts.

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1. INTRODUCTION

1.1. Background and Rationale

Slums are results of the unprecedented urbanisation the world is witnessing (Roy, Lees, Palavalli, Pfeffer, & Sloot, 2014). They are entry points for the rural poor, who migrate to the city because they view cities as hubs of rising income and asset ownership (Singh & Kalirajan, 2015; Roy et al., 2014). However, slums are characterised by unacceptable and vulnerable living conditions, security threats to women, low health and educational standards, and an array of exclusions and segregations (Roy et al., 2014). UN-Habitat (2007) defines a slum household as a group of individuals living under the same roof which lacks at least one of the following 1) security of tenure 2) structural quality 3) durability of dwellings 4) access to safe water, and 5) access to sanitation facilities.

Upgrading is carried out to tackle the ever-growing slums and the challenges posed by them (Patel, Crooks, & Koizumi, 2012; Roy et al., 2014). Urbann upgrading can provide residents with the security of tenure, better essential services and help with livelihood generation hence contributing to reducing social inequality and strengthening sustainable urbanisation along with improving the public space and urban safety (UN-Habitat, n.d.). The strategies are of many types such as, in situ redevelopment, resettlement and upgrading, relocation, and forced evictions (Singh & Kalirajan, 2015).

It is also important to consider that upgrading of the slums does not just impact them in isolation. Rather, upgrading has consequences which influence the population dynamics of the entire city (Schwarz, Flacke, & Sliuzas, 2016). Upgrading affects the physical, social and economic fabric of the town. Adverse effects such as income segregation may arise with upgrading (Schwarz et al., 2016; Alvarez, 2016). The effect of upgrading on segregation is especially worrisome since slums already marked by economic and class-based segregation (Susewind, 2017). The far-reaching and diverse impacts of slum upgrading coupled with its complex nature and the already existing issues of the slums, makes a study on slum upgrading very relevant and engaging.

India and China have the highest proportion of slum dwellers (Hindman et al., 2015). As per the census conducted in 2011, 17.4% of the urban population in India lived in slums which is a reduction from 18.3% in 2001, but even though the proportion of slum dwellers is decreasing, the absolute numbers are increasing due to population growth (Mishra, 2015). Efforts have been made in India to tackle the needs and necessities of its slum population and the issues and problems that arise because of slums. Some of the urban upgrading efforts carried out in India are as follows:

1. Jawaharlal Nehru National Urban Renewal Mission (JNNURM): provides shelter, essential services, land and tenure, and it aims for policy changes to improve the conditions of slums (Mishra, 2015).
2. Rajiv Awas Yojana (RAY): provides financial support to the states for slum upgrading (covers all the slums and residents) and providing housing. The scheme awarded property rights and brought infrastructure in the slums at par with the rest of the city (Mishra, 2015).
3. Pradhan Mantri Awas Yojana (PMAY): an ambitious project which aims to provide housing for all by 2022. It has four main components: slum redevelopment, affordable housing through credit linked subsidy, affordable housing in partnership and subsidy for beneficiary led housing (Mishra, 2015).

4. Slum Rehabilitation Authority in Pune (SRA): The authority allows developers to rehabilitate slum residents in situ through Slum Rehabilitation Scheme (SRS). The new settlement is vertically extended to reduce ground footprint, and the landowners and developers receive transferable development rights (TDRs). TDR allows development in other locations in the city, and it makes the process profitable for developers (Cronin, 2011).

These efforts have been successful in the improvement of lives of 59.7 million slum dwellers who previously lived in dire conditions (Mishra, 2015). But, despite all the efforts made in India, urban upgrading remains burdened by many challenges some of which are, land tenability and ownership issues, the informal housing market, and lack of cohesiveness and comprehensiveness in the efforts made for the improvement of lives of urban poor (Mishra, 2015). Cost recovery plays a vital role in how upgrading programs will fare. For instance, Basic Services to Urban Poor (BSUP) is mainly unsuccessful regarding the usage/occupancy of upgraded facilities due to high costs recovery from the beneficiaries despite the subsidies provided by the public authorities (Hindman et al., 2015; Mitlin & Thapa, 2015). There are many different ways in which cost recovery is carried out. Innovative methods like a public-private partnership in upgrading being help avoid cost recovery of upgrading altogether.

Since cost recovery in urban upgrading can affect the outcome of the program and upgrading can influence the population dynamics in the city, especially the segregation patterns, the objective of this MSc thesis is to assess whether different kinds of cost recovery methods in slum upgrading influence the segregations of slums in the context of India.

1.2. Research Problem

Based on the discussion Section 1.1, it can be established that slums in India are concentrations of socio-economically disadvantaged people. Furthermore, upgrading efforts can reinforce the segregation in the city (Schwarz et al., 2016; Alvarez, 2016).

If upgrading with cost recovery is carried out inefficiently, meaning cost recovery that leads to unmanageable financial burdens on government and final beneficiaries, the end product of such upgrading may be physically unsatisfactory (in terms of the quality of upgraded facilities). This dissatisfaction may lead to low occupancy/usage rate of the upgraded services/houses, and movement of residents back to the old houses as is seen in BSUP program carried out in India (Hindman et al., 2015). The movement back to old houses reinforces the segregation that already existed. On the other hand, programs such as SRS required no cost recovery from the end user due to the public, private partnership (Nijman, 2008). The upgrading is carried out by private developers who can finance the new houses by verticalising the slums (and hence clearing up the sprawl). The developers resell the vacated land at market prices which bear the cost of the upgraded houses (with the profits going to the developers and the government earning a 25% profit). Such a method ensures no cost recovery from the end user. It also creates housing meant for relatively higher income households in areas that are dominated by low-income households.

While this linkage between cost recovery and income segregation is observed when studying literature on the topics, the relationship between the two is yet to be studied.

A study conducted by Schwarz et al. (2016) using InformalCity, an Agent-Based Model (ABM) developed by Schwarz (2015) to investigate the effects of urban upgrading on the population dynamics and income segregation found that upgrading efforts lead to income segregation within the city. However, due to the simplistic nature of cost recovery option in the model, it was found that cost recovery does not influence income segregation. The relationship between the two was not studied in detail. So this research aims at taking the study Schwarz et al. (2016) a step further by understanding the consequences of cost recovery in urban upgrading on segregation in the city using a modelling approach. While previous models have studied the emergence, life cycle, even the upgrading of slums (Patel et al., 2012; Roy, Lees, Pfeffer, & Sloot, 2017; Schwarz et al., 2016), the effects of cost recovery in urban upgrading remain uninvestigated using modelling. This study will be beneficial in an Indian context since recently ambitious upgrading programs such as, Housing for All (2015) have been launched which take a divergence from the traditional methods of upgrading by involving methods such as verticalisation, innovative cost recovery and financing. Since such programs and methods are in the phase of implementation right now, an insight into their outcomes will be particularly useful for the policy makers, making the outcomes of this study very relevant and useful.

1.3. Research Objectives and Questions

General Objective

The general objective of this study is to "analyse the relationship between cost recovery in urban upgrading and income segregation using agent-based modelling in the context of India."

Specific Research Objectives and Questions

1. Developing the background for adapting the model (InformalCity) to the context of India and expanding the components of upgrading and cost recovery
    1.1. What are the main processes related to income segregation of Indian slums?
    1.2. What are the different types of urban upgrading carried out in India?
    1.3. What are the different types of cost recovery in urban upgrading carried out in India?

These questions have been answered, and the objective is met in chapter 2 which provides a literature review of slums in India, the segregation of slums, the upgrading and cost recovery practices that have been carried out and are being carried out.

2. Developing and implementing changes to adapt InformalCity
    2.1. Which are the changes in the agents and the model environment of InformalCity?
    2.2. What are the upgrading options to be included in the adapted model?
    2.3. What are the cost recovery options to be included in the model?

In chapter 4, sections 4.2 and 4.3 provide information about all the changes that have been made in the cost recovery and upgrading options in the model. Along with the changes to upgrading and cost recovery options some general changes have been made to the model for it to fit better to an Indian context.

3. Understanding the effect of different cost recovery options on urban upgrading on segregation in the city.
    3.1. What are the income segregation levels without any cost recovery and upgrading options selected?
    3.2. What is the effect of different cost recovery and upgrading options on income segregation?

Chapter 5 presents simulation results and chapter 6 discusses and interprets the results to answer these questions.

2. LITERATURE REVIEW

To be able to reach the objectives of this study a thorough literature review of the knowledge existing on slums and their segregation (section 2.1), their upgrading, and the cost recovery (section 2.2) involved was essential. Since the method used to investigate the objectives is agent-based modelling, a discussion on existing models for informal settlements is given here as well (section 2.3).

2.1. Slums and segregation in India

Slums are essentially forced agglomerations of poor people (Susewind, 2017) which are formed and rapidly grow when the informal housing is required to meet the demand surplus for formal housing (Hindman et al., 2015; Sietchiping, 2004). Often, due to the high real estate and land prices, the poor occupy slums (Adusumilli, 2001). Estimates suggest that for 66.30 million households there is a shortage of 24.72 million (Jones Lang LaSalle, 2012). Rural folk who move into cities through slums to improve their financial conditions view slums and cities as hubs of rising income (Roy et al., 2014). Slums exist in a state of congestion and desuetude (Jones Lang LaSalle, 2012), as can be observed in the case of Hyderabad, India where slums are on an average three times as dense as the rest of the city's average density (Adusumilli, 2001). They are also often located precariously (Werlin, 1999) with facilities such as municipal solid waste dumping sites close by (Hoornweg & Bhada-Tata, 2012). Due to exposure to unfit conditions slum population have high mortality and morbidity (United Nations Human Settlements Programme, 2004). 32% of slum population lives in slums in areas where they have a threat from environmental disasters and social crisis (Watson, 2016).

United Nations Human Settlements Program (2007) views slums as settlements consisting of households with the absence of security of tenure and shelter deprivations which include lack of water, sanitation, space, and durable housing structure. But not all slums are short on infrastructure, and many enjoy services such as water, electricity, and roads (Singh & Kalirajan, 2015). However, even so, they often have unacceptable garbage disposal, sanitation, and healthcare systems. Slums also have some law and order problems which are usually due to illiteracy, gambling, and lack of awareness (Singh & Kalirajan, 2015). Many believe that it is the shortcoming of the city authorities in providing infrastructure and services for the efficient development of housing that has caused slums to mushroom (Sietchiping, 2004).

In India, the Ministry of Housing & Urban Poverty Alleviation (2016) defines a slum as a compact area of at least 300 people or 60-70 households living in congested conditions and unhygienic environment with poor infrastructure and improper sanitary and drinking water facilities (Zérah, Dupont, & Lama-Rewal, 2011). Slums across the world are different, but as Patel (1998) notes, slums in India are unique regarding their social environment due to the strong social cohesion existing in the family, caste, community, and religious bonds. The perception is that slums are uniform, but differences exist between slums and have been observed in the slums of big cities and medium-sized cities (Hindman et al., 2015).

As is known, slums are settlements that are compact and congested. The financial capital of India, Mumbai, houses 42% of its population in slums (Zhang, 2017) in just 12% of its total geographical area (Balachandran, 2016). In Delhi, 30% of the slum population lives on 3% of the land (Somvanshi, 2015). Out of 4041 statutory towns in India, 2613 towns have slums constituting 17.4% of the total urban population of India (National Building Organisation, 2015). The size of houses in slums varies from one city to another with 30% of Mumbai's slum population living in tenements ranging from 300-400 ft^2 in size (Society for Promotion of Area Resource Centres, 2004). An average household of 5.5 members occupies an area of

16m^2 in Hyderabad (Adusumilli, 2001). Ministry of Housing and Urban Poverty Alleviation (MHUPA) has set that affordable housing for the economically weaker section should cover a minimum carpet area of 25 m^2 and the cost for such housing should not exceed 30% of the gross monthly income of the buyer (Jones Lang LaSalle, 2012). By the same guidelines of the MHUPA, the lower income group and the middle-income group should have houses of 48m^2 and 80m^2 respectively with the cost of the house not exceeding 40% of the gross monthly salary (Gopalan & Venkataraman, 2015).

Another critical feature of slums which is vital to this study is the spatial segregation of poverty, which leads to concentrations of poverty (Indian Institute of Human Settlements, 2011). Feitosa, Reyes, & Zesk (2008) define residential segregation as a "measure of social clumping in an urban environment" which can have different categories such as ethnic, class, race and income segregation. Reardon & Bischoff (2010) define income segregation as "the uneven geographic distribution of income groups within an area." In their paper, they also explain how income segregation is a multidimensional process which can be defined by either the spatial segregation of poverty or by that of prosperity. The scales at which segregation can occur also differs with segregation sometimes occurring at the level of the whole city and sometimes two neighbouring areas can be occupied by entirely different income groups each (Reardon & Bischoff, 2011). Segregation often leads to spatial mismatch, which means that due to their location, job opportunities reduce for low-income individuals (Chan, 2014), to inequality in social outcomes (Reardon & Bischoff, 2011), inequality in educational outcomes and it may increase poverty in the poor neighbourhoods (Quillian, 2014).

It is this spatial segregation of the poor which leads to formation and stagnation of slums (Vaughan, Clark, & Sahbaz, 2005). Slums are characterised by economic segregation and also by class-based segregation (Susewind, 2017). In India, slum dwellers are people who have migrated from backward districts and are from the deprived class of the society (Singh & Kalirajan, 2015). However, slums are not just concentrations of people by income but also by caste and religion. Indian society is known for its caste-based segregation (United Nations Human Settlements Programme, 2009) with Adivasi (tribal), Dalit (lower caste), and Muslims dominating the poorer neighbourhoods and slums (Sahoo, 2016). Lower caste residents tend to live in low-class areas of the cities with 60% of the slum dwellers in Delhi belonging to Scheduled Castes/ Scheduled Tribes and 91% of slum dwellers in Ahmedabad (reported by UN-Habitat) belonging to Other Backward Castes (OBCs) and Muslim communities (Zérah et al., 2011). In the case of India, where 59.7% of the urban poor belong to lower caste categories, caste and income class are often related (Panagariya & More, 2013). As Murthy, 2011 notes, Scheduled Castes, Scheduled Tribe, Other Backward Castes, and Muslim population together account for 91% of the below poverty line population of urban areas (Zérah et al., 2011). Scheduled Castes/Scheduled Tribes use community facilities such as public washrooms associated with slums more than other communities and individual facilities such as drinking water facilities, attached bathrooms are least available to Scheduled Castes/Scheduled Tribes, suggesting that these communities are predominant in slums (Zérah et al., 2011).

2.2. Slum Upgrading and Its Cost Recovery in India

To tackle rapid pace at which slums are growing and the problems that their nature poses, urban slum upgrading is a crucial method to improve the living condition of millions of disadvantaged slum dwellers throughout the world. In India too, policies for the improvements of the slum have been carried out. After India gained independence, the urban planning authorities tried to ensure that no new slums came about, but as the slum settlements grew the colonial policies of "clearance, rehabilitation, and relocation" were used (Zérah et al., 2011). Hachmann, Jokar, & Vaz (2017) view clearing or demolition as a common but unsatisfactory practice and instead assume slum upgrading, which aims at "integrating informal settlement areas into the city through improving and formalising existing structures" as a more affordable viable and flexible approach. Since then, the policies have changed, and the government of India recently acquired a $275 million loan for improving urban services to 300,000 households from Asian Development Bank (Asian Development Bank, 2013). Slum upgrading addresses issues related to tenure status, technical services, social infrastructure, physical environment, and housing units. ("Analysis of Government Policies on Slums Upgradation," n.d.). It is important to note here that in the case of India; the welfare of slum dwellers is often motivated by their advantages to politicians. Patel et al. (2012) note that in India slum dwellers who live in areas with high slum population pay less rent than others which is due to politicians who view slum dwellers as a vote bank and understand that pleasing many slum dwellers will get them many votes.

Hindman et al. (2015), classifies the policies undertaken to provide adequate housing into *slum redevelopment and slum upgrading*[1]. Slum redevelopment policies try to improve the conditions of slums from scratch, and upgrading allows slum dwellers to improve their condition with the municipality providing them with services.

Singh & Kalirajan (2015) classified the policy options as*, in situ upgrading, clearance and resettlement, and in situ resettlement*. According to them, in situ upgrading involves the provision of basic services but no construction and it is often unsatisfactory due to the high levels of congestion in slums. While also noting the failure of clearing and relocation policies (shifting slums dwellers from their homes to other locations) they mention the success of in situ resettlement policies especially in countries such as Singapore. They describe in situ resettlement as "changing the landscape of the existing slum settlement while ensuring rehabilitation of entire population at almost the same locality in modern state-of-the-art housing complexes". An in situ redevelopment policy being carried out in India at the moment is Housing for All. What is interesting about this policy is that is being carried out in a public-private partnership. To understand public-private partnership better, a concept of importance is that of cost recovery, which is a central concept in this study.

Cost recovery is an essential component of slum upgrading which can affect the overall outcome of a project. Since no definition of cost recovery is a fit for this study, the operational definition for the study is:

Cost recovery means recovering the costs or a part of the costs spent on the upgrading of houses or facilities from the beneficiaries of an upgrading programme.

The importance of cost recovery in upgrading efforts is evident in the case of India, where cost recovery carried out in government projects is often poor and increases debt and interest burdens on government. Some policies provide houses free of cost or with very little cost to gain political popularity among the slum dwellers (Hingorani, 2011a). This, in turn, influences the resource allocation to urban infrastructure department (Mulkh, 1991). Cost recovery is also beneficial as it gives the beneficiaries a sense of ownership and pride towards their new dwellings, but for an upgrading programme to be repeated, maintained, and scaled up, it is essential that the costs be appropriately affordable to the different kinds of beneficiaries (Cronin, 2011). Affordability is especially important since not all slums and slum dwellers can afford the same things.

Different types of cost recovery methods are employed in India, with some programs, such as National Slum Development Program, Basic Services for Urban Poor providing subsidies and loans for the cost recovery which are funded by the government. The government in most cases carries out minimal cost recovery by providing grants and subsidies, but also provides loans to slum dwellers who are to repay the

[1] For the purposes of this study, both upgrading and in situ redevelopment will here on forth be referred to slum or urban upgrading

loans in stipulated time with the appropriate rate of interests. Due to the inadequate cost recovery mechanisms and limited capacity of government in a developing country such as India, the debt and interest burdens on the government end up increasing (Mulkh, 1991).

The funding for projects where there is a public-private partnership is different from traditional upgrading programmes. Activities in projects with public-private partnerships receive funding through cross-subsidisation. Cross-subsidies are created by in situ resettlement, and they fund in situ resettlement of slum dwellers. High -density dwelling units replace the sprawl of the constructed and funded by private developers. In return for this vertical construction, developers receive additional floor space or Transferable Development Rights (TDRs), which they then sell commercially. Other innovative methods of cost recovery such as recovering costs from old house materials exist (Hindman et al., 2015).

In the following section upgrading programmes carried out in India and their cost recovery mechanisms will be described.

The funding mechanism for an upgrading programme is of great importance; it can dictate whether costs are recovered (and how much is recovered) or not. So, the upgrading programmes described in the following sections are grouped according to the bodies funding the projects.

Table 1 Slum Upgrading Programs and their Cost Recovery in India

Schemes	Provisions	Government Contribution	Beneficiary Contribution	Effects of Segregation
GOVERNMENT FUNDING				
National Slum Development Programme	Provide adequate water supply, sanitation, education facilities, health care, housing and environmental improvements through the creation of sustainable support systems. 300 crores annually are provided for assistance.	70% loans given 30% grants given	Loan repayment	Not measured
Basic Services for Urban Poor	Providing basic services to urban poor and building dwelling units	88% subsidy	12% paid by beneficiaries	Not measured
Land Sharing	Shelter upgrading by sharing of squatted land between the owners and the residents.	80% loan	20% contribution to either labour, cash, or recycled materials from the old house	Not measured
Prime Ministers Grant Project	Acquire tenure of land and loans for upgrading personal dwellings In-situ redevelopment	Subsidies and loans	No information on cost recovery	Not measured
Andhra Pradesh State Housing Co-operation Limited	18,000 dwelling units built	Rs 3000 subsidy + Rs 25,000 loan	Rs 2000	Not measured
CROSS SUBSIDY				
Slum Redevelopment Scheme	In-situ redevelopment	Cross subsidization	Rs 15,000	Not measured
Slum Rehabilitation Scheme	In-situ redevelopment	Cross-subsidization	No cost recovery	Not measured
Housing for All	In-situ redevelopment Housing construction Housing Improvement	Cross-subsidization 6.5% interest subsidy Rs 1.5 lakh to eligible urban poor (for improvements)	Proposed low-cost recovery Rs 3179/month for 20 years	A similar scheme in the US resulted in racial segregation.
NGO				
The Alliance	Building up the financial resources and capacity of slum dwellers.	N.A.	No information on cost recovery	Not measured

Shelter Associates	Dwelling Units	VAMBAY grant of Rs 50,000	Rs 5000+ loan repayments of Rs 486 per month for seven years	Not measured

2.2.1. Government

The Prime Ministers Grant Project (Jagdale, 2013)

The project provided a one billion rupee grant for upgrading Dharavi slums. The grant provided two options; the first was that the dwellers could acquire tenure for the land. The second option saw the demolition existing slum and development of residential complexes of high density.

The first option gives a loan for development of the land whose tenure is granted. In the second option, the residents were expected to pay for the new dwelling units but at a subsidised rate. Since redevelopment at that time was ten times as costly as upgrading, the government exhausted its resources by providing subsidies for the new apartments hence were not able to address a vast number of households in Dharavi. Even though the demand for housing exceeded the output greatly, a lesson learnt was that for a high-density slum like Dharavi, in situ redevelopment was the best option. Despite the house subsidies, many of the intended beneficiaries could not afford the new accommodation.

An extension of this project outside of Dharavi was the Slum Redevelopment Scheme launched in 1991. Slum Redevelopment Scheme was different from The Prime Ministers Grant Project in the method of its financing. The scheme gave no grants or donation. Regulations were relaxed to raise the capital from the free market. This relaxation of rules was done to incentivise private developers to demolish the slums and provide in situ resettlement. The developers were induced by added floor-area Ratio on which extra units could be constructed and sold at market price generating a cross-subsidy. The scheme puts a limit of 25% on the profits of the developers. The upgraded houses were not free, and dwelling units in prime locations cost Rs. 15,000. There is a consensus among scholars that this scheme was not a success (Bardhan, Sarkar, Jana, & Velaga, 2015).

Land Sharing in Gandhikuteer, Hyderabad (Adusumilli, 2001)

In Hyderabad, a privately owned piece of land was squatted upon for some years. Gandhikuteer, the land, was eventually shared by the landowners and the squatters. Such land sharing was advantageous for both parties since slum dwellers got the security of tenure, no eviction threats, permanent houses, assets and improved status, and the landowners got immediate possession of a part of the land. 24 families received houses ranging in size from 24 - 47 m^2 in size. Since space was limited, families who were related to each other were housed in double storied structures.

The shelter upgrading started with 80% of the cost financing from Housing and Urban Development Cooperation Limited loans which was to be repaid by the beneficiaries over 20 years at an interest rate of 7%. State subsidies and beneficiaries bore the remaining 20% costs. The beneficiary contribution could be labour, cash, or recycled materials from the old house.

The project was carried out in 1985 and studied in 1987 and in 2001. The studies found that the community ties are still substantial. There was hardly any encroachment onto common roads or conversion of building use in the last decade and a half. Some of the youngsters are not aware that it was a slum before. The education levels have remarkably gone up, and the community feels that this is due to the elevation of status due to shelter upgrading. Over 50% of the present occupants are original owners and among the rest are rented units. In all, over 60% have retained the ownership. The third floors have been added incrementally, and the shelter size now makes it above lower income-level.

Basic Services for the Urban Poor (BSUP)

The scheme launched in 2005 aimed to provide basic services to the poor in 63 of the biggest Indian cities by providing security of tenure and improved services, but ultimately it provided subsidised housing (Mitlin & Thapa, 2015; Hindman et al., 2015). It is a component of a larger scheme, Jawaharlal Nehru National Urban Renewal Mission (Mitlin & Thapa, 2015). Managed by the Ministry of Housing and Poverty Alleviation (Hingorani, 2011b), it provides seven services, which are, security of tenure, affordable housing, water, social security, education, health, and sanitation to lower income groups in the selected cities (Jones Lang LaSalle, 2012). The focus of the scheme is on providing shelter (Hingorani, 2011b). In the scheme resettlement of four kinds occurred (Patel, Sliuzas, & Mathur, 2015)

1) Direct resettlement in BSUP dwelling unit
2) After short stay in temporary location, resettlement in BSUP dwelling unit
3) Prolonged stay in the temporary/interim location
4) Stay in makeshift shelters on demolished slum sites.

Research conducted by Patel et al. (2015), indicates that BSUP led to the further impoverishment of the poor due to unclear guidelines which led to the resettlement of the poor in faraway locations. The failures of resettlement were due to the lack of involvement of the intended beneficiaries from design, planning, and decision making.

The government provided a housing subsidy of 88% with the beneficiaries paying the remaining 12% (Hindman et al., 2015). Due to the limited financial capacity of the government, delays in construction took place which resulted in cost escalation (both for the beneficiaries and the government). Cost escalation resulted in poor quality of construction (Hindman et al., 2015). Cities such as Bhopal and Pune saw the occupation of only 22% and 45% of the newly built dwelling units (Mitlin & Thapa, 2015).

National Slum Development Programme

The scheme followed a slum upgrading approach promoted by World Bank which tries to preserve the investments made by slum dwellers (Hindman et al., 2015). National Slum Development Programme aimed to upgrade 47,124 slums across India by improvement of physical amenities such as water supply and sewers, community infrastructure such as community toilets, and social amenities. (Hindman et al., 2015; Hingorani, 2011b). The programme also includes a component of shelter upgrading and improvement and better convergence of different social sector programmes to create sustainable support systems ("Analysis of Government Policies on Slums Upgradation," n.d.). A major disadvantage of this scheme is that it is only able to target 50% of the slum settlements because it does not cover illegal slums (Rajan & Sood, n.d.)

The government gave loans to states for the purpose. The government invested in community amenities and provided loans to beneficiaries for housing. Sponsored by the central government 70% of the cost was provided in the form of loans and 30% in the form of grants ("Analysis of Government Policies on Slums Upgradation," n.d.). Only 70% of the funds were disbursed, and the project overall saw misused funds and time delays.

Due to limited funding, cheap solutions such as community toilets are brought about. These have low take-up rates with average for community toilets at 6% (Hindman et al., 2015).

Andhra Pradesh State Housing Corporation Limited (Adusumilli, 2001)

By the year 2001, Andhra Pradesh State Housing Corporation Limited had built 18,000 (in Hyderabad) upgraded dwelling units. These houses are available to households which have an income till Rs 18,000 per annum. The cost of the house is Rs 30,000 of which Rs 3000 is given as a subsidy, Rs 25,000 as a loan, and Rs 2000 is the beneficiaries contribution. Due to this being a low-cost project, only the land tenure and building framework are provided, the beneficiaries were expected to build the walls on their own. Due to this, many houses remained unoccupied.

2.2.2. Cross Subsidy

Slum Rehabilitation Scheme (SRS)

The scheme enacted by the SRA started in 1995 when the property prices in Mumbai were among some of the highest in the world (Jagdale, 2013). The scheme used land as a resource by which in situ redevelopment of slums is carried out. The scheme provides free of cost housing to all eligible slum dwellers by involving private developers who carry out the construction of houses for slum dwellers (Jagdale, 2013). The private developers do so because in return they are given incentives in the form of Transferable Development Rights (TDR) (Cronin, 2011). The government plays an enabling role by controlling the land; slum community organises themselves and the private developers who carry out the construction of low-cost, high rise housing (Nijman, 2008). Such a process is enabled by using the free market to provide incentives for developers to engage in the slum rehabilitation (Hindman et al., 2015). In this scheme, for every 10 square feet of rehabilitated space, builders were given 7.5 square feet free sale (Cronin, 2011). This process is known as cross-subsidisation, and because of it, slum dwellers receive free housing. Thus, SRS is driven by the interest of the developer and high land cost (Bardhan et al., 2015). To increase their profits further innovative methods to reduce the cost of construction such as using prefabricated concrete have been used to reduce the cost by 30% (Hindman et al., 2015). The scheme is profitable for private developers as they only have to pay 25% of the reckoner rate, obtain 70% of the slum residents consent and build high-density houses for them but in return, the developer can build luxury towers on the freed up land (Bharuchal, 2015). After 20 years of its inception, the schemecx created a functioning slum development market in Mumbai (Hindman et al., 2015). However, in many cases, due to the prerequisite of high-cost housing (such as GND, mentioned in the following section), the success of SRS is debatable. Developers closely monitor slums and take up only the ones in which they can generate enormous profits for themselves thereby excluding many of the slums from benefitting.

Case Studies

- Nanapeth, Pune (Cronin, 2011): This was the first redevelopment project under SRA in Pune. Squatters on private land were rehabilitated in-situ in high rise high-density buildings. The project was carried out and funded by a private property developer**, iParmer group**, who recovered the costs of providing housing by obtaining TDRs. TDR allows developers to sell additional built-up space for profits. However, due to the overall lack of transparency in the project which is enabled by no cost recovery, the beneficiaries did not trust the developers, and so they did not have a sense of ownership towards the dwellings. Also, since no NGOs were involved in the development process, the developers lack expertise (about slum communities) led to a feeling of dissatisfaction among the beneficiaries and inadequate social sustainability of the outcomes of the whole project.
- Ganesh Nagar D, Mumbai (Nijman, 2008): NGOs are also involved in the process of upgrading slums, and sometimes these NGOs work in the frameworks of existing government slum upgrading

schemes like SRS. Such a case has been documented by Nijman (2008). Ganesh Nagar D (GND), was densely populated and closely knit slum that in 1988 dealt with a fire, which exposed the need for rehabilitation of the slum and this attracted the attention of an NGO, **Slum Rehabilitation Society**. Using the framework of Slum Rehabilitation Scheme, the residents received 390 apartments and five shops. The apartments were an improvement from their former residence, but the take off for the rehabilitation was not easy despite a strong consensus for it among the slum community. This was because since the area was densely populated and surrounded by slums it was not attractive to the developers, so the NGO and the Ganesh Nagar D Housing Co-operative (established with the help of the NGO) explored an alternate route- the Co-op assisted by the NGO (Slum Rehabilitation Society) would take on the role of the developer and bear the costs by revenues from the selling land commercially. However, the initial payment was still a problem due to the lack of a developer, so every household contributed Rs 7700 which led to a collection of three million rupees that was used to finance initial expenses including an application for a loan. After some difficulties, the co-op was successful in obtaining a loan from a private bank for the up-front construction. Under SRA, houses of 225 feet^2, are to be provided free of cost, but in some cases, between Rs 10,000- 40,000 were asked of families to finalise the agreements (Nijman, 2008).
The case of GND is compelling as it followed the critical principle of SRS, and used the market forces to fund the construction, but the blueprint of SRS failed as for the rehabilitation, no developer was interested in the project. The critical role of NGO in the project and the self-help activities of the community also deviate from a traditional SRS project (Cronin, 2011).

SRA has been regarded as a failure by some scholars. Nijman (2008) summarises the outcomes of SRA as follows:

- By 2004, only about 19,000 tenements were built despite aims of constructing 8 lakh tenements in 5-6 years (Society for Promotion of Area Resource Centres, 2004). Due to poor locations of dwellings, developers and builders could not be brought in (as is seen in the case of GND).
- Despite good intentions, in some cases costs were passed on to the beneficiaries to maximise profit
- Developers convinced the beneficiaries into selling the pre-construction homes to them, which the developers then sold at market price.

<u>Pradhan Mantri Awas Yojna (Housing for All)</u>

Housing for All (2015) is a policy by the Ministry of Housing and Urban Poverty Alleviation, which aims to address a housing shortage of 20 million by 2022 (Ministry of Housing & Urban Poverty Alleviation, 2016). The scheme has four components to which one pertains to in-situ redevelopment (Puttkamer, 2015). As per the Ministry of Housing & Urban Poverty Alleviation (2016):

- The scheme aims to tap the unused potential of slum land through public-private partnership, using slum land as a resource
- The open bidding process would be used to select the private partners.
- The scheme provides a grant of Rs 1 lakh per household for all those which are eligible.
- All acceptable slums will be analysed for their location, land value, number of eligible residents, area. By this analysis, it will be decided whether the particular slum can be developed using a public-private partnership.
- A rehabilitation project would have two components, the first of providing housing to eligible slum dwellers (the size of each tenement being 30 m^2). The second would be the free sale for the private

developers to cross-subsidise the process. Slums are verticalised in situ, and the freed up land is given to private developers to cross-subsidise the redevelopment of slums.

- Consultation with slum dwellers for the formulation of redevelopment projects through their corporations and other means.
- The scheme would see a convergence of ministries such as Ministry of Railways and other land owning central government ministries to provide adequate housing to eligible slum dwellers.

The current requirement is of 18 million houses, and the majority of these are households belonging to lower income groups (Gopalan & Venkataraman, 2015). In the scheme, there is a component of slum redevelopment.

Hindman et al. (2015) and Puttkamer (2015) explain that subsidised housing is provided to the urban poor by using the land occupied by squatter settlements as a resource. Since the shortfall of houses is staggering and beyond the providing capacity of the government alone, public-private partnerships, similar to SRA are going to be used to provide housing. State and urban local bodies provide slum areas with additional floor space index which results in the verticalisation of slums. Land freed up by verticalisation is used by private developers for commercial resale

Housing for All is similar to the U.S. Housing Act of 1945, which provided federal grants and loans to create public housing with low rents, but this was a social cost of increased racial segregation (Hindman et al., 2015). This was due to local authorities segregating tenants in public housing according to race (Hoffman, 2000).

<u>Mumbai Urban Transport Project (MUTP)</u> (Mishra & Srinivas, 2012)

To improve the transport services in Mumbai, in 2002, about 100,000 people living along railway tracks and roads were resettled elsewhere. 95,000 of these were people who did not hold any legal title to the land on which they lived. **The Mumbai Metropolitan Region Development Authority** was the agency dealing with the resettlement process, and they not only resettled the displaced population but also provided the resettlement colonies with schools, day-care centres, and women's centres. An independent study found increased empowerment in the resettled families. The authority did not just engage with private developers but also held consultations and negotiations with the affected people by engaging with NGOs. This was useful in speeding up the process and removing resistance from the side of the beneficiaries. As is explained in the following section, sometimes NGOs work within the framework of existing policies. In this case, NGO **The Society for the Promotion of Area Resource Centres (SPARC**) a member of **the Alliance** (**National Slum Dwellers Federation and Mahila Milan** are the other two members) was appointed as the chief interlocutor by the MUTP (Jagdale, 2013). The project saw financial constraints, and cross-subsidisation helped deal with them. The houses and shops provided to the resettled community were provided free of cost. TDRs and FSIs were provided to private developers to motivate them to provide housing to the slum dwellers.

2.2.3. Nongovernmental Organisations

NGOs are not just involved in carrying out upgrading when contracted by government schemes or using the framework of existing schemes, but they also take up projects on their own and execute the upgrade, including enabling the financing required for the upgrade. NGOs work by the principle that, "poor people have the best solutions to their problems and are quite capable of not only devising strategies which work best for them but also implementing them" (Cronin, 2011).

The Alliance (Society for Promotion of Area Resource Centres, 2004)

SPARC is a prominent NGO in India that contributes towards slum redevelopment. SPARC works in partnership with two NGOs, **National Slum Dwellers Federation (**NSDF) and **Mahila Milan**, and together they are called **the Alliance**. They help the poor organise themselves at the grassroots level, by building up building their assets, searching for land, preparing managing the building and housing before they get tenure, shelter, and services. The Alliance takes up projects on its own, and they are involved in enumerating the slums and making detailed maps of the slums. In a case of forced eviction of slum dwellers along tracks by the railways, they were able to obtain alternate accommodation by presenting the maps of the slums they had prepared which had the location of every house.

In the case of Mumbai, due to the skyrocketing property price, slum dwellers are not expected to buy land, but by building up their financial resources, they are expected to contribute towards the construction and maintenance of their homes.

The Alliance's financial strategy is of help in building the financial assets and capacities of the members of target communities and the financial management capacities of the co-operation leadership. This helps the urban poor engage in the process of urban upgrading.

The financial assets are built by:

- Savings and credit: the savings can in future be used as credit for crisis, consumption and down payment for loans
- Investing in Mutual Funds
- Saving for maintenance expenses and slum sanitation

Shelter Associates (Cronin, 2012)

Kamgar Putla, Pune, a slum settlement located precariously close to river Mutha was partly flooded in 1997, after which the residents were moved away from the rivers to the Hadaspar. New houses were constructed under the coordination of a local NGO, **Shelter Associates** with the help of the affected community. The residents funded the construction and a government grant from the scheme Valmiki Ambedkar Malin Basti Awas Yojna (VAMBAY is a centrally sponsored scheme for the benefit of slum dwellers) provided the residents with a grant of Rs 50,000 per household. With the help of Shelter Associates, the families had managed to save Rs 5000. The amount remaining was less than 40%, for which the families were willing to mortgage their tenements and take a loan. Initially banks were reluctant to provide loans, but eventually, 11 households which had members employed in the formal sectors were able to obtain loans. Afterwards, 69 households too were able to obtain loans. This was done by three hgouseholds forming a module where two households became a guarantor for one. The loans were to be repaid over seven years at a rate of interest of 8.5% which mean Rs. 486 per month was to be paid by each households, an acceptable even to the lowest income households.

Of the 176 families to be rehabilitated, 144 were able to move into their houses. The remaining 32 houses were unfinished due to funds not being released by the banks. Half of these households have put in their own money to finish the houses.

2.2.4. Synthesis of Upgrading and Cost Recovery Practices in India

The many types of urban upgrading and related cost recovery, as well as their varied outcomes, have been discussed above. In the following, the different schemes are broadly categorized.

- In cases where the government provides subsidies covering the majority of the cost of upgrading, the financial burden put on the government can lead to lower occupancy of the dwellings, making financial capacities a significant factor. This is because more economic burden leads to the building of poor quality housing which not many intended beneficaries are willing to take up. Quality of upgraded facilities is hence another essential factor to the success of a programme. Financial burdens also lead to delays due to which escalation of costs occurs, making the amount of cost recovery unaffordable to the beneficiaries. Due to this often the intended beneficiaries move back to their old houses or some other slums as is seen in the case of Basic Services for Urban Poor.
- The government provides loans for a significant portion of the upgrading cost and recovers the remaining portion which is not provided as a loan immediately. The method of recovering the portion of cost not provided as the loan can be innovative, involving repayment by, labour, cash, or recycled materials from the old house. Such a scheme was mostly successful in achieving high occupancy. So, it can be understood that innovative methods of cost recovery play a role in the success of the scheme in terms of the occupancy of the upgraded dwelling units.
- In some projects, there is no cost recovery from the end user. This is enabled by the private-public partnership for housing construction that allows cross-subsidisation of the costs of upgrading. While this may seem like a "win-win" situation, for such cross-subsidization to work a necessary prerequisite is high property price around the target settlement. If the property prices are low, then developers will not see profit in the deal, and the project will not take off. Another factor of importance is the housing density (as is seen in the case of GND). If the housing density does not permit space for additional commercial houses, then the project falls flat as no developer will provide homes for free, without other incentives as such schemes aim to provide. Despite their shortcomings programmes such are Slum Rehabilitation Scheme, 1995 required no cost recovery from the end user through public-private partnership (Nijman, 2008) and provided housing in areas that were previously homogeneously occupied by lower income groups, to people from different income groups. The lower income groups remained there as well. Such a method should logically reduce income-based segregation in the area by bringing in people from various income groups.
- NGOs work by organising the slum communities at the grassroots level and helping them build up financial resources to fund the construction of their houses. This way when the time comes the slum dwellers have assets to fund the upgrading and maintenance of their homes.
  The essential factor here is building up the financial capacity of the slum dwellers the efforts of NGOs since in this case the slum dwellers pay for the construction costs.

2.3. Existing Models Simulating Urban Processes

For this study, modelling is used to see what effect different kinds of cost recovery in slum upgrading have on the segregation of slum population in an Indian city. Models are a representation of real systems which are built to answer questions or solve problems about the concerned real-world system (Railsback & Grimm, 2011). Modelling allows us to understand different scenarios by simulating them when studying these scenarios, in reality, would be time consuming and laborious. Modelling as a tool has been used to simulate urban processes for quite some time now.

Models have already been developed for simulating processes related to informal growth, slum formations and related processes. Some of them as reviewed by Roy et al. (2014) are:

- *Informal Settlement Growth Model by Sietchiping (2004)* is one the earliest models and simulates the location and emergence of informal settlements. It is a cellular automata model which is useful for urban planners and decision makers to obtain insights into the appearance of informal settlements in developing cities. The model also helps understand the socio-temporal processes of informal settlements and come across new findings of them using computer simulations.
- *The Peripheralization Model (Barros, 2004)* is an ABM that looks at slum formations through household behaviour. All agents have the same preference; they want to settle closer to the city centre. This is restricted by their economic power and their willingness to travel. There are three transition rules in this model, the first is a transition from higher to lower income group, the transition from lower to higher income group, and movement of higher income groups to suburbs.
- *Informal settlement growth pattern model by Odunuga Olaniyi (2009)* is an advancement of the work of *Barros (2004)*. It is used to explain the expansion of the city due to forming of low-income houses on the periphery. The search process for a house is based on utility maximisation approach. The model has three agent groups of, high, middle, and lower income. For the environment, the map of Ukonga ward of Dar es Salaam was used. The model also consists of four layers, the economic layer, spatial constrained areas, major roads, and landscape.
- *Slumulation by Patel et al. (2012)* is a spatial ABM that simulates slum formations based on Ahmedabad, India. The main agents in this model are the households (making locational decisions), the developer (adding to existing housing stock), and local politicians (providing subsidies to gain political votes). Since the developers and the politicians are at different scales, the model environment also has two different scales. This model is unique as it includes political agents, as well as developers who convert low-density housing into high-density housing.

Dynaslum by Roy et al. (2017) is another ABM which is useful for understanding the lifecycle of slum households. This is done by understating the impact of social determinants on the behaviour of a slum household. This model provides understanding to planners and policymakers who want to make low-cost housing about how slum dwellers make their residential choices. The study found that independent youth are responsible for the formation of smaller slum households.

InformalCity (Schwarz, 2015a) is a theoretical ABM that simulates an artificial city (using the context of Sub-Saharan Africa) and does not refer to a specific case study although, it does use some empirical data. InformalCity simulates "the effects of slum upgrading on both the built environment and the population distribution, including income segregation"(Schwarz et al., 2016).

Many of the models discussed above used a modelling technique called Agent-Based Modelling. This is because Agent-Based Models (ABM) include the individual behaviour of the agents which is useful for modelling processes and analysing the output as an emergent result of the individual behaviour (Roy et al., 2014). ABMs for slum dynamics are useful because, in ABM, agents are discrete entities with behaviours and rules governing their interactions (Nikolic, 2010). Agents which can have different variables and characteristics, interact with each other and their environment, and through these interactions give rise to the phenomena of interest- in the case of this study segregation (Patel et al., 2012). They are helpful in understanding and representing the emergence, growth and process of slums (Roy et al., 2014). ABMs offer the possibility of studying society and space in new ways (Barros, 2004). In ABMs, social processes are reproduced by defining some local conditions of interactions among the agents (Feitosa et al., 2008).

For this study ABM InformalCity developed by Schwarz (2015a) is used. InformalCity is a handy tool since it has already been successful in examining segregation due to urban upgrading (Schwarz et al., 2016). The model has added to the growing knowledge about urban upgrading. Details of the model can be found in section 4.1.

3. METHODOLOGY

For this study, an ABM developed by Schwarz (2015a) was adapted. The model simulates a hypothetical city which is based on the context of sub-Saharan Africa.

3.1. Literature Review

Since the model is a theoretical model, not an empirical one, no fieldwork was required. As the purpose of the study was to examine the effect of cost recovery in slum upgrading on segregation of slums in an Indian context, the simplistic options of upgrading and cost recovery in the parent model were changed using the information collected from the literature review. Even though the model is theoretical it uses some empirical data, and empirically founded components in the current model are, for instance, the size of the plot, the utility function and the incremental housing development style accommodated in the model which is similar to the development carried out by a Swahili house. Such components are based on Sub-Saharan Africa and did not need to be changed. The changes were developed using a literature review.

3.2. Modelling

In InformalCity the ABM used for this study, the city in the model has 49 districts in total. The number of plots per district is specified by the user so is the initial population and the population growth rate. The population is distributed into three income groups, low-income, middle-income and high-income. The proportion of each income group is also chosen by the user. More details about the original model are in section 4.1. For this study, using ABM, different combinations of upgrading and cost recovery options (mentioned in section 3.4) are tested to see the what emerges regarding segregation.

For developing the model and making the changes, NetLogo (Wilensky, 1999) was used. It is a modelling software for ABM. The changes and additions to the model were conceptualized first (section 4.2), and then brought together in the ODD+D matrix (section 4.3), after which they were implemented.

3.3. Conceptualization of The Model

In a detailed manner, the components of the model, such as the initial parameters, variables, agents and their attributes and the rules deciding their behaviour were decided. Some of the changes made in the model are based on empirical values. Such as the cost of upgrading a house (Hindman et al., 2015), the cost of construction, the price of land (NUMBEO, 2017) and the size of plots (Gopalan & Venkataraman, 2015). The changes made to the model were noted down along with the basis for these changes (section 4.2). Changes in the upgrading and cost recovery options were put into the conceptual design of the model. The conceptual design was written following the ODD+D protocol (Müller et al., 2013) in section 4.3.

ODD stands for "Overview, Design concepts, and Details". As Grimm et al. (2010) discuss in their paper, the ODD protocol published in 2006, standardises how agent-based models are described. An early criticism of ABMs is that they were hard to evaluate due to inadequate documentation was a motivation for developing the ODD protocol. The ODD+D matrix is an expansion of the ODD matrix "to establish a standard for describing ABMs that includes human decision-making" (Müller et al., 2013).

Table 2 The structure of the ODD+D matrix

Overview	1. Purpose
	2. Entities, state variables, and scales
	3. Process overview and scheduling
Design Concepts	4. Design concepts • Basic principles • Emergence • Adaptation • Objectives • Learning • Prediction • Sensing • Interaction • Stochasticity • Collectives • Observation
Details	5. Initialization
	6. Input data
	7. Submodels

3.4. Analysis

A sensitivity analysis is useful for examining the differences in the output that occurs as a result of the changes in the input parameters and variables (Roy et al., 2014). It also helps in the validation and calibration of the model (Railsback & Grimm, 2011). Sensitivity analysis is useful for exploring scenarios. Saltelli et al. (2004) (as cited by Saltelli et al. 2008) view sensitivity analysis as "the study of how uncertainty in the output of a model (numerical or otherwise) can be apportioned to different sources of uncertainty in the model input". It helps in understanding the behaviour of a model under different possible conditions (Barros, 2004) and is an essential tool for modellers who wish to help policymakers with their models (Pannell, 1997).

For this study, a sensitivity analysis was used to test different scenarios. These scenarios were built by altering and applying different parameter values and running them in different combinations.

There are seven main scenarios. Table 3 shows the different scenarios tested.

Scenario 1: This is the baseline scenario, without any interventions in the form of upgrading or verticalising.

Scenario 2 to 5: focus on cost recovery. They differ in their level of financial capacity from 2 to 10 (scenario 2 to 5). Each scenario is divided into six sub-scenarios which provide subsidies of 0 to 80 % (0, 20, 40, 60, 80) on the cost recovery from the beneficiaries.

Scenario 6: The last scenario is run with verticalisation turned on. This scenario does not use financial capacity, cost recovery and subsidies.

Table 3 Different scenarios and sub-scenarios

Scenarios	Upgrading	Financial Capacity	Subsidy?	Verticalisation
1	NA	NA	NA	NA
2.1	✓	2	NA	NA
2.2	✓	2	0	NA
2.3	✓	2	20	NA
2.4	✓	2	40	NA
2.5	✓	2	60	NA
2.6	✓	2	80	NA
3.1	✓	5	NA	NA
3.2	✓	5	0	NA
3.3	✓	5	20	NA
3.4	✓	5	40	NA
3.5	✓	5	60	NA
3.6	✓	5	80	NA
4.1	✓	7	NA	NA
4.2	✓	7	0	NA
4.3	✓	7	20	NA
4.4	✓	7	40	NA
4.5	✓	7	60	NA
4.6	✓	7	80	NA
5.1	✓	10	NA	NA
5.2	✓	10	0	NA
5.3	✓	10	20	NA
5.4	✓	10	40	NA
5.5	✓	10	60	NA
5.6	✓	10	80	NA
6	NA	NA	NA	✓

The initial parameters that did not change through all of the simulations are

1) Population: 2000
2) Growth Rate: 5%
3) Maintenance: On
4) Threshold Infrastructure: 30
5) Threshold for Upgrading and Verticalising: 0.5
6) Income Distribution: LogNormal

3.5. Measurement of the Results

For generating the results, the model was run in the BehaviourSpace and to make the results comparable ten random seeds were specified. Random numbers generated in a run in NetLogo are pseudo-random as they are generated using the random seed which is chosen (Netlogo Help, n.d.). A random seed is a number used to initialise a pseudorandom number generator (Stephanie, 2017). The 10 random seeds used here are 2, 4, 6, 8, 10, 12, 14, 16, 18 and 20. Using random seeds makes the results replicable and comparable.

The results obtained were about the behaviour of the of the same agents under different scenarios. The results were analysed using Excel 2016 and SPSS and were visually represented using boxplots, bar graphs and maps. For displaying the information such as the mean income per district or the total household per district, the district level data (in NetLogo terms, patch-level) was exported to ArcGIS and visually represented and characterised.

Measurement of the many different dimensions of segregation such as evenness, exposure, clustering, concentration, and centralization can be done using methods such as calculating the dissimilarity index, the entropy index, Gini coefficient, Atkinson's index (Massey & Denton, 1988). For the analysis of segregation in this study, the Gini coefficient was calculated for each time step.

The Gini coefficient measures how evenly the object of interest is distributed (United Nations Human Settlements Programme, 2009). Its values range from 0 to 1, with 0 representing most even distribution and 1 representing most uneven distribution. Massey & Denton (1988) define Gini coefficient as "the mean absolute difference between minority proportions weighted across all pairs of areal units, expressed as a proportion of the maximum weighted mean difference." For the study the Gini coefficient for lower-income households (which measures how lower-income households are distributed compared to the whole population throughout the city) and the Gini coefficient for higher-income households (which measures how higher-income households are distributed compared to the whole population throughout the city) wer measured. Measuring them separately helped in comparison of the segregation levels of the two income groups. The Gini coefficient for lower-income households was calculated in the original model, but the Gini coefficient for higher-income households is an addition to the adapted new model.

4. MODEL CONCEPT

4.1. InformalCity: Original Model[2]

For this study, the model, InformalCity was adapted to understand the relationship between cost recovery (in urban upgrading) and income segregation.

The research question answered with the help of the original mode was:

> How does the design of urban upgrading schemes in informal settlements affect infrastructure quality and city-wide population distribution including income segregation?

The model is of use to scientists working in the global south.

The Agents

The households are the agents, and they are either tenants or owners. They have additional parameters which are, tenure status (owner or tenant), income (ranges between 0 to 1), savings (the initial savings are a random number of 1-15 times the income), preference regarding their locational choice (depending on distance to central district), plot ID of home, number of occupied rooms, list of rented plots (if landlord). Agent have low, medium and high income if they have income less than 0.25, 0.75, and 1 respectively. The number of agent's increase over time with a population growth rate that can be specified by the user. Agents move across districts and tenants can become owners as time steps progress. Details of the movement of agents can be found in the ODD+D matrix under sub section III.iv.a.

The Model Environment

The model contains 49 districts which span over a seven by seven grid with the central business district in the middle. The initial number of plots per district are user specified with only a house per plot. The size of the plot is 250m^2. The cost of acquiring a plot is not considered, but the cost of constructing a house is deducted from the savings of the agent (owners) who build a house on plots. Plots have additional parameters which are, location within the grid, number of rooms for rent, size, list of owners and tenants, the maximum number of rooms. One house can have a maximum of 10 rooms, which are built in steps of 3, 3, 3 and 1. The building costs changes with the number of rooms built and the cost of construction can be chosen by the user.

The Infrastructure Quality

The type of infrastructure is not specified in the model, but it is understood to mean the quality of drinking water supply, electricity, and roads. The infrastructure quality is dependent on the household density. It can be enhanced by upgrading programs. The higher, the higher the infrastructure quality, the better is the infrastructure.

[2] (Schwarz et al., 2016)

Time Steps

At the time of initialization, the city is empty, with no houses or agents. Newly created agents look for a room to rent if they cannot find one they settle down as owners. Newly added agents no matter what time-step try to settle as tenants. In any time-steps after the initialization the agents try to increase their savings, and 10% of the agents enter a decision making process, due to factors such as the arrival of new family members. In this decision making, if the availability and affordability of a new plot are satisfactory, the utility of the plot is calculated. This is done so using the following equation:

Utility= a x proximityCBD + b x quality infrastructure

where a: an agent's preference to live close to the CBD; b: an agent's preference for infrastructure quality; proximityCBD: 1 e distance to the CBD (with distance to the CBD ranging from 0 to 1); quality Infrastructure: the quality of infrastructure in a district as computed using an equation

After this calculation, a district (agents cannot move to a plot within the same district) with the highest utility is chosen. If owners do not have sufficient savings, they may expand their house to put rooms on rent and increase savings. Tenants may move and become house owners if it fits with affordability. If the savings are not sufficient (equal to or more than the building cost), then they may move to another district and rent.

Urban Upgrading

Infrastructure quality is influenced by housing density. If the option of upgrading is turned on then districts with infrastructure quality below the threshold (set by the user) are upgraded. The upgrading is implemented using the following rules:

- Which time-step is upgrading implemented in?
  Two options are provided to the user which are “early” and “late”. If the option of “early” is chosen, then the first district to have infrastructure quality of less than 50% is upgraded. If the option of “late” is chosen, then upgrading is carried out as soon as 50% of the inhabited districts have infrastructure quality less than 50%.
- Number of districts upgraded
  The number of districts to be upgraded are also chosen by the user. The two choices are “many districts with low quality (80% of the districts)” and “few districts with high quality (10% of the districts)”
- Which districts are upgraded?
  The two options that the users of the model can choose from are; random (in which any district is chosen) and districts with the lowest quality first.
- How is the infrastructure improved?
  The first option, “many districts with high quality” increases the infrastructure quality of chosen districts by 20%. The second option is “few districts with high quality”, and this increases the infrastructure quality of the chosen districts by 100%.
- Cost recovery
  This option can be turned on and off. If it is turned on then if the savings of the inhabitants in the target districts are more than or equal to 1, they are reduced by 1.

4.2. Basis for The Changes in The Model

Using the literature review carried out in chapter 2, changes were made to the current model, which are mentioned below. A new ODD+D model description is presented in Section 4.3. The ODD+D matrix uses the original model's ODD+D matrix (Schwarz, 2015b) as the basis and only the changes made in the model and the differences in the simulation variables are altered in the matrix (the original OOD+D is in times new roman font, and the new text is underlined).

Some values introduced in the model are based on empirical data. For monetary values in the model, normalisation from real values in India is done. In the model, the income of .25 per time step represents lower income. In the case of India, the maximum income per day a low-income family earns approximately $ 10 (Pew Research Center, 2015), so for the entire year, the income is $ 3650. So the model currency of .25 stands for $3650 in the Indian context. Hence, 1 in the model currency for $11600 in the Indian context. The value of 1 has been used to normalise the different values (cost of construction, asset building, financial capacity, cost of upgrading, the price of land) for the model environment. More details into the normalisation technique are provided in the ODD+D matrix.

Some of the options required to study the impact of cost recovery in slum upgrading on the income segregation in the context of India already existed in the model, such as the cost of construction, the option of upgrading and the cost of upgrading. The functions of these options required changes to accommodate better the objectives of this study. Four categories of changes were required. They are 1) Verticalisation 2) Upgrading 3) Cost Recovery 4) Adaptation for Indian Context. In the following subsection, the changes are grouped with the main changes that require them.

4.2.1. Verticalisation

The verticalisation of houses is an addition to the upgrading options in the model. If this option is chosen (a switch by the name "verticalise?" to turn the option on and off), then plots equalling to 75% of the plots in the district before the verticalisation will be added to the district. This addition is a workaround to signify verticalisation where in reality the earlier existing houses are verticalised and in the land freed up new houses are built, but since the model does not contain a method to accommodate vertical growth, the plot number is increased as the plots represent housing units (one house per plot) and in the case of verticalisation essentially there is an increase in the housing units. This is helpful in maintaining the simplicity of the model. The infrastructure quality is improved to 1.

For example, a district has 75 plots. Upon upgrading the total plots will increase to 131 plots in the verticalised districts with 56 of them newly added due to the verticalisation.

This rule is introduced because according to the guidelines of SRS, TDR for upgrading allows development of sale component up to .75 times the total rehabilitated area (Burra, 2005).

Verticalisation is a significant addition to this model since the verticalisation of slum household clears up land which is then used commercially. The money thus generated funds the upgrading of slum households. Verticalisation of slum households is also a very intriguing concept when it comes to its effect on the segregation patterns within the area. This has already been discussed in Section 2.2.4.

For this change to function in the model, a few other additions need to be made. They are:

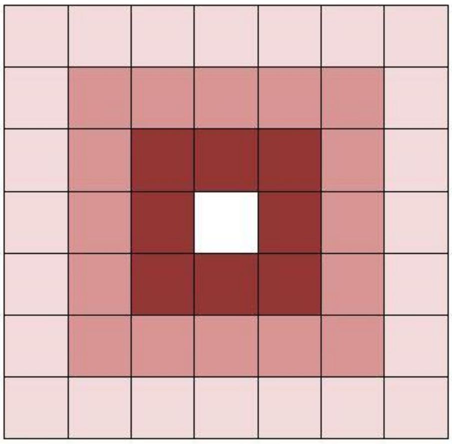
1.a) Price of land:

The land in the city has a price which decreases according to distance away from the city centre. The highest value for the land, 15, is at the city centre and the lowest of 5 in the areas farthest from the city centre. The normalisation techniques for these are discussed in the ODD+D matrix. For simplicity, the land price remains same overall time steps. The land price in the code was added to the already existing building costs.

1.b) Informality:

In the model, districts are divided into formal and informal districts. The agents who cannot afford to pay for the price of a plot in a formal district will settle on a plot in an informal district and only pay for the price of construction of the house. Six informal districts are spread throughout the city.

Two are at distance less than 0.3 but more than 0.2
Two are at a distance less than 0.6 but more than 0.3
Two are at a distance less than one but more than 0.6



Colour	Distance to centre	Number of informal districts
	Centre	NA
	0.2- 0.3	Any 2 districts
	0.3- 0.6	Any 2 districts
	0.6- 1	Any two districts

Figure 1. Informal districts in the model city

Having different statuses (formal or informal) ensures that to settle in the informal district the residents do not pay for the price of land (they do pay when they settle in formal districts). This detail makes the model realistic as without it the lower income groups would only be able to reside in the outskirts, which is not the case as lower income groups settle on high priced land without paying its price. As is explained in Section 2.2.4, upgrading by verticalisation is most successful (and often carried out) when the target settlement (target of verticalisation) is located on high priced land. Verticalising such settlements clear up land for private developers. So, for such upgrading options to function a distinction between formal and informal is required, where the informal settlements occupy the commercially valuable land. It is also an important detail for the case of upgrading where if a district is upgraded it is converted to a formal district.

1.c) Utility Equation:

Preference for formality was added to the utility equation (which is discussed in section 4.1). Without this preference, all agents would settle informally even if they can afford to settle formally. The preference in the utility equation corresponds with the income levels meaning if the income levels are high then that household has a higher preference for formal housing.

4.2.2. Upgrading

For the option of classical upgrading to function some changes in the model were required. They are:

2.a) Check if upgrading should be implemented at the current time step:

A new district for upgrading is selected every five time steps. Upgrading is carried out in correspondence with election cycle in India which is every five years. A fundamental difference here from the original model is that more than one district can be upgraded throughout all the time steps, although in a single time step only one can be upgraded. This change makes the model better suited to the case of India, where the welfare of the poor is dependent on their political vote bank significance.

An example of this has been discussed in Section 2.2 citing the work of Patel et al. (2012).

2.b) Select target districts:

As in discussed in the point exactly above, residents in areas where there is a higher number of slum households receive more benefits, as their satisfaction provides more votes for the politicians. Hence in the model, informal districts with the largest population are targeted. Due to this change, the option of "target" in the user interface was removed.

2.c) Number of target districts:

To maintain simplicity, if the option of upgrading is turned on, one district will be upgraded. Due to this, the option of "distribution" was removed from the user interface.

2.d) Financial capacity:

Financial capacity was introduced in the model. This financial capacity represents the money with the city authorities or a programme for slum upgrading. The financial capacity can be altered, and this option was added in the user interface in the form of a slider, where the value ranges from 0 to 10.

Financial capacity is essential in the model because the amount can impact the results of an upgrading scheme. As is seen in the case of BSUP, where the project was mainly unsuccessful because huge subsidies provided were beyond the financial capacity of the government. This led to delays in the upgrading and cost escalation for both the government and the beneficiaries. As is discussed in Section 2.2, this cost escalation can lead to the intended recipients of the scheme to move back to the slums or to some other slums.

2.e) Delay:

The delay calculates the number of time-steps that would be required to gather enough financial capacity to cover the costs of upgrading. If there is no delay, then the infrastructure quality is upgraded to maximum for the district (which is 1). However, if the delay exceeds 0, then the financial capacity is either improved to .75 (if the delay is less than 4) or .50 (if the delay is more than 4). With each number of delay also comes an increase (8 %) in the cost of upgrading. This is decided using information provided by Hindman et al. (2015) which states that there is an 80 % increase in the cost of construction over ten years. Since one unit of delay means one time-step (representing one year), an 8% increase per one value of delay is carried out.

This change was made to take advantage of the addition of financial capacity in the model. Delays in upgrading often lead to cost escalation and unacceptable quality housing being built, as is discussed for some of the cases listed in Section 2.2.

4.2.3. Cost Recovery

To recover the costs of upgrading from the beneficiaries of upgrading the user can switch on the option of "cost-coverage?". To understand how this functions, first the changes made in the model to allow cost recovery to work are discussed.

3.a) The cost of upgrading:

One unit is upgraded for a value of .39, after normalising the value of ₹3,00,000 per house which was used during the programme BSUP (Hindman et al., 2015). This amount is funded by the overall financial capacity of the model. The ODD+D matrix provides details on the normalisation technique.

3.b) Subsidy:

A new slider option called "subsidy?" was introduced to the model interface. The values in the slider ranged from 0 to 100 %. These values are to be chosen by the user, and they signify the percentage of discount a beneficiary household (beneficiary of upgrading) would receive on the total cost of upgrading which is recovered from the beneficiary.

For example, if the total cost of upgrading per beneficiary is 1 and the discount chosen is 80% then the beneficiary would only pay .20.

3.d) Movement of beneficiaries:

If cost recovery is turned on and the delay is greater than 4, the owner beneficiaries of the upgraded district come under decision making and calculate the utility of all the districts, and of the upgraded district. If there is a district with better utility than that of the upgraded one, the household checks whether any of the random districts with the better utility is affordable to them. If they can afford a district with better utility, then they move to that district. If not, then the cost of upgrading one plot is deducted from their savings.

To enable cost recovery from the beneficiaries in the model "cost-coverage" in the user interface can be turned on by the user. Cost coverage works in correspondence with the slider option of "subsidy?". When cost coverage is switched on the model uses the "subsidy" to calculate a cost to recover from the beneficiary households.

The cost recovery option is useful as it provides in the model an option which is similar to many of the government-funded schemes in India. In such schemes, a portion of the total cost is recovered from the beneficiaries, and the rest is provided as a subsidy. If the amount provided as the subsidy exceeds the financial capacity of the government, then delays in construction and cost escalation of the construction costs can occur. In such a case the upgraded facilities have very low occupancy/usage. In many cases, the intended beneficiaries of such schemes move back to slums which they find affordable. Such a movement back to the slums would reinforce the segregation of lower-income groups.

4.2.4. Adaptation for Indian Context

The changes listed below are made to better adapt the model to the Indian context to yield more realistic results. These changes use numerical values related to costs and income, size of plots, cost of construction, selection of target districts, and building asset.

4.a) The size of the plots:

For all plots, the size of 64 m^2 was taken. This size was chosen following the guidelines provided by the Ministry of Housing and Urban Poverty Alleviation (Gopalan & Venkataraman, 2015) which suggest 48 m² and 80 m² households for the lower-income group and middle-income group respectively. 64 m² is an average of the two.

4.b) The cost of construction:

For 64 m² the cost of constructing three rooms is 1.8 in the model. The normalisation technique used for this has been discussed in the ODD+D matrix in section 4.3.

4.c) Asset Building:

With this option, addition money is added to the savings of the lower-income households in the model. This addition is highly suited for the case of India where NGOs help lower-income households save money so that the households are able to bear some of the costs of their upgrading. A switch on the interface allows this option to be switched on or off. This allows the user to investigate the effect of asset building on the ability to pay for cost recovery on the parts of slum dwellers. When turned on 0.038 is added to the overall savings of lower income households per time step. This is done by normalising the amount NGO SPARC helps slum dwellers save, which is $ 450 (Society for Promotion of Area Resource Centres, 2004).

NGOs help build up the financial capacity of the slum dwellers. This option accounts for all the innovations and capacity building that are carried out while slum upgrading which influences the ability of the beneficiaries to pay for the services provided to them.

4.3. ODD+ DI Model Description[3]

Overview[4]

I.i Purpose

I.i.a What is the purpose of the study?
The model aims to understand how income segregation within a city is influenced by cost recovery carried out in urban upgrading. To investigate this, upgrading, verticalisation and cost recovery options are introduced into the model. Using InformalCity, a model built in the context of sub-Saharan Africa; this model has been adapted to the context of India.

I.i.b For whom is the model designed?
The model is designed for scientists and policymakers working on urban upgrading issues in the global south as well as for teachers and students who wish to study the issue.

I.ii Entities, State Variables and Scales

I.ii.a. What kinds of entities are in the model?
Agents represent households **which are** of two types: tenants and owners. Both agent types have additional characteristics which influence the decisions taken.
The environment consists of 49 districts that are represented by raster cells. These districts are thus spatially explicit located in an urban region. The districts consist of plots that are increasingly sealed with residential houses.

I.ii.b. By what attributes (i.e., state variables and parameters) are these entities characterised?
Agents have the following attributes: id, tenure status (owner/tenant), income numeric from 0 to 1), savings, preferences regarding their location choice (quality of public infrastructure, proximity to CBD, formal/informal), plot id of own home, number of occupied rooms, (if also landlord) list of rented plots. Agents are of three income classes; low, medium and high for incomes lower than 0.25, 0.75 and 1, respectively.
Districts have the following attributes: id, location within the grid, list of agents in the district, list of plots in the district, quality of public infrastructure, formal/informal.
Plots have the following attributes: id, number of all rooms, number of rooms for rent, size, list of owner and tenants, and maximum number of rooms.

I.ii.c What are the exogenous factors/drivers of the model?
Population growth as a percentage, including both in-migration from rural hinterland and natural population growth rate in the city. Furthermore, upgrading, verticalisation, and cost recovery options can be chosen.

I.ii.d If applicable, how is space included in the model?
Spatially explicit with raster cells representing districts.

I.ii.e What are the temporal and spatial resolutions and extents of the model?

[3] (Müller et al., 2013)
[4] The text underlined are additions to the original ODD+D by Schwarz (2015b). The text in Times New Roman is the original text.

One-time step represents one year; simulations cover 21 years.
One raster cell represents one district with an initial number of plots to be set at the beginning of the simulation. A total of 49 districts are represented in the model.

I.iii Process Overview and Scheduling

I.iii.a What entity does what, and in what order?

Two main phases are distinguished for the model: initialisation and one simulation step.

- Initialisation (tick = 0)
  Model, initial agents and space are created and initialised, using settings read from the GUI.
- Simulation step (ticks 1 to n)
  - Infrastructure quality is updated (see III.iv.a – Infrastructure update)
  - New agents are created as tenants, accounting for population growth and immigration. All agents perform their decisions one after the other (see III.iv.a – agent's simulation step)
  - Data structures are updated for exporting and visualising data

Design Concepts

Ii.I Theoretical and Empirical Background

II.i.a Which general concept, theories or hypotheses are underlying the model's design at the system level or the level(s) of the submodel(s) (apart from the decision model)? What are the link to the complexity and the purpose of the model?

InformalCity is rooted in location theory and applies the approach of the Alonso model (Alonso, 1964). Slums are often located in the central parts of the city where the land value is high. The government tends to relocate them to the outskirts, but they do not find adequate opportunities there and hence move back to the slums which are centrally located (Takeuchi, Cropper, & Bento, 2008). To take this process into account and to simultaneously keep the approach as simple as possible, InformalCity deviates from Alonso's assumptions in three points regarding decision making (see II.i.b).

II.i.b On what assumptions is/are the agents' decision model(s) based?

Combination of theory (Alonso model, see II.i.b) and empirical observations that deviate from Alonso's assumptions:

- The utility function relates to the utility derived from location choice. Thus, composite goods are not represented explicitly, and only the budget available for housing is considered. Agents maximise their utility within the limit of their budget constraints (i.e. savings). Thus, the basic decision model follows the concept of homo oeconomicus.
- Infrastructure quality is added to the utility function. This is underlined by Young's (2010) empirical finding that – next to proximity to CBD - infrastructure-related aspects like access to drinking water or roads were the factors most often mentioned in her empirical study on informal settlements in Dar es Salaam, Tanzania.
- Preference for formal plots is added to the utility equation. It is assumed in the model that the formal plots have better infrastructural facilities and land tenure as compared to the informal plots as is the case in reality.
- In the model, the different districts have different land prices (which in the code are added to the building cost). This is because in a city land has different values with the highest being in areas near the city centre (Hindman et al., 2015). The agents will pay for the land they choose to settle on and

will consider the price of land while deciding the affordability. This rule only applies to the formal plots. For settling on the informal plots, the price of land is not considered, only the value of building cost is.

II.i.c Why is /are certain decision model(s) chosen?

To keep the model as simple as possible, the approach of homo oeconomicus was chosen. There are only three preferences in the decision making (for the CBD, infrastructure quality and formal district). No empirical data were available on the nature of the decision-making process itself, i.e. the information sought, consideration of different options.

II.i.d If the model/submodel (e.g., the decision model) is based on empirical data, where do the data come from?

The values in the model which are based on empirical data are:
The Normalisation Technique:
To normalise some values for the model real values have been used which are gathered from different sources.
In the model, lower income households earn .25 or lower than that per time-step. In India, a lower income household earns up to $3,650 per year (Pew Research Center, 2015), the value of 1 in the model currency is calculated to be $ 11,600 in the case of India. Using this value of 1, some of the values in the model have been calculated, like:

1) Price of land: Using data gathered on the city of Mumbai from NUMBEO (2017) the price of land in the model has been set in a linear gradient. The price of an apartment near the city centre in Mumbai for the year 2017 is approximately $ 6885 per meter^2 and outside the centre is $2548 per meter^2. So for a 64 per meter^2 plot, the value would be around $ 440,640 in the city centre and 163,072 outside the city centre. These values were normalised for the model, and they were 37 in the city centre and 15 for the districts further away. However, in the model, there is no system of providing loans or taking mortgages, which is how in reality people can buy houses. Since the cost of 37 is much above the maximum savings (initially) any household can have, and no system to mortgage exists in the model, the highest land price was reduced from 37 to 15 (the maximum savings possible). In the model, the price ranges from 5-15 depending on the distance from the city centre. 15 is the maximum savings possible in the model, so this is taken as the maximum price of land.
2) Cost of Constructing: The cost of construction for 64 meter^2 in Mumbai is approximately $21197. An internet search on a few Indian property websites was used to inform this figure. Using the value of 1 in the model (11600), $21197 is normalised and set at 1.8 in the model.
3) Cost of Upgrading: The cost of upgrading a dwelling unit for the scheme Basic Services for Urban Poor is approximately $4621 (Hindman et al., 2015). Using the value of 1 in the model, the cost of upgrading in the model is normalised to .39.
4) Asset Building: NGO SPARC helps beneficiaries in asset building by helping them save about $450. This value is normalised using the value of 1 and the model the value of asset building is 0.038.
5) Cost Escalation: As Hindman et al. (2015) discuss in their work, in 10 years an 80 % increase in the costs of construction occurs. This comes down to about 8% per year. Since one time-step in the model represents 1 year, with each year delay an 8 % increase in the costs of upgrading occurs.

II.i.e At which level of aggregation were the data available?

The data used is at two different levels. The data for the financial capacity is at the city level, and all the other data is at the household level.

II.ii INDIVIDUAL DECISION- MAKING

II.ii.a What are the subjects and objects of the decision-making? On which level of aggregation is decision-making modelled? Are multiple levels of decision making included?
One level of decision making: household level.
The subject of decision making: household.
The object of decision making: Finding a room to rent, finding a plot to build, enlarge existing house, rent out rooms.

II.ii.b What is the basic rationality behind agent decision-making in the model? Do agents pursue an explicit objective or have other success criteria?
The agents consider their savings only to consider those options that are feasible. Agents optimise their utility by considering infrastructure quality, proximity to CBD **and whether the district is formal or informal.** See III.iv.a for details.

II.ii.c How do agents make their decisions?
Utility function at the core, combined with a decision tree that accounts for the amount of savings already acquired.

II.ii.d Do the agents adapt their behaviour to changing endogenous and exogenous state variables? And if yes, how?
No.

II.ii.e Do social norms or cultural values play a role in the decision-making process?
No.

II.ii.f Do spatial aspects play a role in the decision process?
Spatial proximity to the CBD is an attribute of the district. Proximity to CBD = 1 - distance to CBD (with distance to CBD in a range of 0 to 1).

II.ii.g Do temporal aspects play a role in the decision process?
No.

II.ii.h To which extent and how is uncertainty included in the agents' decision rules?
Not at all.

II.iii LEARNING

II.iii.a Is individual learning included in the decision process? How do individuals change their decision rules over time as consequence of their experience?
Not at all.

II.iii.b Is collective learning implemented in the model?
No.

II.iv Individual Sensing

II.iv.a What endogenous and exogenous state variables are individuals assumed to sense and consider in their decisions? Is the sensing process erroneous?
Agents consider the following endogenous state variables of the districts: available empty plots or available empty rooms, respectively, quality of infrastructure, costs to build in the district, cost of land (for agents settling informal plots), proximity to CBD, whether formal or informal.
Agents do not consider exogenous state variables. The sensing process is not erroneous.

II.iv.b What state variables of which other individuals can an individual perceive? Is the sensing process erroneous?
None.

II.iv.c What is the spatial scale of sensing?
Global: agents perceive the attributes of all districts.

II.iv.d Are the mechanisms by which agents obtain information modelled explicitly, or are individuals simply assumed to know these variables?
Agents are assumed to know these variables.

II.iv.e Are the costs for cognition and the costs to gather information explicitly included in the model?
No.

II.v Individual Prediction

II.v.a Which data do the agents use to predict future conditions?
Household agents do not predict future conditions.

II.v.b What internal models are agents assumed to use to estimate future conditions or consequences of their decisions?
Agents do not predict future conditions.

II.v.c Might agents be erroneous in the prediction process, and how it is implemented?
Agents do not predict future conditions.

II.vi Interaction

II.vi.a Are interactions among agents and entities assumed as direct or indirect?
Interaction among agents is indirectly based on:

- availability of free rooms to rent / free plots to build on
- increased savings if landlords rent out rooms,
- decreased infrastructure quality because of high population density.

The interaction between agents and districts/plots is direct, as agents move to a particular district and occupy a plot.

II.vi.b On what do the interactions depend?
Interactions among agents depend on their location choice (for tenant-landlord) or are local (change in infrastructure quality due to population density). Agents consider all districts when deciding on a new location.

II.vi.c If the interactions involve communication, how are such communications represented?
The interactions do not involve communication.

II.vi.d If a coordination network exists, how does it affect the agent behaviour? Is the structure of the network imposed or emergent?
No coordination network.

II.vii Collectives

II.vii.a Do the individuals form or belong to aggregations that affect and are affected by the individuals? Are these aggregations imposed by the modeller or do they emerge during the simulation?
No.

II.vii.b How are collectives represented?
Not at all.

II.viii Heterogeneity

II.viii.a Are the agents heterogeneous? If yes, which state variables and/or processes differ between the agents?
Agents differ concerning tenure status (owner, tenant), income, initial savings, and preferences for proximity to CBD, formal (or informal) and infrastructure quality.

II.viii.b Are the agents heterogeneous in their decision-making? If yes, which decision models or decision objects differ between the agents?
Agent types differ regarding the objects of decision making/options they can choose from:
Tenants decide whether to move as a tenant to another rented room or to become the owner and build on a free plot.
Owners decide whether to move to another plot and later rent out their old house, to enlarge their house and to rent out rooms for tenants. However, both maximise their utility under given budget constraints.

II.ix Stochasticity

II.ix.a What process (including initialisation) are modelled by assuming they are random or partly random?
Initialisation of household agents: preference for infrastructure quality, preference for proximity to CBD, preference for formality, initial amount of savings, income, and which districts are informal are drawn from distributions.
Decision making of household agents:

1. Consideration of own situation in 1 out of 10 cases
2. Occupation of rooms after moving: randomly from 1 to 3

II.x Observation

II.x.a What data are collected from the ABM for testing, understanding and analysing it, and how and when are they collected?

Aggregated data on the city level:

Number of households, number of tenants, number of owners, number of informal households, number of formal households, number of low income households (income less than .25), number of middle income households (income between 0.25 and .75), number of high income households (income larger than .75), number of occupied plots, number of free plots, number of rented rooms, number of rooms occupied by owners, number of households moving, mean built-up rate, mean infrastructure quality, Gini-coefficient low-income households, Gini-coefficent high-income households, Gini-coefficient builtup-rate, Gini-coefficient infrastructure quality, Gini-coefficient household density.

Data on gradients from CBD:

Mean household number, infrastructure quality, built-up rate, mean household income.

Data per district:

Time step of upgrading, household density per hectare, mean infrastructure quality, mean household income, number of lower-income households, the total number of households, whether the district is formal or informal, built-up plots, occupied plots, rented plots.

II.x.b What key results, outputs or characteristics of the model are emerging from the individuals? (Emergence)

Income segregation (i.e., the spatial distribution of households differentiated by income level), differences in built-up rates and infrastructure quality depending on upgrading options.

Details

III.i Implementation Details

III.i.a How has the model been implemented?

NetLogo 6.0.1

III.ib Is the model accessible, and if so where?

The original model (InformalCity) is published in the model library of openabm.org: http://www.openabm.org/models. The current model is added to the appendix of this thesis.

III.ii INITIALISATION

III.ii.a What is the initial state of the model world, i.e., at time t=0 of a simulation run?

The environment consists of 49 districts with fixed plots number (to be set at the beginning of the simulation). The plots 64 m² large. There are 6 districts in the model which are informal, and the rest are formal. The CBD is located in the middle. An initial number of household agents is created. During initialisation, agents are not distributed over the district but select the district in the first computation step. Agents' preferences, income and initial savings are assigned randomly: The income distribution can be set at the beginning of the simulation (equal distribution, normal distribution and log-normal distribution). Agents' preferences for infrastructure quality and distance to CBD are assigned from a normal distribution, and the preference for formal are assigned according to income and scaled to add up to 1. Initial saving is a random number between 1 and 15 times income.

III.ii.a Is the initialisation always the same, or is it allowed to vary among simulations?
The initialisation varies among simulations due to the random processes for attributing income, initial savings, preferences and location of formal and informal districts.

III.ii.c Are the initial values chosen arbitrarily or based on data?
Most of the initial values are arbitrarily chosen, but some values such a price of land, cost of construction, cost of the upgrade are based on empirical data.

III.iii Input Data

III.iii.a Does the model use input from external sources such as data files or other models to represent processes that change over time?
No.

III.iv Submodels

III.iv.a What, in detail, are the submodels that represent the processes listed in 'Process overview and scheduling'?
Agents' simulation step

- If agents are newly created, they settle for the first time:
  - [1] If they find a room to rent, they do so.
  - [2] Otherwise, they become owners and build a house (even without having enough savings), occupying 1-3 rooms (randomly)
- Else: agents are already located somewhere in the city:
  - [3] Agents save money by adding their income to their savings. If they own rooms that are rented to tenants, they further increase their savings.
  - [4] Agents consider their own situation randomly: in 1 out of 10 cases, they enter a decision 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:

 [5] They move if they have enough savings to build in another district and have found a district that fits better with their needs than the current one:

- find new district which has empty plots, costs that are lower than current savings and has the highest utility (quality of infrastructure, proximity to CBD, formal?)
- build a house on a new plot
- occupy 1-3 rooms (randomly)
- vacate old plot and district

 [6] They stay if the current district has the highest utility, and then add more rooms if they have enough savings.

- If agents want to move and are tenants:
  - [5] If they have enough savings to build in a district and have found a district that fits better to their needs (which has empty plots and has the highest utility (quality of infrastructure, proximity to CBD, formal?)) than the current one, they become owner and

- choose this district
- build a house on a new plot
- vacate old plot and district

▪ [7] If they have less savings, they stay tenants and

- find new district which has empty rooms for rent and has the highest preference (quality of infrastructure, proximity to CBD, formal?)
- move there
- vacate old room/plot and district

- Else: agents do not want to move

▪ [8] If agents are owners: If they have enough savings, they can enlarge their house to rent out rooms.

▪ Tenants who do not move do nothing else.

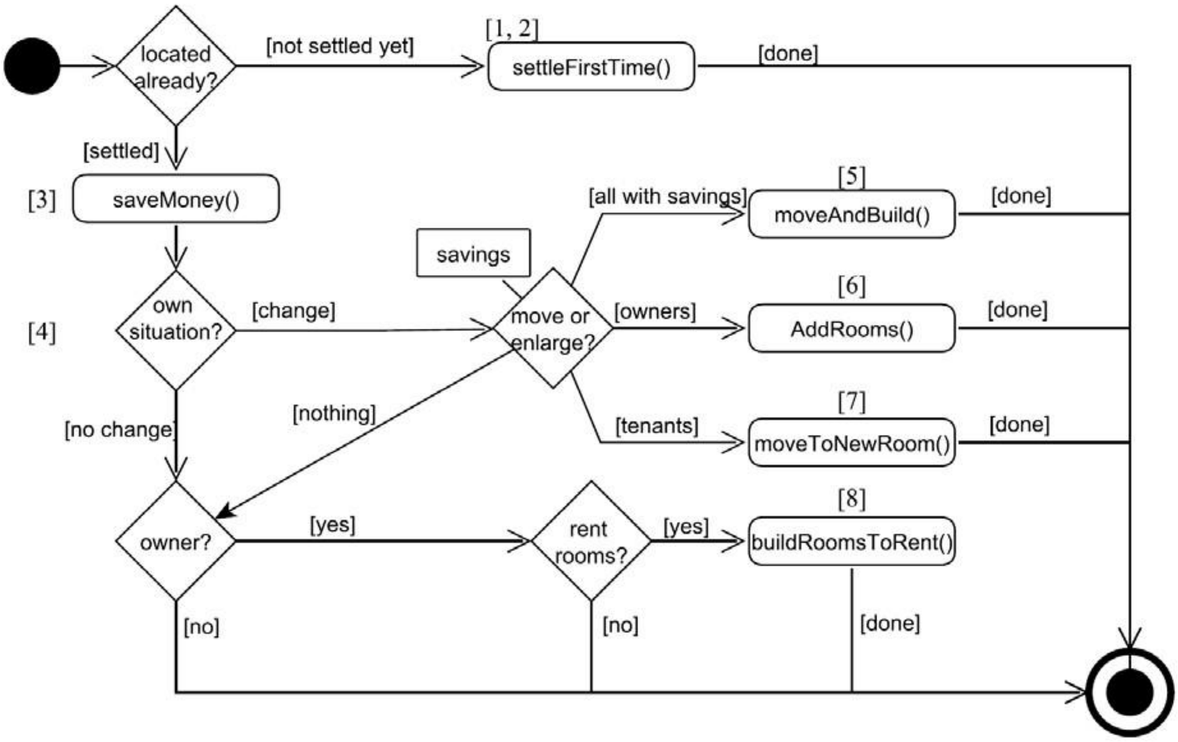


Figure 2 Agent's simulation step[5]

Building works in steps of: 3 rooms, 3 rooms, 3 rooms.

Utility of a plot is computed with the following equation:
Utility = a x proximityCBD + b x qualityInfrastructure + **c** x formal?

with

a: agent's preference to live close to the CBD;
b: agent's preference for infrastructure quality;
c: agent's preference to live in formal districts

[5] Agents also move in case there is a delay and the cost recovery is turned on. This is shown in Figure 4.

proximityCBD: 1 - distance to CBD (with distance to CBD in a range of 0 to 1); qualityInfrastructure: quality of infrastructure in a district; formal? Whether the district is formal or informal (formal districts have value 2, and informal have value 1)

Infrastructure update

- Infrastructure quality is computed as an asymptotic function of housing density. If maintenance of urban upgrading programmes is present, infrastructure quality is preserved in districts where upgrading has been implemented. The following formula is used to compute infrastructure quality with housing density:

$$\text{infrastructure quality} = (-1 \quad / \pi) \arctan(\text{density} - \text{threshold}) + 0.5$$

- Implementation of urban upgrading programme (if selected)
  - Check if upgrading should be implemented in current time step:

    Every 5 time steps
  - Compute a number of target districts:

    1 district with infrastructure quality lower than the value chosen on the GUI slider "threshold-for-upgrading-and-verticalising."
  - Select target districts

    Informal district with the largest population
  - Calculate delay

    Total cost of upgrade / total financial capacity
  - Set infrastructure quality

    1: if there is no delay

    .75: if delay is less than 4

    .50: if delay is more than 4
  - Set formality

    Formal (2): if delay is less than 4

    Informal (1): if delay is more than 4
  - Acquire costs from households in districts

    If "cost coverage" is turned on.

Figure 3 shows in detail the process of upgrading

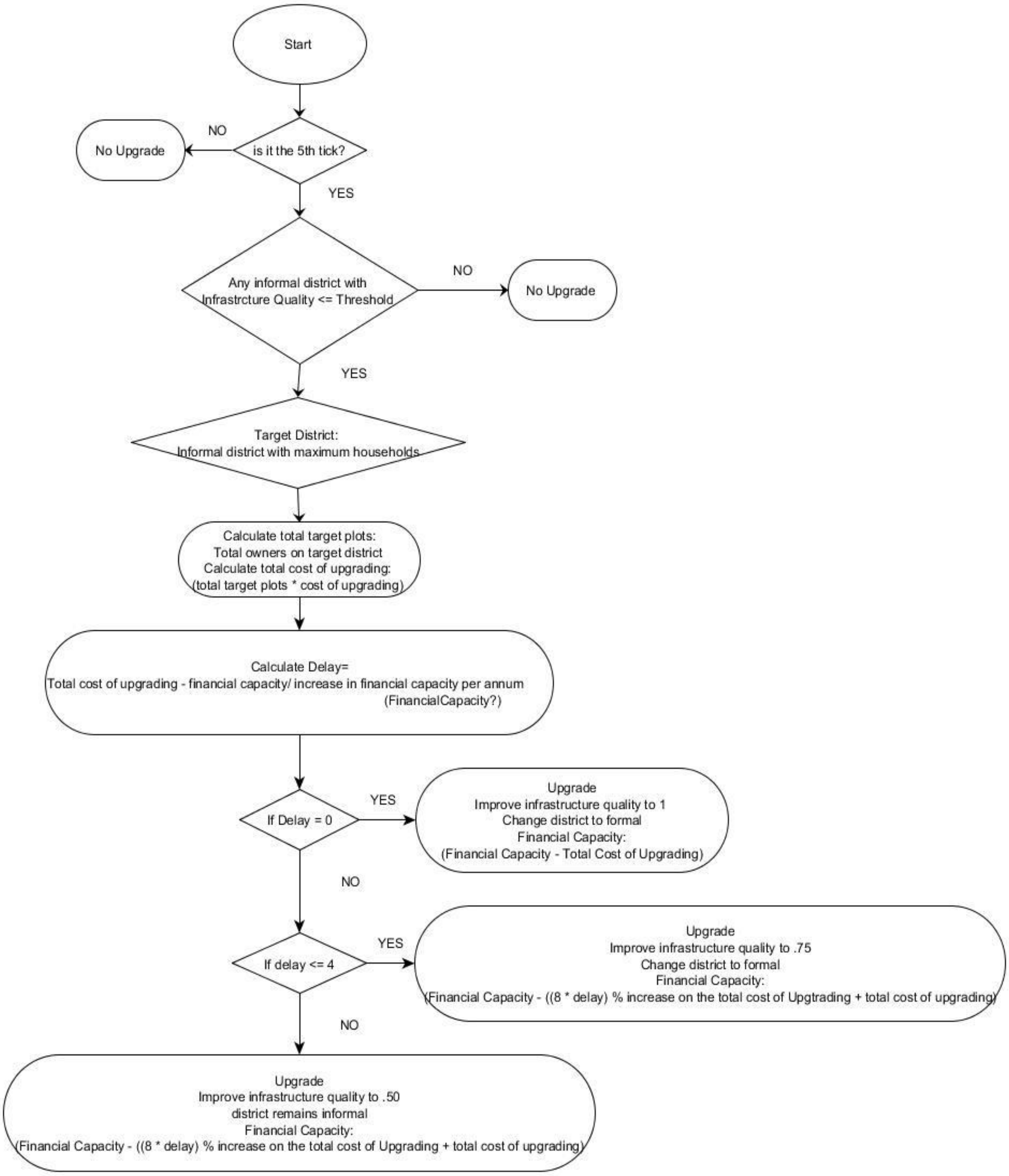


Figure 3 Upgrading process in the model

- Implementation of cost-coverage programme (if selected)
  - Check if cost recovery should be implemented in current time step:

    In the same time step as the upgrade
  - Total agents to recover costs from

    From all the owners on the target patch
  - The total cost of upgrade per household

    The total value of upgrade per household is .39, and for every number of delay there is an 8% increase in this value

- Change in Financial Capacity

The total cost of upgrade per household is multiplied with the total owners on the district. The cost is added to the financial capacity of the model. If the delay is more than zero, then the amount added to financial capacity is divided by the delay. This is done because currently, the model does not have a system to pass on the costs and upgrade to the next time-steps. In reality, the amount would only be added after the district is upgraded after the delay but since in the model the district is upgraded in the time-step even if there is a delay, more amount would get added to the financial capacity that it would have at that time-step had the delay been accounted for. To make sure the financial capacity is not increased unrealistically, the total cost to be added to the financial capacity is divided by the delay, and so only the amount that is realistic for that time-step is added.

Flowchart in figure 4 provides the details of the process of cost recovery

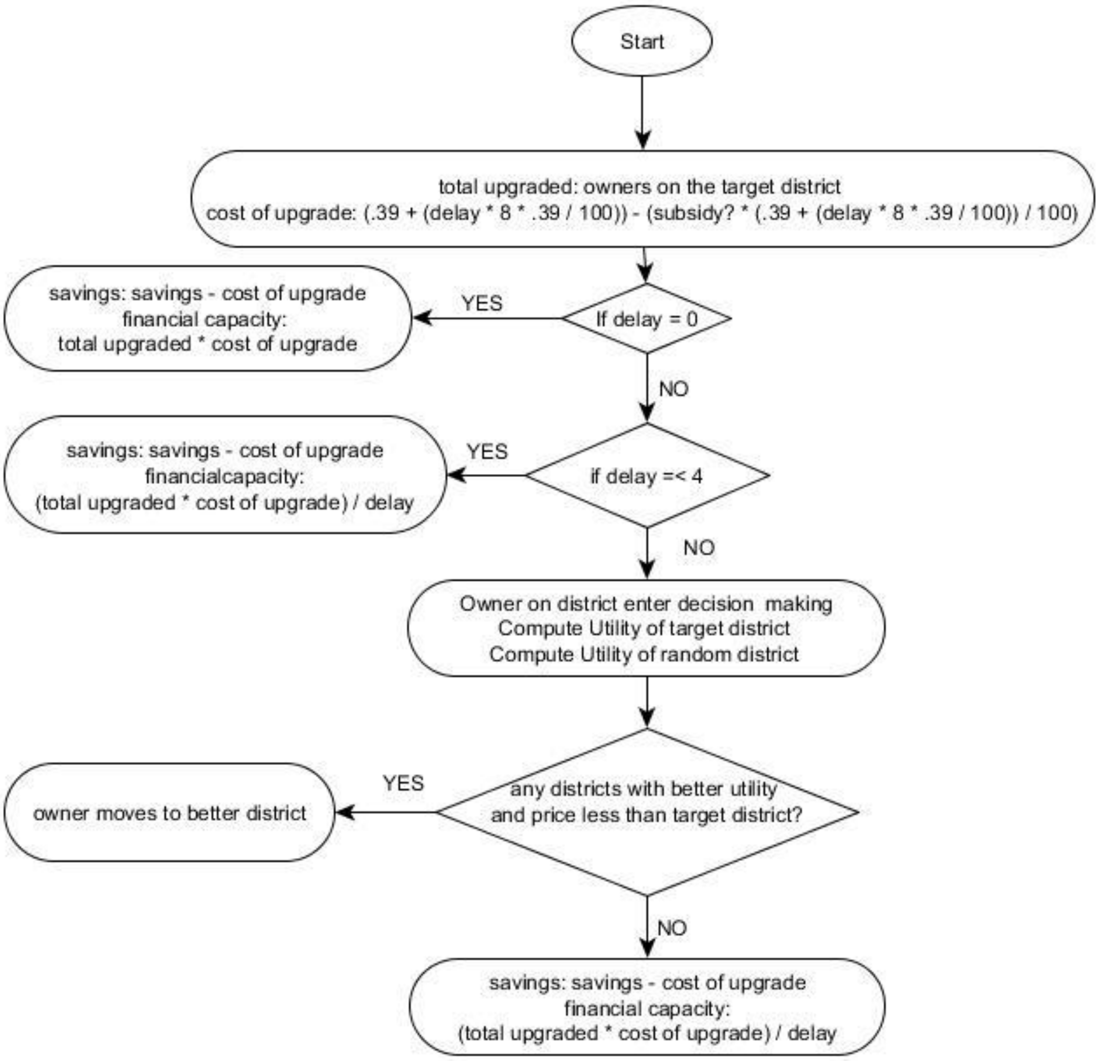


Figure 4 Cost recovery process in the model

- Implementation of the verticalise programme (if selected) is shown in figure 5.
  - Check if verticalisation should be implemented in current time step:

    Every 5 time steps
  - Compute a number of target districts:

1
- Select target districts

Districts with the largest population
- Set infrastructure quality

1
- Acquire costs from owner households in districts

No costs acquired

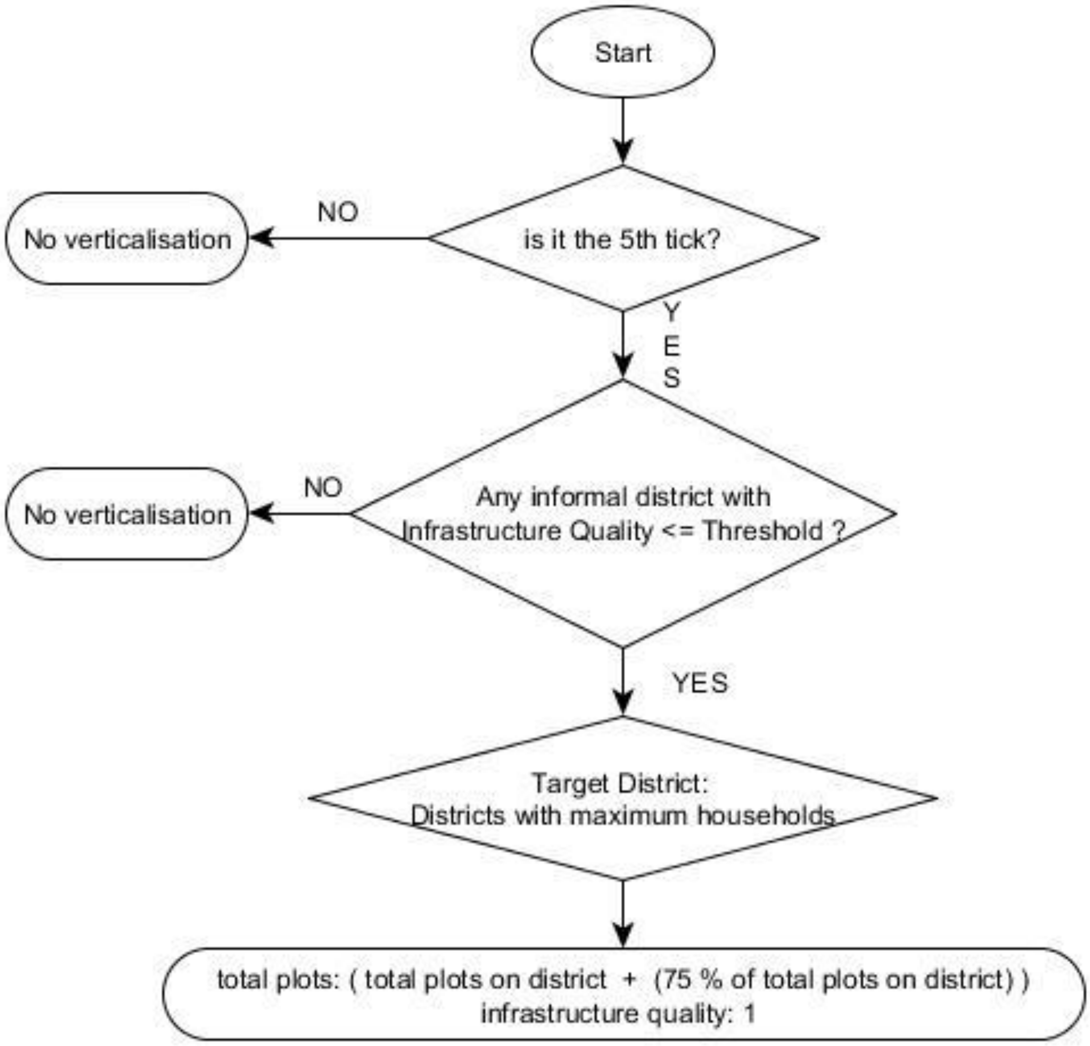


Figure 5 Verticalisation process in the model

III.iv.b What are the model parameters, their dimensions and reference values?

Table 4 Attributes of a city as a whole

Name of attribute	Initialisation	Change during runtime
Initial number of agents	User input (default: 2.000)	Due to population growth
Population growth rate	User input (default: 5%)	none
Financial Capacity	0	User input (default 5)
Asset Building	0.038	Same amount added per time-step

Table 5 Attributes of districts

Name of attribute	Initialisation	Change during runtime
Id	consecutively	none
costs to build in district -> global	User input (default: 10)	none
location within grid	consecutively	none
list of agents in the district	empty	households move into the district or move out of the district
number of plots in the district	user input (default: 75)	The number changes for districts that are verticalised
infrastructure quality	1	Updated according to household density. If the district is upgraded (with no delay) or verticalised, then the infrastructure quality is set to one. If the delay in the upgrade is of more than 0 but less than 4, then infrastructure quality is set to .75, and if the delay is of more than four the infrastructure quality is set to .50
Formal/informal	In total 6 districts are informal. Two at a distance of 0.2-0.3, two at 0.3-0.6 and two at 0.6-0.1.	Upon upgrading, if the delay for this district is calculated to be less than or equal to three then the informal district is converted to a formal one. However, if the delay is bigger then four then the district remains informal.

Table 6 Attributes of plots

Name of attribute	Initialisation	Change during runtime
id	consecutively	none
number of all rooms	0	owners build (3 rooms initially) and enlarge (3 rooms, three rooms, one room)
number of rooms for rent	0	owners enlarge the house
size of plot	64 sq m	none
list of owners and tenants	empty	owners and tenants move to the plot or away
maximum number of rooms	10	none

Table 7 Attributes of infrastructure

Name of attribute	Initialisation	Change during runtime
selection of target districts[6]	Informal district with largest population	none
maintenance of upgrading	user input (default: no)	none
cost coverage for upgrading	user input (default: no)	none
threshold for density decrease[5]	user input (default: 10)	None

Table 8 Attributes of household agents

Name of attribute	Initialisation	Change during runtime
id	consecutively	none
tenure status	tenant	tenants can become owners, not vice versa
income	lower limit 0, upper limit 1. User input (default: log-normal) 3 distributions available: • normal distribution with mean 0.5, standard deviation 0.25* • log-normal distribution with mean -2 and standard deviation 1* • equal probability * Values smaller than 0 or larger than 1 are set to 0 and 1, respectively	none
income level	is assigned according to income: low: income < 0.25 middle: 0.25<income<0.75 high: 0.75<income	none
savings	randomly between 0 and 15 times income	In each time step, income is added to the savings. Furthermore, each room rented to tenants adds 1 unit.
preference for CBD proximity to	drawn from normal distribution with mean 0.5, standard deviation 0.25, lower limit 0, upper limit 1.	none
preference for infrastructure quality		none

[6] Removed from the adapted model

Preference for settling formally	The preference for formality correlated to the income level of the agent. All the preferences are scaled so that the three preferences sum up to 1.	none
plot id of current location	null	is set once agents settle for the first time, changes if agents move
number of occupied rooms by owners only owners	0	is randomly set to 1-3 once agents build their own house
list of rented rooms only owners	0	is changed if agents rent out rooms

III.iv.c How were the submodels designed or chosen, and how were they parameterised and then tested?

Design of submodels

Agents:

Generally, migration models consider two stages of decision-making: if the household should move and where it should move to (Knox & Pinch, 2010). The model uses a similar approach by differentiating a) if the household should act and b) if yes, how.

- Push-factors/triggers:
    1. randomly 1 out of 10 times, household agents re-consider their current situation.
    2. If the delay calculated during upgrading is more than 4, then agents re-consider their current situation.
- Pull-factors: the proximity of district to CBD, infrastructure quality, preference for formality. Constraints: availability of free plots, availability of free rooms, the cost of building, cost of land (informal districts).

Infrastructure:

The decrease of infrastructure quality due to housing density is modelled with an asymptotic function. This function implies a strong change in infrastructure quality close to a critical value of 30 households per hectare. However, users can set the threshold according to their wishes.

Upgrading programmes differ regarding aspects (maintenance, cost coverage by residents) at are discussed in urban development (e.g. Satterthwaite, 2012, Abbott, 2002).

5. RESULTS OF THE SIMULATIONS

The following sections present the simulation results for all scenario settings (section 3.4). As is explained in Section 3.5 the model was run in the BehaviourSpace of NetLogo with ten random seeds, which remained the same over all of the scenarios. Using random seeds helps in making the results more comparable, especially since in the model there are six randomly chosen informal districts. So for each of the scenario, the initial parameters and the location of the informal districts remains the same for that random seed.

The results obtained after running the model have been statistically analysed using SPSS and Excel. Following this, some of the results are spatially represented in maps to analyse further and understand the effects of different interventions on the spatial dynamics of the city. The results of only one random seed, number 2 are spatially represented.

The third objective aims to understand the effect of different upgrading and cost recovery interventions on the income segregation within the city. The following figures visualise the results, and they are described in relevant sub-sections. All the results presented below are without the option of asset building because during the preliminary tests of the model it was found that the option of asset-building does not change the results in the model.

5.1. Simulation Results Without Interventions

The first question of the third objective is, "What are the income segregation levels without any cost recovery and upgrading options selected?". The answer to this question is in the results of Scenario 1, which includes no upgrading, verticalisation or cost recovery interventions.

As is seen in figure 6.a, on an average 1544 plots are occupied in scenario 1 and figure 6.b provides an overview of the changes in Gini coefficient for lower-income households. The mean value of the Gini coefficient for lower-income of all the ten random seeds at time step 21 is .446 (figure 6). The Gini coefficient for higher income in Scenario 1 is .652 (figure 9). The differences in the coefficients of lower-income and higher income suggest that the distribution of higher-income households is more uneven than that of lower-income households. An average of 5370 moves occurred (figure 10)

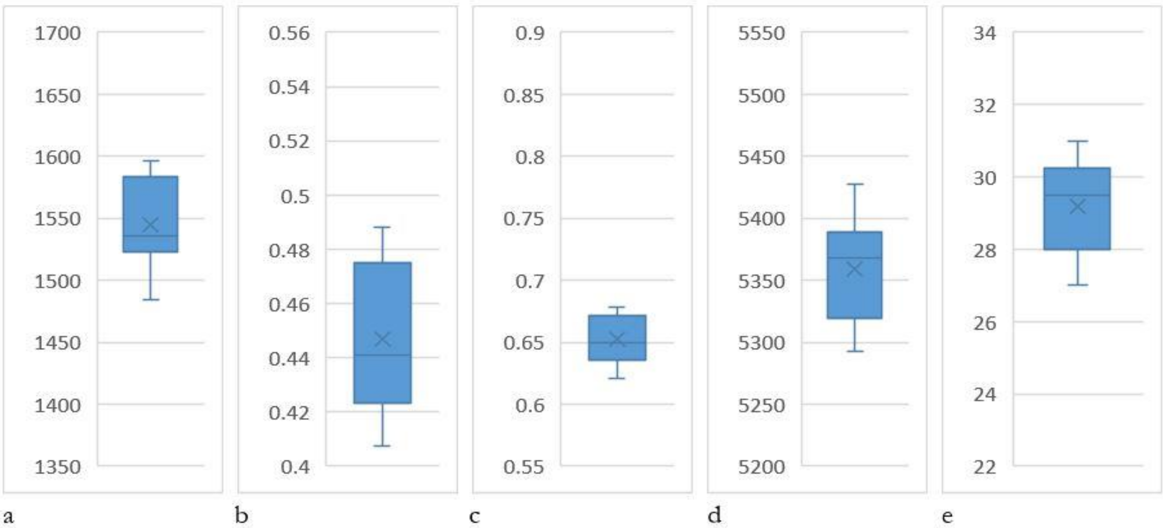


Figure 6 a) Total occupied plots b) Gini coefficient for lower-income households c) Gini coefficient for higher-income households d) Total moves e) Total occupied districts

As shown in figure 7, at time-step 21, there are three districts with a population of less than 100, and 18 districts are not populated at all. The majority of the districts in this scenario are not densely populated, with 15 out of 30 districts having a population ranging from 100 – 200 households and surprisingly, this category includes three of the six informal districts. The location of most of the districts in this category is on the outer boundary of the built-up city. Eight districts belong to the category of 200 – 300 households of which three are informal, and these districts are also primarily found on the edges. Only four centrally located districts have a population ranging from 300 - 400. Two districts, of which one is the central district, have a population of between 500 - 600 households. The districts with a maximum distance from the centre are not densely populated. It is a surprising finding that informal districts are not the densely populated.

Figure 8 presents, the mean income of districts at time step 21. For the baseline scenario 1, the highest mean income in any of the districts is in the range of 0.25 - 0.3. There are two such districts, one of which is immediately below the city centre and the second one is located at the outer edge of the built-up area. Districts belonging to the income group 0.20 - 0.25 dominate the outer edge of the districts built up area. The districts located in the centre and all of the six informal districts have a mean income of less than .20. Although two of the six informal districts are on the outskirts where the general pattern is of higher-income, the informal districts on the outskirts too have a mean income belonging to the category 0.15 - 0.2. Two of lowest mean incomes districts are informal. Such concentrations tell that in the baseline scenario, relatively higher-income households settle on the peripheries of the city, and informal districts have households with lower-income.

It is easy to notice from figure 9 that there is a higher concentration of lower-income households around the city centre than there is on peripheries. Majority of the districts on the peripheries have between 50 – 75 % of their population in the lower-income category whereas the districts with more than 75% households in lower-income are located on the peripheries of the city. All of the six informal districts have more than 75% of their households from the lower income group even if they are located on the borders. This might be due to the low infrastructure quality in these informal districts (> 0.1). Only one informal district (which is surprisingly near the city centre) has slightly better infrastructure quality (between <0.1 – 0.25). Just two districts in the baseline scenario have between 0.50 – 0.75 infrastructure quality (figure 10). This can be expected since in the baseline scenario no interventions to improve the infrastructure take place.

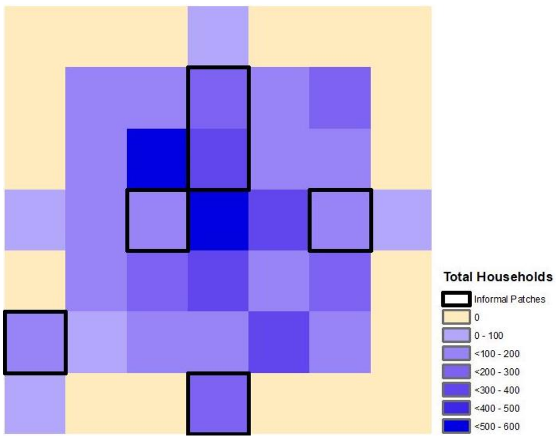


Figure 7 Share of low-income households in scenario 1

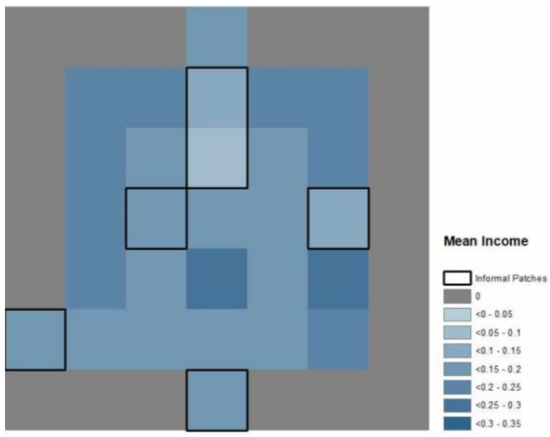


Figure 8 Mean Income of districts in Scenario 1

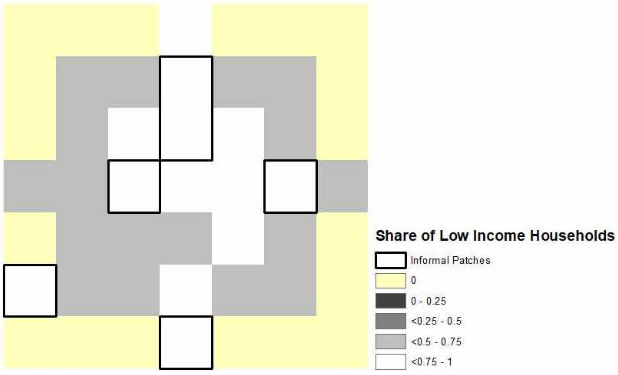


Figure 9 Total households in scenario 1

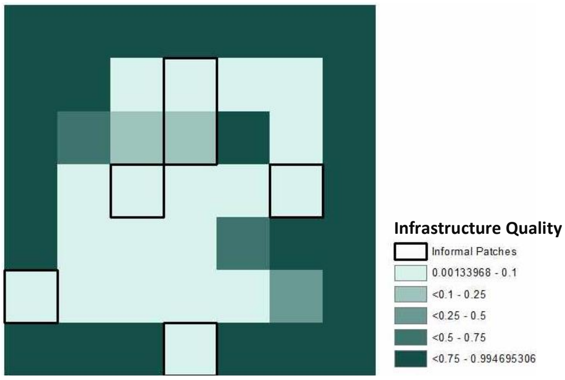


Figure 10 Infrastructure quality of districts in scenario 1

Lower-income households dominate informal districts. This pattern remains even in the informal districts away from the centre and on the outskirts even though the other districts at that distance do not have the same share of informal households.

5.2. Simulation Results With Interventions

5.2.1. Effects of Financial Capacity, Cost Recovery and Subsidy in Classical Upgrading

As shown in table 9, there is a positive correlation between the Gini coefficient for lower-income households and upgrading and financial capacity which implies that with increasing financial capacity the Gini coefficient increases. This means the distribution of lower-income households become more uneven distributed leading to increased segregation. Likewise, there is a negative correlation of delay with Gini coefficient for lower-income households, as financial capacity and delay are highly negatively correlated ($r+0.8$, $p<0.01$). This is reflected again in figure 11 showing the Gini coefficient for lower-income households. The Gini coefficient for lower-income households in some scenarios with financial capacity of 2 (2.1, 2.2, 2.3, 2.5, 2.6) is lower than that of the baseline scenario. Of the scenarios with financial capacity two, the lowest mean Gini coefficient is reported for scenario 2.1 and 2.5 (0.435).

Among the scenarios with interventions, the lowest Gini coefficient for higher-income households (figure 12) is recorded in scenario 2.6 (0.657). Two things can be understood from this:

1) Since even with interventions higher-income households are more unevenly distributed than lower income households, we can understand that interventions do not play a role in changing that since the same happens in the baseline scenario.
2) The higher segregation levels of higher-income households may also be affected by the significantly fewer higher-income households as given by the log-normal distribution of income among household agents.

Table 9 Correlation table of the scenario parameters of the model and the different results[7]

Scenario Parameters	Results delay	total Tenant	total Owner	total Moves	mean Built Up Rate	mean Infra Quality	gini BuiltUp Rate	gini Low Income	gini High Income	gini Infra Quality	gini HH Density
verticalise	.[b]	-.297**	.297**	.512**	-.141*	-.338**	-0.063	-.185**	-0.061	.351**	-.291**
upgrading	.[b]	.269**	-.269**	-.489**	-0.065	.491**	.225**	.265**	.154*	-.507**	.419**
Cost Coverage	-0.016	.183**	-.183**	-.256**	-0.043	.280**	0.105	0.078	0.112	-.289**	.191**
subsidy	0.026	0	0	0.037	0.066	-0.053	-0.051	-0.121	.246**	0.056	-0.034
Financial Capacity	-.789**	.151*	-.151*	-.491**	-.515**	.677**	.643**	.582**	0.123	-.663**	.726**
delay	1	-.190**	.190**	.610**	.646**	-.853**	-.809**	-.722**	-.158*	.836**	-.907**
total Tenant	-.190**	1	-1.000**	-.527**	-.625**	.230**	.535**	.211**	0.003	-.230**	.237**
total Owner	.190**	-1.000**	1	.527**	.625**	-.230**	-.535**	-.211**	-0.003	.230**	-.237**
total Moves	.610**	-.527**	.527**	1	.682**	-.656**	-.740**	-.558**	-.179**	.655**	-.701**
mean BuiltUp Rate	.646**	-.625**	.625**	.682**	1	-.497**	-.885**	-.525**	-.124*	.482**	-.578**
mean Infra Quality	-.853**	.230**	-.230**	-.656**	-.497**	1	.719**	.645**	.179**	-.999**	.901**
gini BuiltUpRate	-.809**	.535**	-.535**	-.740**	-.885**	.719**	1	.725**	.194**	-.703**	.810**
gini LowIncome	-.722**	.211**	-.211**	-.558**	-.525**	.645**	.725**	1	.236**	-.631**	.772**
gini HighIncome	-.158*	0.003	-0.003	-.179**	-.124*	.179**	.194**	.236**	1	-.178**	.320**
gini InfraQuality	.836**	-.230**	.230**	.655**	.482**	-.999**	-.703**	-.631**	-.178**	1	-.892**
gini HHDensity	-.907**	.237**	-.237**	-.701**	-.578**	.901**	.810**	.772**	.320**	-.892**	1

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

b. Cannot be computed because at least one of the variables is constant.

[7] generated by running the model. The red cells are positive and significant, and the blue ones are negative and significant.

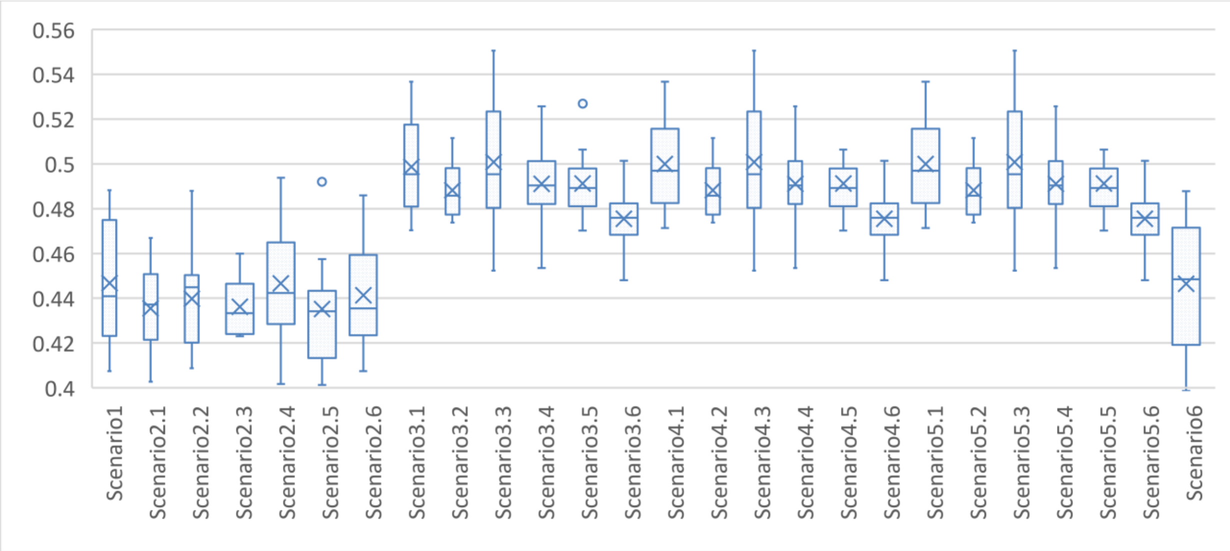


Figure 11 Gini coefficient for lower-income households at time-step 21[8].

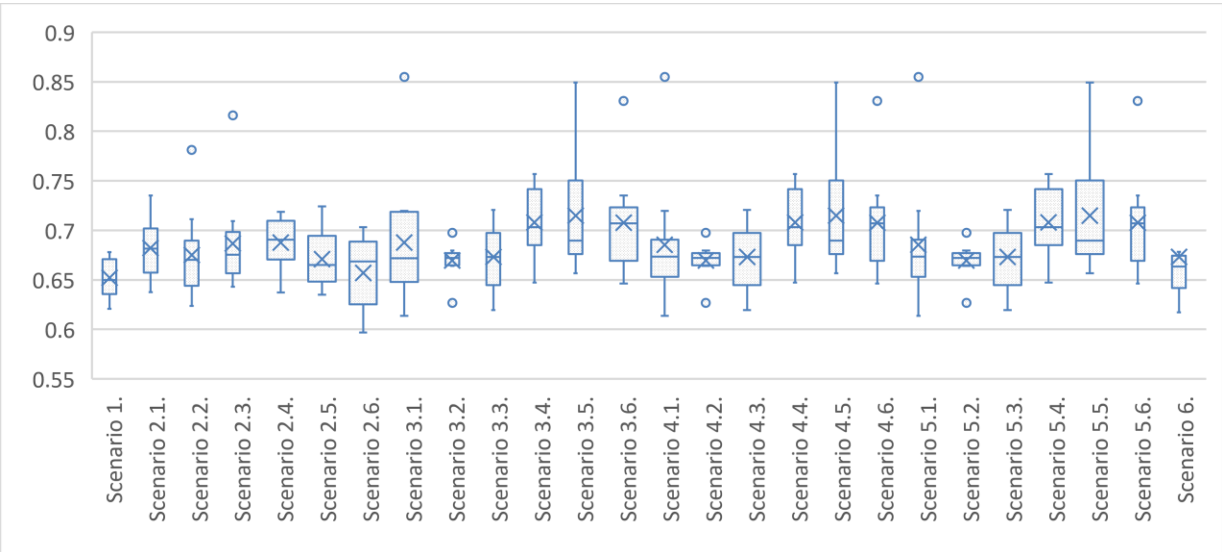


Figure 12 Gini coefficient for higher-income households at time-step 21[8]

What is striking in table 9 is a positive correlation between mean infrastructure quality and Gini coefficient for lower-income households. This indicates that with improvement in infrastructure quality, segregation increases. Figure 13 demonstrates, upgrading carried out with a financial capacity of two leads to small improvements in infrastructure quality, but also increased costs of upgrading and delays (indicated by the red colour of the numbers on the districts) of the district. Such districts remain informal too. When such an upgrading takes place, the beneficiaries in the model enter the decision-making mode about their location and compute the utility of all other districts to find if there are other suitable districts which are more affordable to them. This might force some (or all) of the households to move. In fact, from figure 14, it is clear that more districts are occupied in scenarios with financial capacity two than in any of the other scenarios. It can be seen from table 9, that there is a negative correlation between the total moves and Gini coefficient for lower-income. Figure 15 and figure 16, also show that the financial capacity of two leads to a higher number of occupied plots and total moves in comparison to other scenarios with upgrading (not when scenario six is considered). All of these facts appear to indicate that there is more dispersion in the

[8] The "X" in the plots mark the mean.

distribution of the population which might be leading to the decrease in segregation. Table 9 points towards a decrease in the number of tenants with increasing financial capacity. As was already discussed, inadequate upgrading (with low financial capacity) leads the target districts to remain informal. Due to this the number of tenants might decrease because since the district remain informal, there is more affordable (but informal) housing available than would exist if the district were formalised.

Figure 13 Mean infrastructure quality per district for time-step 21[9].

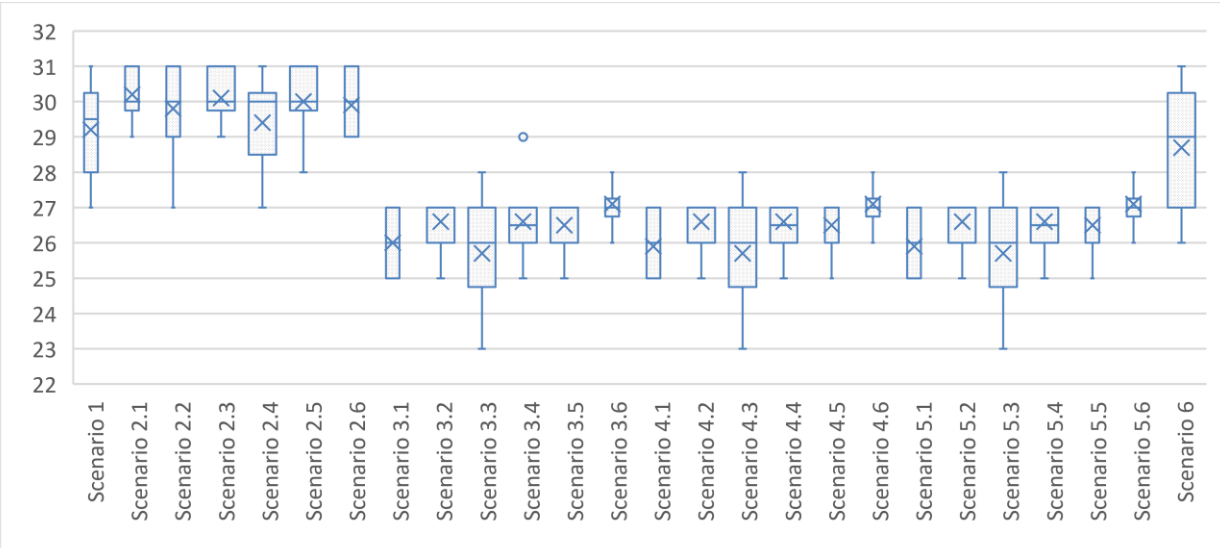


Figure 14 Total districts occupied at time-step 21[10]

[9] The number 1. 2, 3 & 4 on the district indicate that the district was upgraded/ verticalised in time-step 5, 10, 15 & 20 respectively. The districts with numbers in red were not improved satisfactorily

[10] . The "X" on the boxplots marks the mean.

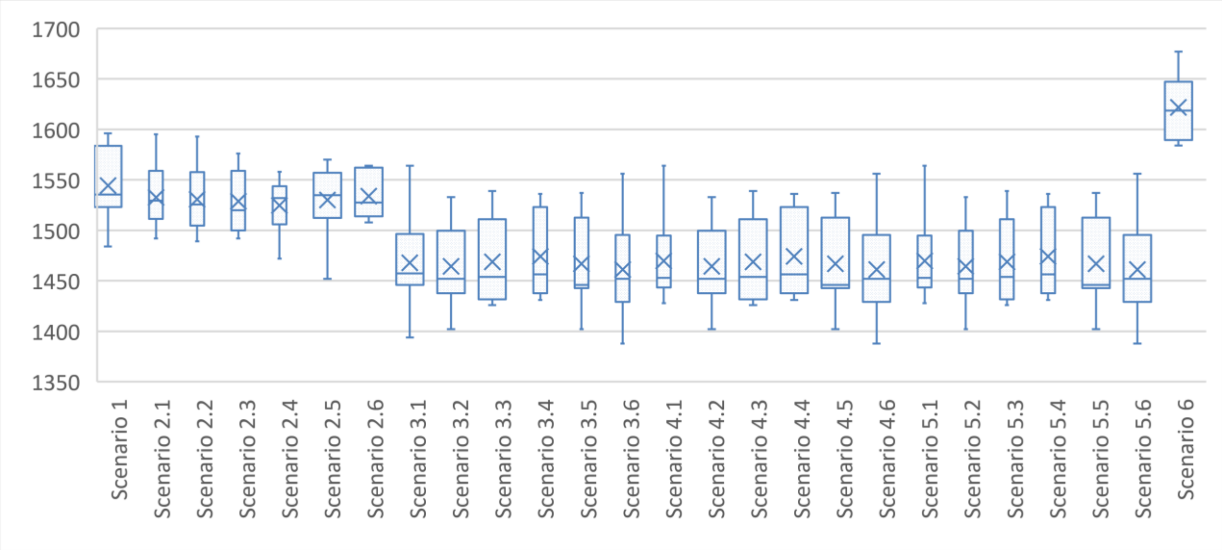


Figure 15 Total occupied plots at time-step 21[11].

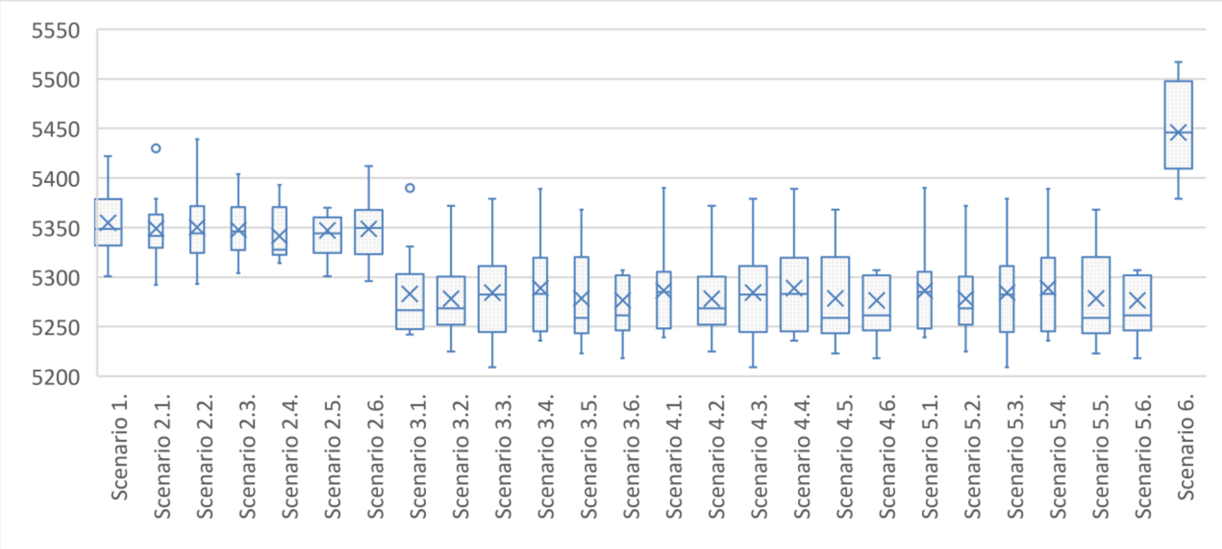


Figure 16 Total moves at time-step 21 for all the scenarios[11].

From the plots, in figure 17 it can be seen that Scenario 2.1 and 2.4 have only one district each which lies in the maximum population category of 500-600 which reaffirms the earlier observation that the population is more dispersed in the case of scenarios with financial capacity two. The significantly positive correlation between Gini coefficient for lower-income households and Gini coefficient for built-up rate tells us that evenness of overall distribution might be playing a role in the decreasing segregation. Figure 18 shows another improvement regarding the segregation as in scenario 2.1 eleven districts and scenario 2.4 ten districts have more than 75 % of their population in the lower-income category. However, what stands out for these two scenarios in comparison to other scenarios is that districts with more than 75% population in the lower-income category are less close to each other even when compared to the baseline scenario.

[11] The "X" on the boxplots marks the mean.

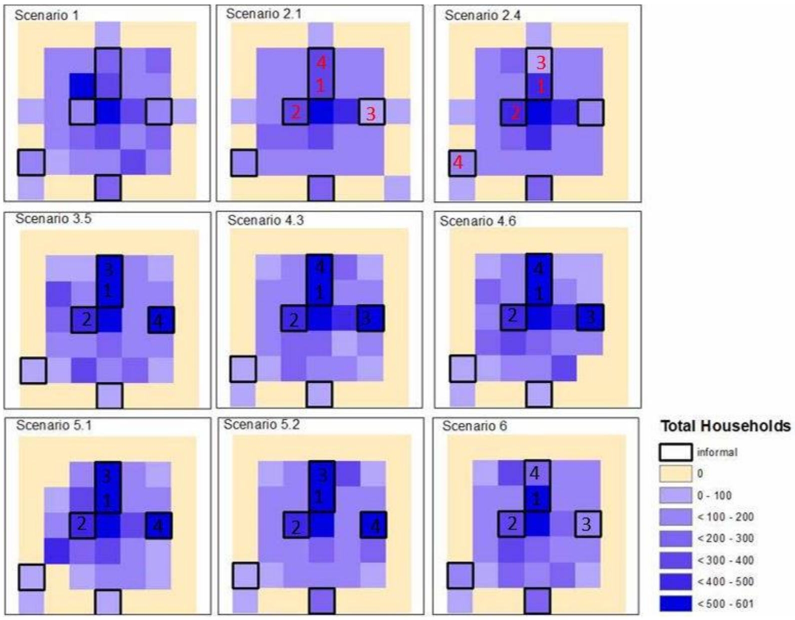


Figure 17 Total Households per district for time-step 21[12].

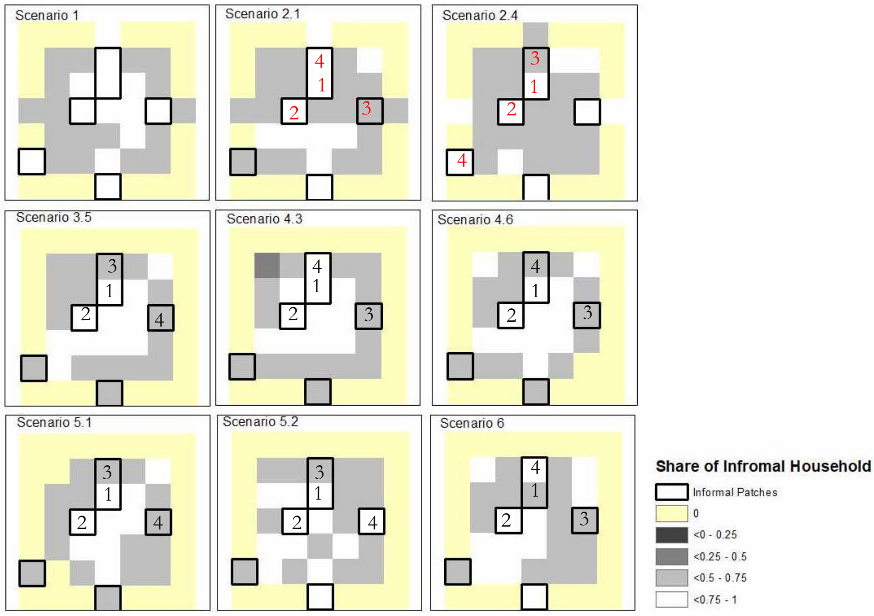


Figure 18 Share of low-income hh per district for time-step 21[12] .

Another relevant point is visualised in figure 19 which shows the mean income per patch. The highest mean income category in these scenarios is between 0.25 – 0.3. Four districts in scenario 2.1 and 2.4 each belong to this category whereas in comparison the baseline scenario has only two. The existence of a more number of districts with higher mean income in these scenarios indicates that the higher-income households are more concentrated. Like all other scenarios, scenarios with a financial capacity of two have higher mean income districts on the peripheries of the city. However, the informal districts in scenarios with financial capacity of five, seven, ten have higher mean incomes when compared to the baseline, scenarios with financial capacity two and scenario 6 (Verticalise). So even though, the segregation levels do not decrease

[12] The number 1. 2, 3 & 4 on the district indicate that the district was upgraded/ verticalised in time-step 5, 10, 15 & 20 respectively. The districts with numbers in red were not improved satisfactorily

when measured using the Gini coefficient, it is evident that informal districts witness the arrival of households from different income groups in scenarios with higher financial capacities.

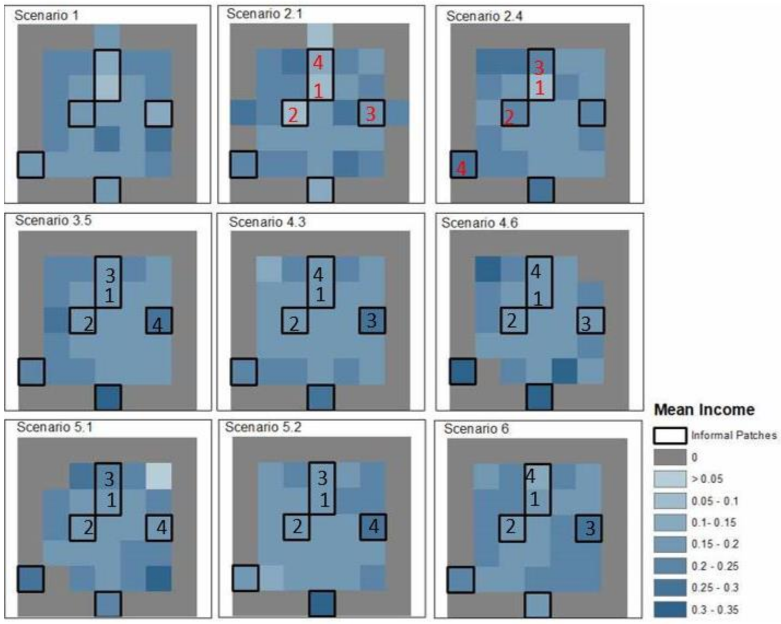


Figure 19 Mean income per district for time-step 21[13].

Scenarios with financial capacity of five, seven and ten have higher Gini-coefficients for lower-income households than that of the baseline scenario and scenarios with financial capacity two. The positive correlation between financial capacity and Gini coefficient for lower income households indicates that with increasing financial capacity the unevenness in the distribution of lower income households increases but the graph for the Gini coefficient in figure 11 shows that scenarios 3.1 - 3.6, 4.1 - 4.6 and 5.1 - 5.6 have a nearly identical pattern. This might be because that financial capacity five, seven, and ten (the financial capacities tested) are all adequate and lead to the same results. The scenarios with a 100% subsidy (3.1, 4.1, 5.1) have a mean Gini coefficient of .498. While the correlation table shows no significant correlation between subsidy and Gini coefficient for lower-income households, figure 11 shows an initial increase in the Gini coefficient for lower-income households from subsidy 0 to subsidy 20 and then a decrease. Scenarios with 80 % subsidy (0.475) have the lowest Gini coefficient of all the scenarios with financial capacity more than two. The highest coefficient (0.5) is in scenarios 3.3, 4.3 and 5.3, all of which have a subsidy of 20 %.

The identical pattern of the boxplots Gini coefficient for higher-income households in scenarios 3.2 - 3.6, 4.2 - 4.6, and 5.2 - 5.6 further indicates that financial capacities five, seven and ten all lead to the same results. The highest coefficient (.671) is for scenarios 3.5, 4.5 and 5.5 and the lowest is in cases involving 0 % subsidy (figure 12). The correlation between the two is a positive one suggesting that increased subsidies lead to increase in the Gini coefficient for higher-income groups (table 9).

All of the scenarios with the financial capacities of five, seven and ten have four districts with a population between 500 – 600 (figure 17). Scenario 5.1 has the least expansion of the city, with only 25 occupied districts (figure 14). The total occupied plots are least in these scenarios as well (figure 15). These facts indicate that

[13] The number 1. 2, 3 & 4 on the district indicate that the district was upgraded/ verticalised in time-step 5, 10, 15 & 20 respectively. The districts with numbers in red were not improved satisfactorily

the population is contained in a lesser number of districts in comparison to the baseline and scenarios with financial capacity 2.

There is a positive correlation between the number of tenants and the financial capacity and between the number of tenants and the mean infrastructure quality. As we already know, mean infrastructure quality and financial capacity are positively correlated which suggests that mean infrastructure quality is higher if the financial capacity is more. The figures mentioned indicate that due to increasing financial capacity, the upgrading carried out is successful (meaning the infrastructure quality is improved and informal district is converted to formal). Logically, this would reduce the number of affordable living units (since the informal districts are converted to formal). In a case where the number of affordable living units is decreased the number of tenants would increase (which it does).

Figure 18 shows the share of households in the low-income category per districts, and it is evident that in comparison to scenarios with financial capacity two, the remaining scenarios contain concentrations in the form of districts with a higher share of lower-income households around the centre of the city.

5.2.2. Verticalisation

With the intervention of verticalisation, the Gini coefficient for lower-income households does not decrease but remains similar to that of the baseline with the average coefficient at 0.446 (figure 11). The absence of correlation between the verticalisation and Gini coefficient backs this up. Similarly, upon verticalisation, the Gini coefficient for higher-income households is 0.672, which is only a slight increase from the baseline (figure 12). The number of tenants and verticalisation show a negative correlation (table 9), and the highest number of plots are occupied (figure 15), and a maximum number of total moves occur in this scenario (figure 16). These numbers are expected since in verticalisation new plots are added to the informal district which is verticalised. The districts verticalised are near the city centre, and the addition of new plots acts are a pull factor. With verticalisation, the distribution of districts with more than 75 % households improves in comparison to the interventions with financial capacity five, seven and ten (figure 18). However, compared to scenarios with financial capacity 2, districts with 75 % households in lower-income category lie next to each other.

The mean income in scenario 6 increases for all the informal districts but the 4th district verticalised (figure 19). As is in the case of all other scenarios, the districts with higher income are located near to the peripheries of the city whereas lower-income households are concentrated around the centre.

Other important points:

While cost recovery does not show any significant correlation with any of the Gini coefficients, it does have a positive correlation with mean infrastructure quality which means that carrying out cost recovery leads to improvement in infrastructure.

6. DISCUSSION

In reviewing the literature, almost no reports discussing the relationship between cost recovery in urban upgrading and income segregation were found, and it is due to this lack of empirical studies that a modelling approach to analyse the relationship was chosen. A modelling study by Schwarz et al. (2016), reports an increase in income segregation with when upgrading is carried out with maintenance, early timing and over many districts. But the authors do not note any changes in income segregation in relation to cost recovery, this MSc thesis steps in to investigate that. Chapter 5 discusses and analyses the results of the simulation runs, and this chapter provides an overall discussion of the results in relation to the literature on the subject.

6.1. Effects of different interventions

The literature review (section 2.2.1) tells us that a slum upgrading effort is considered successful if the infrastructure is improved satisfactorily and without delays as delays often lead to cost escalation which makes the product of the upgrade unaffordable to the beneficiaries. Urban upgrading programs such as BSUP have been unsuccessful as they led to the abandonment of the upgraded living units (section 2.2.1). Therefore, delays have been added to the model so that a delay in upgrading results in the following (see section 4.2.2 for details):

- The infrastructure quality is not improved to 1. This means that the infrastructure quality is not optimally improved which mimics the effects of delays in schemes such as BSUP which did not enhance the quality of the upgraded facilities was not optimal (section 2.2.1).
- In cases where the delay is of more than 4 time-steps, the informal target district remains informal. But in cases of less delay informal district is converted to formal
- Increase in the cost of upgraded units

For this study, in cases where the infrastructure quality is improved to less than .75 and the district remains informal the upgrade is regarded as unsuccessful, leading to delays. In such unsuccessful upgrades, the simulation results also report abandonment of upgraded units where some of the intended beneficiaries move out of the target district due to cost escalations. An exciting outcome of this movement is the reduction in the level of segregation of low-income and high-income households when measured using the Gini coefficient. This movement can be understood as a response to a push factor forcing households out of one district, and while it results in desirable results in terms of Gini coefficients, it is not voluntary but a reaction to the increase in the cost of upgraded houses (section 2.1). In reality, such a movement leads the intended beneficiaries to occupy slum plots either at the same location or in another slum area. This results in loss of livelihood for the very people who were meant to benefit from the interventions (Patel et al., 2015). Now, one might argue that the benefits of reduced segregation may compensate for the loss of livelihood as the harmful effects of income segregation are well known and many as discussed in the literature review (section 2.1). However, analysing mean income and share of lower-income households in the target districts shows that if the financial capacity is insufficient, the mean income of informal districts does not increase and the share of lower-income households in informal districts does not decrease. This means no changes in segregation occur at the level of the informal district. Another interesting result of such an upgrade (an unsuccessful upgrade) is that the urban sprawl does not decrease as it does in cases with ample financial capacity. A study by Guo, Buchmann & Schwarz (2017) has found a negative correlation between urban sprawl and income segregation and similar results appear to emerge in this study as well.

As opposed to this, with higher financial capacity and successful upgrade (i.e. infrastructure quality is more than 0.75, and informal district becomes formal district), the Gini coefficient levels do not decrease but instead increase in comparison to the simulation without any upgrading. At first glance, this seems counter-intuitive, because better results are always expected if more money is spent. Simulation results show that the mean income increase and share of lower-income households decrease in the upgraded districts. A possible explanation for this is the existence of a pull force towards these upgraded districts. Upon a successful upgrade, the informal target district becomes formal, and its infrastructure quality is improved which makes the target district attractive to different income groups. This might not drastically impact the city-wide distribution, but it does change the distribution of different income-groups in informal districts. An advantage of a successful upgrade is the reduction of urban sprawl as fewer districts are occupied when the financial capacity is higher.

While the amount of financial capacity influences the outcomes of an upgrading scheme, the amount of subsidy or cost recovery in classical upgrading (as opposed to verticalisation) does not appear to have a significant impact on the outcomes of the upgrade (only slight increase in Gini coefficient for higher income households with increasing subsidy and a positive correlation between the two). The study by Schwarz et al. (2016) used the original model and found similar results although the function of cost recovery was different. Despite these results, it is essential to consider the literature on the subject, which suggests that cost recovery from the beneficiaries is useful as it makes beneficiaries feel a sense of ownership towards their upgraded houses (section 2.1). It also plays a role in reducing the economic burdens on the authorities carrying out the upgrading.

The results of verticalisation appear to combine the best of both the cases discussed above. The Gini coefficient for lower-income and higher-income households does remain similar to the baseline, while the mean infrastructure quality increases and the share of lower-income households decrease in informal districts in comparison to the baseline. However, the distribution of relatively higher income households (Figure 13) shows that these districts are not as well dispersed as in the cases of inadequate upgrading. Nonetheless, in comparison to the other scenarios (including the baseline), there are obvious improvements. The urban sprawl of residential areas also decreases considerably in comparison to the baseline. This is encouraging because the relatively lower scores of Gini coefficient, in this case, cannot be attributed to a more spatially dispersed population. The lower number of tenants associated with verticalisation also put verticalisation in a positive light. The performance of verticalisation meets the expectations built on the literature review of the real world (section 2.2.4). The increase in the number of plots in target district that occurs when verticalising is bound to improve the mean income of informal districts, as well as decrease the share of lower-income households in them.

As Schwarz et al. (2016) note, upgrading can have many targets, and this study aims at identifying the best one to reduce income segregation. Picking one best practice is challenging since income segregation has many aspects with different indicators to measure them (section 3.3)

All of the scenarios tested improve some aspect of segregation (discussed in section 3.5). So it is imperative to consider the problematic outcomes of each scenario.

- Upgrading with lower financial resources has the apparent disadvantage of bad infrastructure quality and districts remaining informal. Such upgrading also increases the urban sprawl.
- While upgrading options with optimal financial capacity do reduce the urban sprawl and improve the infrastructure quality, they increase the segregation of lower-income or higher-income households. Such upgrading schemes also require considerable financial resources. The economic

condition of countries in the global south is often not very good so finding funding for urban upgrading poses a challenge. With BMC's slum improvement budget of Rs 199 crore (*25173500 euros*) for the year of 2017-18 (DNA Web Team, 2017), approximately Rs 256 (*3.225 euro*) per slum dweller living in the greater Mumbai is available. Often due to insufficient funds delays occur in projects during which the cost of construction increases and this places financial burdens on the deprived beneficiaries.

- As the literature review has shown, verticalising has drawbacks which could not be measured in the simulation runs. Nevertheless, they do exist; vertical densification of the slums forces many small household industries, and business to lose their base, and the vital social ties which exist in slums get disrupted. Also, such an intervention can only be successful in areas of high property values, and not all slums are located in such areas. As section 2.2.4 explains, verticalisation is driven by the financial interests of the property developers who do not engage in projects unprofitable for them. They are interested in areas which have high property values and high population. In the real world, some of the target districts identified in the simulation would most likely not be of interest to the property developers. This is because the land price and the total population in the target districts away from would not be high enough for it to be a financially profitable deal for the private developers

6.2. Limitations of the study

As has been discussed earlier on in the thesis, for this study InformalCity, a model based in the context of Sub-Saharan Africa has been adjusted to create the existing model which is in the context of India. The study focused on making relevant changes to the original model. However, for future studies, some details need to be improved. Such as, some of the empirical data from the original model remains in the model adapted for this study, and such empirical data is based on Dar es Salaam. An example of this is the increase in the number of rooms which is based on the Swahili-type houses.

In the original model all of the districts of the hypothetical city were informal, but for the adjusted model for this study, only some districts were kept as informal (section 4.2.1 presents the details). The remaining districts are formal. However, both formal and informal districts have the same plot size and same total number of plots (the number of plots in a district only increases for a verticalised district). Slums have high densities, and slum population in cities tend to live on very little of the land, such as in the case of Mumbai where the slum population lives on just 12 % of the geographic land (Kamper, 2017). As mentioned in section 2.1, the MHUPA suggests different criteria for housing different income groups which include differently sized dwelling units.

Due to the limited time available for this study, a full software verification was not feasible. While major processes have been checked before running the full set of scenarios, minor mistakes might still remain in the code. On such minor mistake was found after analysing all simulation results, with no time left to remedy it. The value of 1 in section 4.3 II.i.d, is calculated to 11600, whereas logically it should be 14600. However, this minor error should not significantly alter the results of this study. Still the translation from values in India to the "model currency" should be revisited in the future.

6.3. Future Research

For future research, suggestions are made about the validation of the model, measurement of the results and improvements for the model.

Validating the model results is beyond the scope of this study due to limited time, but it is possible to validate the model by conducting an empirical study could be conducted to validate the model. Census data should also be useful for validating the model. Even though there is no data on the income levels is available, data on ownership of assets (such as cars) could be used to gauge the income. While the Census of India website provides such data at national level, more disaggregated data could be requested for validation.

The segregation levels are measured only using the Gini coefficient which measures the distribution of a minority group over the entire city, not just in the built-up area of the city. But as is discussed in section 3.3, there are various other indicators to measure segregation also available. These indicators measure the different aspects of segregation described which are evenness, exposure, concentration, centralization and clustering (Massey & Denton, 1988). It would be useful to measure segregation using other measures as well especially since new methods to measure segregation are being developed (Reardon, 2009).

The following points discuss additions to the model. While these additions could enhance the functioning of the model, they would naturally reduce its simplicity

1. The model currently does not use rent very well. If a household agent in the model settles as a tenant, the agent does not pay the rent although the rent is added to the savings of the landlord. The rent is also consistent throughout all of the districts in the model even though in reality this is not the case. A simple web search tells us that rent does differ according to distance as a 3-bedroom apartment near Mumbai's city centre costs approximately Rs 106,774 while the same accommodation outside the centre would cost Rs 46,034 (NUMBEO, 2017). The rent in an informal settlement is even lower with a one-bedroom apartment in Mumbai's famous Dharavi costing about Rs 10,000 (Siddiqui, 2015). Changing the rent according to its distance from the city centre will be useful in achieving more realistic results in terms of the segregation. Another exciting addition to the model could be if the land price and rent varied not only according to distance but also according to demand for housing in the district. For this to function first a method to calculate the demand will be needed in the model.
2. Currently, household agents do not have memory. The memory of agents will be useful in recording their movements across the city, and this will enable the user of the model to analyse the effects of an upgrade better. Adding memory to agents would also enable the demand mentioned above to be calculated.
3. In the model developed for this study, the city is initialised with a set number of informal districts. It would be interesting to see how the results differ if informality evolves over time in the model.
4. The execution of the intervention of verticalisation could be enhanced to test the pitfalls of it. A developer agent with memory could be introduced. Such an agent would consider the demands and property values trends and only engage in verticalisation when it is profitable for the developer.
5. The model does not have any mechanism to accommodate the delay realistically. Upgrading is carried out in the chosen time-step even if a delay is calculated. It would be interesting to see how the agents behave if due to lack of financial capacity it takes more time-steps to upgrade. This means that the upgrade is passed on to the next time-steps until there is enough financial capacity.
6. As is mentioned by Schwarz et al. (2016), in many contexts homelessness and street dwellers could be significant. In the context of India this could be especially important because, in 2006, there were 100000 homeless people in Delhi (Perappadan, 2014). To get a realistic account, the component of homelessness could be introduced.

6.4. Conclusions

Urban upgrading is carried out to improve the condition of slum households, and it can have many targets (Schwarz et al., 2016). One of these aspects is the role of cost recovery in the outcome of an upgrade. While cost recovery in urban upgrading has been studied and so has the income segregation in a city, few empirical studies have analysed the result of cost recovery on income segregation. A study by Schwarz et al. (2016) studied the relationship between the two by developing an agent-based model, InformalCity, but found no changes in the income segregation without cost recovery. However, since the concept of cost recovery in InformalCity is simplistic, for this study, improvements and changes were made to the upgrading and cost recovery options of this model. These changes were developed in the context of India even though the model is a theoretical one. The primary objective of this study was to analyse the relationship between cost recovery in urban upgrading and income segregation in the Indian context. The first sub-objective was to develop a background to adapting the model to the context of India and expanding the components of upgrading and cost recovery. The results for this objective are provided in Chapter 2 which provides details of the upgrading and cost recovery practices in India. The second sub-objective was to develop and implement the changes to adapt InformalCity. The resulted in Chapter 4 which is the basis for the changes in the model. Section 4.3 provides the ODD+D description of the model in which the changes made are underlined; the appendix contains the code of the model. The third and final sub-objective was to understand the effect of cost recovery in urban upgrading on segregation in the city. This is discussed in Chapter 5.

Based on the literature review of upgrading practices in India, two different kinds of upgrading options were added, the one is of classical upgrading (improvement of infrastructure) and the second one is verticalisation (vertical densification and no cost recovery). In addition to them, the option of cost recovery with a choice for the amount of subsidy is introduced. These options help us analyse the effect of cost recovery on income segregation in the hypothetical city in greater detail. While the processes involving the growth of the city, upgrading and cost recovery are specified in the model, the results in terms of the segregation patterns are emergent. Income segregation was measured using the Gini coefficient for low and high-income households separately, and results on the mean income, total population, infrastructure quality and share of low-income households per district in the city provided additional information about the processes leading to income segregation patterns in the city.

Many upgrading efforts have been carried out in India throughout the years, and they have ranged from slum clearance, rehabilitation and relocation to in-situ upgrading and verticalisation. The mechanisms for cost recovery in these schemes have been just as varied. While in some cases dwelling units were provided free of cost, in others a portion of the cost was passed on to the beneficiaries. Recently schemes with no cost recovery and verticalisation have been gaining importance. Indian cities are shifting to the market forces to upgrade the slums.

The options analysed produce ambiguous results. On the one hand, Gini coefficient does decrease (meaning reduced income segregation) in some cases, but these cases fail to improve the infrastructure quality or the mean income of informal areas. Options which improve the infrastructure and mean income of districts have the opposite effect on the Gini coefficient. Options with cost recovery and varying degrees of subsidy do not lead to any significant changes in the indicators compared to the baseline of no interventions. With the intervention of verticalisation, the segregation levels do not increase, and the overall effect on the mean income and infrastructure quality is also positive, and no cost recovery is carried out from the beneficiaries. This is positive news for the policy experts in India where currently verticalisation of slums by the generation of cross-subsidies is being carried out in programs such as Housing for All. While there are minor changes in the Gini coefficient, none of the changes are relevant enough which indicates that the classical upgrading does not do much to change the income segregation in our hypothetical city.

The approach of using agent-based modelling for this study was particularly useful. It allowed me to not only study the effect of cost recovery in upgrading on income segregation but also test how differences in income segregations emerge with changes in the interventions. Since the hypothetical city and the individual behaviour rules, the effect of different interventions is comparable. A non-modelling study would never be able to achieve this degree of comparability.

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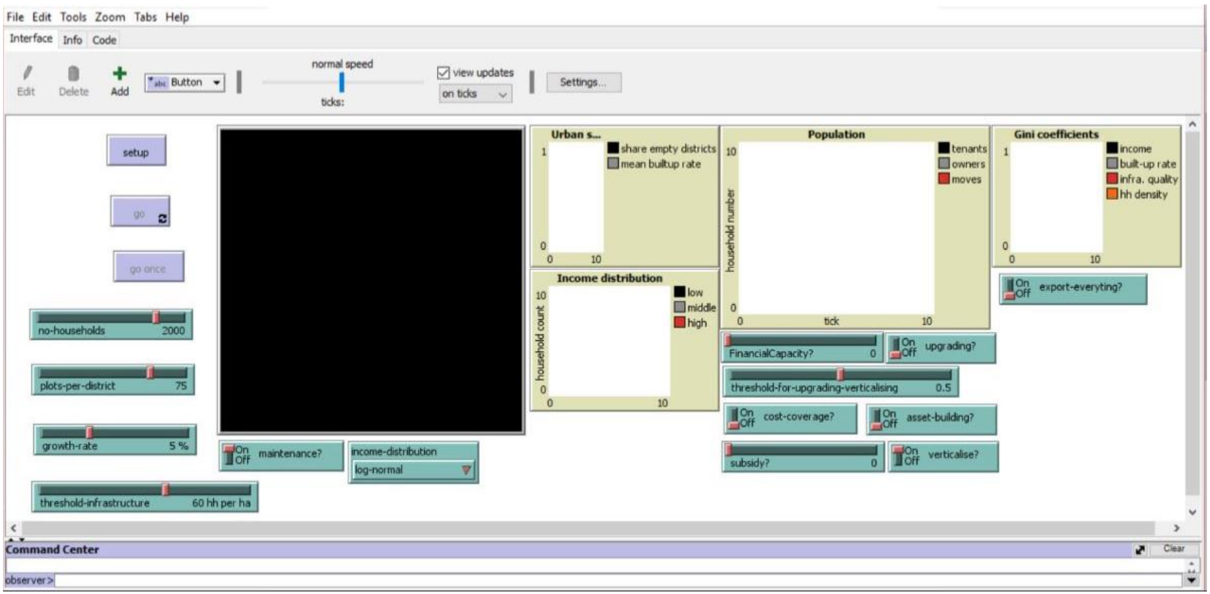
8. APPENDIX

8.1. Model Interface



8.2. Adapated InformalCity Model Code in Netlogo

; Comparison Repast and NetLogo version
; Things to keep in mind: NetLogo is now programmed so that it stops if new inhabitants cannot settle anywhere.
; This causes the simulation to stop for high building costs (20, i.e. landlords cannot afford to build new rooms at the beginning)
; and for low number of plots per district (50, as owners have to find an empty plot).
; The Repast version goes on, and results are discarded in the analysis as soon as the number of free plots reached 0.
; When comparing results for specific ticks: Netlogo tick 19 equals to Repast step 20! (repast step 1 is Netlogo setup)

; For the NetLogo version, the following settings should be used
; building costs: 10
; threshold density decrease: 30 or 60
; number of households beginning: 2,000
; plots per district: 75
; growth rate: 5%
; income distribution: log-normal

; For experiments with the pre-defined behaviour space tools, an empty folder called "results" needs to be present in the folder of the .nlogo file.

globals [infrastructure-upgraded? max-no-rooms giniHighIncome
  totalMoves giniBuiltUpRate giniLowIncome giniInfraQuality giniHHDensity

totalHHNumber totalTenantNumber totalOwnerNumber totalHHIncomeLow totalHHIncomeMiddle totalHHIncomeHigh
totalOccupiedPlots totalFreePlots totalRentedRooms totalRoomsOccupiedByOwners
meanBuiltUpRate meanInfrastructureQuality
builtUpPerDistrict_dist0_0 builtUpPerDistrict_dist0_236 builtUpPerDistrict_dist0_333 builtUpPerDistrict_dist0_471 builtUpPerDistrict_dist0_527
builtUpPerDistrict_dist0_667 builtUpPerDistrict_dist0_707 builtUpPerDistrict_dist0_745 builtUpPerDistrict_dist0_85 builtUpPerDistrict_dist1_0
HHPerDistrict_dist0_0 HHPerDistrict_dist0_236 HHPerDistrict_dist0_333 HHPerDistrict_dist0_471 HHPerDistrict_dist0_527
HHPerDistrict_dist0_667 HHPerDistrict_dist0_707 HHPerDistrict_dist0_745 HHPerDistrict_dist0_85 HHPerDistrict_dist1_0
infraQual_dist0_0 infraQual_dist0_236 infraQual_dist0_333 infraQual_dist0_471 infraQual_dist0_527
infraQual_dist0_667 infraQual_dist0_707 infraQual_dist0_745 infraQual_dist0_85 infraQual_dist1_0
meanHHIncome_dist0_0 meanHHIncome_dist0_236 meanHHIncome_dist0_333 meanHHIncome_dist0_471 meanHHIncome_dist0_527
meanHHIncome_dist0_667 meanHHIncome_dist0_707 meanHHIncome_dist0_745 meanHHIncome_dist0_85 meanHHIncome_dist1_0
financial-capacity FC
Low00 total00 status00 IQ00 MIncome00 BU00 Occ00 RR00
Low01 total01 status01 IQ01 MIncome01 BU01 Occ01 RR01
Low02 total02 status02 IQ02 MIncome02 BU02 Occ02 RR02
Low03 total03 status03 IQ03 MIncome03 BU03 Occ03 RR03
Low0-1 total0-1 status0-1 IQ0-1 MIncome0-1 BU0-1 Occ0-1 RR0-1
Low0-2 total0-2 status0-2 IQ0-2 MIncome0-2 BU0-2 Occ0-2 RR0-2
Low0-3 total0-3 status0-3 IQ0-3 MIncome0-3 BU0-3 Occ0-3 RR0-3
Low10 total10 status10 IQ10 MIncome10 BU10 Occ10 RR10
Low11 total11 status11 IQ11 MIncome11 BU11 Occ11 RR11
Low12 total12 status12 IQ12 MIncome12 BU12 Occ12 RR12
Low13 total13 status13 IQ13 MIncome13 BU13 Occ13 RR13
Low-10 total-10 status-10 IQ-10 MIncome-10 BU-10 Occ-10 RR-10
Low-11 total-11 status-11 IQ-11 MIncome-11 BU-11 Occ-11 RR-11
Low-12 total-12 status-12 IQ-12 MIncome-12 BU-12 Occ-12 RR-12
Low-13 total-13 status-13 IQ-13 MIncome-13 BU-13 Occ-13 RR-13
Low1-1 total1-1 status1-1 IQ1-1 MIncome1-1 BU1-1 Occ1-1 RR1-1
Low1-2 total1-2 status1-2 IQ1-2 MIncome1-2 BU1-2 Occ1-2 RR1-2
Low1-3 total1-3 status1-3 IQ1-3 MIncome1-3 BU1-3 Occ1-3 RR1-3
Low-1-1 total-1-1 status-1-1 IQ-1-1 MIncome-1-1 BU-1-1 Occ-1-1 RR-1-1
Low-1-2 total-1-2 status-1-2 IQ-1-2 MIncome-1-2 BU-1-2 Occ-1-2 RR-1-2
Low-1-3 total-1-3 status-1-3 IQ-1-3 MIncome-1-3 BU-1-3 Occ-1-3 RR-1-3 index00 index01 index02 index03 index0-1 index0-2 index0-3 index10 index11
Low20 total20 status20 IQ20 MIncome20 BU20 Occ20 RR20 index12 index13 index-10 index-11 index-12 index-13 index1-1 index1-2 index1-3 index-1-1 index-1-2 index-1-3 index20 index21
Low21 total21 status21 IQ21 MIncome21 BU21 Occ21 RR21 index22 index23 index-20 index-21 index-22 index-23 index2-1 index2-2 index2-3 index-2-1 index-2-2 index-2-3
Low22 total22 status22 IQ22 MIncome22 BU22 Occ22 RR22
Low23 total23 status23 IQ23 MIncome23 BU23 Occ23 RR23
Low-20 total-20 status-20 IQ-20 MIncome-20 BU-20 Occ-20 RR-20

```
  Low-21 total-21 status-21 IQ-21 MIncome-21 BU-21 Occ-21 RR-21
  Low-22 total-22 status-22 IQ-22 MIncome-22 BU-22 Occ-22 RR-22
  Low-23 total-23 status-23 IQ-23 MIncome-23 BU-23 Occ-23 RR-23
  Low2-1 total2-1 status2-1 IQ2-1 MIncome2-1 BU2-1 Occ2-1 RR2-1
  Low2-2 total2-2 status2-2 IQ2-2 MIncome2-2 BU2-2 Occ2-2 RR2-2
  Low2-3 total2-3 status2-3 IQ2-3 MIncome2-3 BU2-3 Occ2-3 RR2-3
  Low-2-1 total-2-1 status-2-1 IQ-2-1 MIncome-2-1 BU-2-1 Occ-2-1 RR-2-1
  Low-2-2 total-2-2 status-2-2 IQ-2-2 MIncome-2-2 BU-2-2 Occ-2-2 RR-2-2
  Low-2-3 total-2-3 status-2-3 IQ-2-3 MIncome-2-3 BU-2-3 Occ-2-3 RR-2-3
  Low30 total30 status30 IQ30 MIncome30 BU30 Occ30 RR30 index30 index31 index32 index33 index-
30 index-31 index-32 index-33
  Low31 total31 status31 IQ31 MIncome31 BU31 Occ31 RR31
  Low32 total32 status32 IQ32 MIncome32 BU32 Occ32 RR32
  Low33 total33 status33 IQ33 MIncome33 BU33 Occ33 RR33
  Low-30 total-30 status-30 IQ-30 MIncome-30 BU-30 Occ-30 RR-30
  Low-31 total-31 status-31 IQ-31 MIncome-31 BU-31 Occ-31 RR-31
  Low-32 total-32 status-32 IQ-32 MIncome-32 BU-32 Occ-32 RR-32
  Low-33 total-33 status-33 IQ-33 MIncome-33 BU-33 Occ-33 RR-33
  Low3-1 total3-1 status3-1 IQ3-1 MIncome3-1 BU3-1 Occ3-1 RR3-1 index3-1 index3-2 index3-3 index-
3-1 index-3-2 index-3-3
  Low3-2 total3-2 status3-2 IQ3-2 MIncome3-2 BU3-2 Occ3-2 RR3-2
  Low3-3 total3-3 status3-3 IQ3-3 MIncome3-3 BU3-3 Occ3-3 RR3-3
  Low-3-1 total-3-1 status-3-1 IQ-3-1 MIncome-3-1 BU-3-1 Occ-3-1 RR-3-1
  Low-3-2 total-3-2 status-3-2 IQ-3-2 MIncome-3-2 BU-3-2 Occ-3-2 RR-3-2
  Low-3-3 total-3-3 status-3-3 IQ-3-3 MIncome-3-3 BU-3-3 Occ-3-3 RR-3-3
]



;globals set via the interface:
; no-households
; plots-per-district
; growth-rate
; building-costs
; threshold-infrastructure (in hh per hectare)
; income-distribution     options: "normal", "equal", "log-normal"
; upgrading?              OFF: no upgrading is considered at all
; maintenance?            OFF: no maintenance
; cost-coverage?          OFF: costs are not covered by inhabitants
; target          options: "lowest, "random"
; distribution     options: "few-high", "many-low"
; timing          options: "early", "late"


breed [tenants tenant]
breed [owners owner]
```

```
breed [plots a-plot]  ;; meaning that plots are in fact agents that do not move.
; this is a workaround as patches cannot be split up into smaller pieces to represent plots.
; a-plot for a single housing plot instead of "plot", as plot is a Netlogo primitive
; Its advantage is that we can use links to connect tenants and owners to specific plots, which does not
work with patches
directed-link-breed [housings housing]
; housing-to tenant or owner
; housing-from plot

tenants-own [income income-level savings preference-cbd preference-infrastructure settled? preference-
formal?]
owners-own [income income-level savings preference-cbd preference-infrastructure settled? no-rooms-
for-rent-occupied preference-formal? ]

; to clarify which variables belong to which spatial entity, 'd-' stands for district / patch, and 'p-' for plot
patches-own [d-owner d-tenant d-infrastructure-quality d-district-upgraded? d-tick-upgrading d-building-
costs
  d-built-up-rate d-hhdensity-per-ha d-share-low-inc-hh d-share-high-inc-hh d-normalised-distancexy d-
mean-hh-income d-temputility d-formal? d-index d-low d-mid d-high d-status d-hh-number d-district-
verticalised? d-tick-verticalise ]
plots-own [ p-no-all-rooms p-no-rooms-for-rent p-no-rooms-rented p-no-owner-occupied-rooms]

to setup
  clear-all
  ; all variables not mentioned here explicitly are initialised with 0!
  ask patches [set d-infrastructure-quality 1
    set d-building-costs ((-10 * d-normalised-distancexy + 15) + 1.8); here, the districts are initialised with
the global value
    set d-district-upgraded? false
    set d-district-verticalised? false
    set d-normalised-distancexy precision ( ( distancexy 0 0 ) / [distancexy 0 0] of patch max-pxcor max-
pycor ) 3 ;; normalise distance so that it is between 0 and 1 (maximum distance)
    set d-formal? 2
    sprout-plots plots-per-district [hide-turtle]]
   set financial-capacity 0

  ask n-of 2 patches with [ d-normalised-distancexy < 0.3 AND d-normalised-distancexy > 0.2 ] [set d-
formal? 1]
  ask n-of 2 patches with [ d-normalised-distancexy < 0.6 AND d-normalised-distancexy > 0.3 ] [set d-
formal? 1]
  ask n-of 2 patches with [ d-normalised-distancexy < 1 AND d-normalised-distancexy > 0.6 ] [set d-
formal? 1]
  let informal-districts patches with [d-formal? = 1]
  ask informal-districts [set d-building-costs 0 + 1.8]
  create-tenants no-households [initialise-new-tenant]
  ask tenants [settle-first-time]
  set infrastructure-upgraded? false
```

```
  set max-no-rooms 10

  reset-ticks
end


to go
  ask patches [adapt-infrastructure]
  ask tenants [set savings (savings + income)]
  ask owners  [set savings (savings + income + no-rooms-for-rent-occupied)]

  add-new-inhabitants

  ask owners [ ifelse (random 10 = 0)
    [move-as-owner ]
    [enlarge-house-for-rent] ]

  ask tenants [ if (random 10 = 0)
    [ move-as-tenant] ]
  set financial-capacity (financial-capacity + FinancialCapacity?)

  if (upgrade-now? = true) [upgrade-infrastructure]
  if (verticalise-now? = true) [verticalise-infrastructure]
  if (asset-building? = true) [build-asset]

  update-data
  tick
end

to build-asset;
  let l-income-tenants tenants with [ income <= 0.25 ]
  let l-income-owners owners with [ income <= 0.25 ]
 ask l-income-tenants [set savings (savings + 0.038)]
  ask l-income-owners [set savings (savings + 0.038)] ;TO DO
end

to add-new-inhabitants
    ; check whether there is still space available to accomodate new inhabitants of the city
  let freeroomstorent sum [ p-no-rooms-for-rent ] of plots
  let freeplotstobuild count plots with [ p-no-all-rooms = 0 ]
  let freeemptyhouses count plots with [( p-no-all-rooms  > 0 ) AND (p-no-owner-occupied-rooms = 0 ) ]
  let number-new-inhabitants round ((count tenants + count owners) * growth-rate / 100 )

  ifelse (freeroomstorent + freeplotstobuild + freeemptyhouses) > number-new-inhabitants
  [ create-tenants number-new-inhabitants [initialise-new-tenant  settle-first-time] ] ; add new tenants to the
city
  [ user-message ( word "city too full in add-new-inhabitants for planned inhabitants of " number-new-
inhabitants )
```

```
   stop]
end

to initialise-new-tenant
 set settled? FALSE
  set income -1 ; to have a value to check against during while loop
 ifelse (income-distribution = "normal")
 [while [income < 0 OR income > 1] [
    set income random-normal 0.5 0.25]
  ]
 [ifelse (income-distribution = "log-normal")
   [
      while [income < 0 OR income > 1] [
        set income exp (random-normal -2 1)]
    ]
   [set income random-float 1]] ; -> income-distribution = "equal"

 set savings ((random 16) * income)

 ifelse (income < 0.25)  [set income-level "low"
  set color yellow]
  [ifelse (income < 0.75)  [set income-level "middle"
    set color green]
    [set income-level "high"
      set color blue]]
let temp-pref1 random-normal 0.5 0.25
 while [temp-pref1 < 0] [ set temp-pref1 random-normal 0.5 0.25]

 let temp-pref2 random-normal 0.5 0.25
  while [temp-pref2 < 0] [set temp-pref2 random-normal 0.5 0.25]

 let temp-pref3 income

 let sum-temp-prefs (temp-pref1 + temp-pref2 + temp-pref3)

 set preference-cbd            temp-pref1 / sum-temp-prefs
 set preference-infrastructure temp-pref2 / sum-temp-prefs
  set preference-formal?       temp-pref3 / sum-temp-prefs
 if (precision (preference-cbd + preference-infrastructure + preference-formal?) 3 != 1) ;
 [user-message "preferences are not assigned properly!"]

end

; tenants move to initial location, probably become owners
to settle-first-time
let freedistricts patches with [ any? plots-here with [ p-no-rooms-for-rent > 0 ] ]
ifelse ( count freedistricts > 0 )
 [;  -      A.1.1 If they find a room to rent, they do so.
```

```
   compute1Utility freedistricts preference-cbd preference-infrastructure preference-formal?
   let targetdistrict max-one-of freedistricts [d-temputility]
   become-tenant-in-new-district targetdistrict
   set settled? TRUE
 ]
  [; -      A.1.2 no plots with free rooms -> they become owners and build a house
    hatch-owners 1 [ settle-as-owner ]
    die ; tenant has to leave the system
  ]
  set totalMoves ( totalMoves + 1 )
end

to become-tenant-in-new-district [target-district]
   let targetplot one-of ( plots-on target-district)  with [ p-no-rooms-for-rent > 0 ]
   move-to target-district
   create-housing-from targetplot
   ask targetplot [
   set p-no-rooms-for-rent ( p-no-rooms-for-rent - 1 )
   set p-no-rooms-rented   ( p-no-rooms-rented + 1)
   ]
end

to settle-as-owner  ; owners build a house (even without having enough savings), occupying 1-3 rooms
(randomly)
  let freedistrictstobuild patches with [ any? plots-here with [ p-no-all-rooms = 0 ] ]

  let freedistrictswithemptyhouses patches with [ any? plots-here with [( p-no-all-rooms ) > 0 AND (p-no-
owner-occupied-rooms = 0 ) ] ]

  ifelse ( count freedistrictstobuild > 0)
  [
    compute1Utility freedistrictstobuild preference-cbd preference-infrastructure preference-formal?
    let targetdistrict max-one-of freedistrictstobuild [ d-temputility ]
    build-new-in-target-district targetdistrict
    set settled? TRUE
  ]

  [ ; if there are no free plots: check whether there are empty houses
    ifelse (count freedistrictswithemptyhouses > 0)
    [
      compute1Utility freedistrictswithemptyhouses preference-cbd preference-infrastructure preference-
formal?
      let targetdistrict max-one-of freedistrictswithemptyhouses [ d-temputility ]
      move-as-owner-into-existing-house targetdistrict
      set settled? TRUE
    ]
    [
      show "simulation stopped as no more space left "
```

```
     stop]
  ]
end

to build-new-in-target-district [target-district]
  move-to target-district
  let target-plot one-of ( plots-here with [p-no-all-rooms = 0] )
  create-housing-from target-plot
  let new-rooms ( 1 + random 3 )
  ask target-plot [
    set p-no-rooms-rented 0
    set p-no-rooms-for-rent ( 3 - new-rooms )
    set p-no-all-rooms 3
    set p-no-owner-occupied-rooms new-rooms
  ]
end

to move-as-owner-into-existing-house [target-district]
  move-to target-district
  let target-plot one-of ( plots-here with [( p-no-all-rooms ) > 0 AND (p-no-owner-occupied-rooms = 0 ) ]
)

  create-housing-from target-plot

  let emptyrooms ( [ p-no-all-rooms ] of target-plot - [ p-no-rooms-rented ] of target-plot  )
  ifelse ( emptyrooms > 3 )
  [
    ask target-plot [
;      set p-no-rooms-rented no change
      set p-no-rooms-for-rent ( emptyrooms - 3 )
      set p-no-owner-occupied-rooms 3
    ]
  ]
  [ ; 1 to 3
    ask target-plot [
;      set p-no-rooms-rented no change
      set p-no-rooms-for-rent 0
      set p-no-owner-occupied-rooms emptyrooms
    ]
  ]
end

to move-as-owner
  ;; first: check whether owner is currently satisfied by comparing current district with random district
  let randomDistrict one-of patches  ;; utility should be higher than random district, plus still free plots
available
  compute1Utility randomDistrict preference-cbd preference-infrastructure preference-formal?
  compute1Utility patch-here preference-cbd preference-infrastructure preference-formal?
```

```
  if ( ( [d-temputility] of randomDistrict > [d-temputility] of patch-here ) AND any? ( plots-on
randomDistrict ) with [p-no-all-rooms = 0]   )
  [
    let affordable-districts patches with [ ( d-building-costs <= [savings] of myself ) AND  any? ( plots-here
) with [p-no-all-rooms = 0]  ]
    if ( any? affordable-districts )
    [
      set totalMoves ( totalMoves + 1 )
      ; select district with highest utility
      compute1Utility affordable-districts preference-cbd preference-infrastructure preference-formal?
      let target-district  max-one-of affordable-districts [d-temputility]
      if ( target-district != patch-here )
      [
        ; moving out of current plot
        ask housing-neighbors [
          ; p-no-rooms-rented: no change
;          p-no-rooms-for-rent no change
          ;  p-no-all-rooms: no change
          set p-no-owner-occupied-rooms 0
        ]
        ask my-links [die]
        build-new-in-target-district target-district
        set savings ( savings - d-building-costs)
    ]
  ]
  ]

end

;            A.2.4 If agents want to move and are tenants:
to move-as-tenant

   let affordable-districts patches with [ ( d-building-costs <= [savings] of myself ) AND  any? ( plots-here
) with [p-no-all-rooms = 0]  ]
    ifelse ( any? affordable-districts )  ; there are districts in which the tenant can build
    [ compute1Utility affordable-districts preference-cbd preference-infrastructure preference-formal?
    compute1Utility patch-here preference-cbd preference-infrastructure preference-formal?

    if ( max [ d-temputility ] of affordable-districts >  [ d-temputility ] of patch-here )
    [;  tenants become owners and build a house
        set totalMoves ( totalMoves + 1 )
         ask housing-neighbors [
          set p-no-rooms-rented ( p-no-rooms-rented - 1)
          set p-no-rooms-for-rent ( p-no-rooms-for-rent + 1)
          ;  p-no-all-rooms: no change
          ;  p-no-owner-occupied-rooms no change
       ]
```

```
      ask my-links [die]

      hatch-owners 1 [ ; all this is now done by the newly created owner
        let target-district  max-one-of affordable-districts [d-temputility]
       ; moving out of current plot
      build-new-in-target-district target-district
      set savings ( savings - d-building-costs)
      ]
       die ; tenant has to leave the system
    ]
  ]

  [ ; no affordable districts -> the tenant cannot build and will instead look for a new room
    ; find district with empty rooms to rent and highest utility, go there
   let freedistricts patches with [ any? plots-here with [ p-no-rooms-for-rent > 0 ] ]
   compute1Utility freedistricts preference-cbd preference-infrastructure preference-formal?
   let targetdistrict max-one-of freedistricts [d-temputility]
    if ( targetdistrict != patch-here and targetdistrict != nobody) [
       ; moving out of current plot
        ask housing-neighbors [
          set p-no-rooms-rented ( p-no-rooms-rented - 1)
          set p-no-rooms-for-rent (p-no-rooms-for-rent + 1)
          ;  p-no-all-rooms: no change
          ;  p-no-owner-occupied-rooms no change
       ]
      ask my-links [die]
      become-tenant-in-new-district targetdistrict
    ]
  ]

end

to
  compute1utility [freedistricts pref-cbd pref-infrastructure pref-formal?]

  foreach (list freedistricts) [ [ the-district] -> ask the-district [set d-temputility (  pref-cbd * (1 - d-
normalised-distancexy) + pref-infrastructure * (d-infrastructure-quality) + pref-formal? * (d-formal?)  )] ]
end

to enlarge-house-for-rent
  ;; check: how many rooms can still be added? decide whether 0, 1 or 3
  let max-rooms-here max-no-rooms - [ p-no-all-rooms ] of one-of in-housing-neighbors

  if (max-rooms-here > 0) [
    ; determine how many rooms shall be added and the costs associated with that
    let new-rooms 0
    let costs 0
    ifelse ( max-rooms-here > 2)
```

```
    [set new-rooms 3
    set costs 1.8]
    [set new-rooms 1
    set costs 1.8 / 2]
    ; only continue when there are enough savings
    if (savings >= costs)
    [  ;; build: add rooms for rent to no-rooms-for-rent, spend savings
      ask one-of in-housing-neighbors [
        set p-no-rooms-for-rent ( p-no-rooms-for-rent + new-rooms)
        set p-no-all-rooms (p-no-all-rooms + new-rooms)
      ]
    set savings ( savings - costs)
    ]
  ] ;; else: plot already built-up
end


; the original equation reads:
; infrastructure quality=(-1/π)  arctan(density-threshold)+0.5
; Due to an adapted implementation of arctan in Netlogo (atan primitive), I used asin (x / sqrt (1 + x * x))
/ 360 * 2 * PI instead
to adapt-infrastructure
  if (maintenance? = false or (maintenance? = true and d-district-upgraded? = false)) [
   let temp (compute-hhdensity-for-district - threshold-infrastructure)
   set d-infrastructure-quality (-1 * asin (temp / sqrt(1 + temp * temp)) / 360 * 2 + 0.5)

 if (d-infrastructure-quality > 1 or d-infrastructure-quality < 0)
  [user-message word "infra-quality out of range " d-infrastructure-quality]
  ]

end

;to-report test-infrastr [hhdensity]
;   let temp (hhdensity - threshold-infrastructure)
;   let result (-1 * asin (temp / sqrt(1 + temp * temp)) / 360 * 2 + 0.5)
;report result
;end


to-report compute-hhdensity-for-district
  let density 0
  set density ((count owners-here + count tenants-here) / ( plots-per-district * 250 / 10000)) ; hh density
in ha (= 10,000 square metres)
  report density
end
to-report verticalise-now?
  let do-verticalise-now? false
```

```
  let eligible-districts patches with [d-district-verticalised? = false and d-formal? = 1 ];and d-hhdensity-per-
ha]
  ifelse (verticalise? = true) and (ticks mod 5 = 0) and ((count (patches with [d-infrastructure-quality <
threshold-for-upgrading-verticalising])) >= 1) and (ticks != 0) and (count eligible-districts > 0)
  [set do-verticalise-now? true]
  [set do-verticalise-now? false]
  report do-verticalise-now?
end


to verticalise-infrastructure
  let number-target 1
  let eligible-districts patches with [d-district-upgraded? = false and d-formal? = 1];and d-hhdensity-per-ha]
  let target-districts (max-one-of eligible-districts [d-hhdensity-per-ha])
  let total-hh (count tenants-on target-districts + count owners-on target-districts)
  let total-target-plots count (plots-on target-districts)
  ask target-districts
   [set d-formal? 2
     set d-infrastructure-quality 1
      set d-district-verticalised? true
      set d-tick-verticalise ticks
       sprout-plots ((75 * plots-per-district) / 100 ) [hide-turtle]
        set d-building-costs ((-10 * d-normalised-distancexy + 15) + 1.8) ]
end


to-report upgrade-now?
  let do-upgrade-now? false
  let eligible-districts patches with [d-district-upgraded? = false and d-formal? = 1 ]
  ifelse (upgrading? = true) and (ticks mod 5 = 0) and ((count (patches with [d-infrastructure-quality <
threshold-for-upgrading-verticalising])) >= 1) and (ticks != 0) and (count eligible-districts > 0)
  [set do-upgrade-now? true]
  [set do-upgrade-now? false]
report do-upgrade-now?
end

to upgrade-infrastructure;
  let number-targets 1
  let eligible-districts patches with [d-district-upgraded? = false and d-formal? = 1 ]
  let target-districts (max-one-of eligible-districts [d-hhdensity-per-ha])
  let total-hh (count owners-on target-districts)
  show word "total-hh: " total-hh

  let cost-upgrading 0.39
  let total-cost-upgrading 0
  set total-cost-upgrading ( total-hh * cost-upgrading )
  show word "total-cosst: " total-cost-upgrading ; change to total owners
  let delay ((total-cost-upgrading - financial-capacity) /  FinancialCapacity?)
```

```
  if (delay < 0) [set delay  0]
  show word "delay: " delay
  ;WRONG if delay is less than 0 then set it to zero
  ifelse (financial-capacity >= total-cost-upgrading)
  [ask target-districts [
    set d-formal? 2
    set d-building-costs ((-10 * d-normalised-distancexy + 15) + 1.8)
    set d-infrastructure-quality 1
    set d-district-upgraded? true
    set d-tick-upgrading ticks ]
    set financial-capacity (financial-capacity - total-cost-upgrading)
  show word "FCafterupgradeI: " financial-capacity]
  [
    ifelse  (delay > 4)
    [
      (ask target-districts [
     set d-formal? 1
     set d-infrastructure-quality .50
     set d-district-upgraded? true
     set d-tick-upgrading ticks
                         ]
      )
     set financial-capacity (financial-capacity - (total-cost-upgrading + (total-cost-upgrading * (8 * delay) /
100 )))
     show word "FCafterupgradeIII: " financial-capacity ]
    [
      (ask target-districts [
      set d-formal? 2
      set d-infrastructure-quality .75
      set d-district-upgraded? true
      set d-tick-upgrading ticks
                          ]
      )
      set financial-capacity (financial-capacity - (total-cost-upgrading + (total-cost-upgrading * (8 * delay)/
100 )))
  show word "FCafterupgradeII: " financial-capacity ]]


  ask patches with [d-infrastructure-quality > 1] [set d-infrastructure-quality 1]

let cost-upgrade 0
set cost-upgrade (.39 + (delay * 8 * .39 / 100)) - (subsidy? * (.39 + (delay * 8 * .39 / 100)) / 100)
if (cost-coverage? = true)
[ifelse (delay = 0)
 [ show word "cost-upgradeI: " cost-upgrade; have to multiply by the delay
      ask target-districts [ask owners-here
       [set savings ( savings - cost-upgrade )
```

```
show word "CRI-savings: " savings  ]
                    ]
      let total-upgraded-owners (count owners-on target-districts) show word "total owner: " total-
upgraded-owners
      set financial-capacity ( financial-capacity + (total-upgraded-owners * cost-upgrade)); WRONG PUT
DIVIDED BY 0
      show word "FC_CR: " financial-capacity
  ]
  [ifelse (delay <= 4)
       [ show word "cost-upgradeI: " cost-upgrade
      ask target-districts [ask owners-here
       [set savings ( savings - cost-upgrade )
          show word "CRI-savings: " savings  ]
                    ]
      let total-upgraded-owners (count owners-on target-districts) show word "total owner: " total-
upgraded-owners
      set financial-capacity ( financial-capacity + ((total-upgraded-owners * cost-upgrade) / delay ));
WRONG PUT DIVIDED BY 0
      show word "FC_CRII: " financial-capacity
  ]
     [ show word "cost-upgradeII: " cost-upgrade
       ask target-districts [ask owners-here
                    [let randomDistrict one-of patches
        compute1Utility randomDistrict preference-cbd preference-infrastructure preference-formal?
        compute1Utility patch-here preference-cbd preference-infrastructure preference-formal?
                     if (( [d-temputility] of randomDistrict > [d-temputility] of patch-here ) AND any? (
plots-on randomDistrict ) with [p-no-all-rooms = 0])
                     [let affordable-districts patches with [((d-building-costs)  <= [cost-upgrade] of myself)
AND  any? ( plots-here ) with [p-no-all-rooms = 0]]
                     ifelse ( any? affordable-districts )

                     [set totalMoves ( totalMoves + 1 )
                      compute1Utility affordable-districts preference-cbd preference-infrastructure
preference-formal? ;CHECK
                      let target-district1  max-one-of affordable-districts [d-temputility]
                      if ( target-district1 != patch-here )
                      [ask housing-neighbors [set p-no-owner-occupied-rooms 0]]; problem

                       ask my-links [die]
                       build-new-in-target-district target-district1
                       set savings ( savings - d-building-costs )
                       show word "they chose otherwise: " savings
                      ]

                       [set savings ( savings - cost-upgrade )
                        show word "CRII-savings: " savings ]
                      ]
                    ]
```

```
                              ]
                                 let total-upgraded-owners (count owners-on target-districts)
                                 show word "total-upgraded-owners: " total-upgraded-owners
                                 set financial-capacity ( financial-capacity + ((total-upgraded-owners * cost-upgrade) /
delay)); WRONG
                                  show word "FC_CRIII: " financial-capacity
    ]   ]]


end


to update-data

  ask owners [ set no-rooms-for-rent-occupied ( sum [ p-no-rooms-rented ] of housing-neighbors )
  ]

  ;; second: update patches
  ask patches [
    set d-built-up-rate ( ( mean [ p-no-all-rooms ] of plots-here ) / max-no-rooms )
    set d-hhdensity-per-ha compute-hhdensity-for-district
    set d-share-low-inc-hh  compute-share-low-inc-hh-on-patch
    set d-share-high-inc-hh  compute-share-high-inc-hh-on-patch
    set d-mean-hh-income compute-mean-hh-income-on-patch
    set pcolor scale-color blue d-infrastructure-quality 0 1
    set d-hh-number compute-hh
    set d-low compute-low
    set d-mid compute-middle
    set d-high compute-high
    set d-status d-formal?
   set d-index compute-index
  set d-tenant compute-tenants
  set d-owner  compute-owners]

  set index00 [d-index] of patch 0 0
  set index01 [d-index] of patch 0 1
  set index02 [d-index] of patch 0 2
  set index03 [d-index] of patch 0 3
  set index0-1 [d-index] of patch 0 -1
  set index0-2 [d-index] of patch 0 -2
  set index0-3 [d-index] of patch 0 -3
  set index10 [d-index] of patch 1 0
  set index11 [d-index] of patch 1 1
  set index12 [d-index] of patch 1 2
  set index13 [d-index] of patch 1 3
  set index-10 [d-index] of patch -1 0
  set index-11 [d-index] of patch -1 1
  set index-12 [d-index] of patch -1 2
```

```
set index-13 [d-index] of patch -1 3
set index1-1 [d-index] of patch 1 -1
set index1-2 [d-index] of patch 1 -2
set index1-3 [d-index] of patch 1 -3
set index-1-1 [d-index] of patch -1 -1
set index-1-2 [d-index] of patch -1 -2
set index-1-3 [d-index] of patch -1 -3
set index20 [d-index] of patch 2 0
set index21 [d-index] of patch 2 1
set index22 [d-index] of patch 2 2
set index23 [d-index] of patch 2 3
set index-20 [d-index] of patch -2 0
set index-21 [d-index] of patch -2 1
set index-22 [d-index] of patch -2 2
set index-23 [d-index] of patch -2 3
set index2-1 [d-index] of patch 2 -1
set index2-2 [d-index] of patch 2 -2
set index2-3 [d-index] of patch 2 -3
set index-2-1 [d-index] of patch -2 -1
set index-2-2 [d-index] of patch -2 -2
set index-2-3 [d-index] of patch -2 -3
set index30 [d-index] of patch 3 0
set index31 [d-index] of patch 3 1
set index32 [d-index] of patch 3 2
set index33 [d-index] of patch 3 3
set index-30 [d-index] of patch -3 0
set index-31 [d-index] of patch -3 1
set index-32 [d-index] of patch -3 2
set index-33 [d-index] of patch -3 3
set index3-1 [d-index] of patch 3 -1
set index3-2 [d-index] of patch 3 -2
set index3-3 [d-index] of patch 3 -3
set index-3-1 [d-index] of patch -3 -1
set index-3-2 [d-index] of patch -3 -2
set index-3-3 [d-index] of patch -3 -3

set Low00 [d-share-low-inc-hh] of patch 0 0
set Low01 [d-share-low-inc-hh] of patch 0 1
set Low02 [d-share-low-inc-hh] of patch 0 2
set Low03 [d-share-low-inc-hh] of patch 0 3
set Low0-1 [d-share-low-inc-hh] of patch 0 -1
set Low0-2 [d-share-low-inc-hh] of patch 0 -2
set Low0-3 [d-share-low-inc-hh] of patch 0 -3
set Low10 [d-share-low-inc-hh] of patch 1 0
set Low11 [d-share-low-inc-hh] of patch 1 1
set Low12 [d-share-low-inc-hh] of patch 1 2
set Low13 [d-share-low-inc-hh] of patch 1 3
set Low-10 [d-share-low-inc-hh] of patch -1 0
```

```
set Low-11 [d-share-low-inc-hh] of patch -1 1
set Low-12 [d-share-low-inc-hh] of patch -1 2
set Low-13 [d-share-low-inc-hh] of patch -1 3
set Low1-1 [d-share-low-inc-hh] of patch 1 -1
set Low1-2 [d-share-low-inc-hh] of patch 1 -2
set Low1-3 [d-share-low-inc-hh] of patch 1 -3
set Low-1-1 [d-share-low-inc-hh] of patch -1 -1
set Low-1-2 [d-share-low-inc-hh] of patch -1 -2
set Low-1-3 [d-share-low-inc-hh] of patch -1 -3
set Low20 [d-share-low-inc-hh] of patch 2 0
set Low21 [d-share-low-inc-hh] of patch 2 1
set Low22 [d-share-low-inc-hh] of patch 2 2
set Low23 [d-share-low-inc-hh] of patch 2 3
set Low-20 [d-share-low-inc-hh] of patch -2 0
set Low-21 [d-share-low-inc-hh] of patch -2 1
set Low-22 [d-share-low-inc-hh] of patch -2 2
set Low-23 [d-share-low-inc-hh] of patch -2 3
set Low2-1 [d-share-low-inc-hh] of patch 2 -1
set Low2-2 [d-share-low-inc-hh] of patch 2 -2
set Low2-3 [d-share-low-inc-hh] of patch 2 -3
set Low-2-1 [d-share-low-inc-hh] of patch -2 -1
set Low-2-2 [d-share-low-inc-hh] of patch -2 -2
set Low-2-3 [d-share-low-inc-hh] of patch -2 -3
set Low30 [d-share-low-inc-hh] of patch 3 0
set Low31 [d-share-low-inc-hh] of patch 3 1
set Low32 [d-share-low-inc-hh] of patch 3 2
set Low33 [d-share-low-inc-hh] of patch 3 3
set Low-30 [d-share-low-inc-hh] of patch -3 0
set Low-31 [d-share-low-inc-hh] of patch -3 1
set Low-32 [d-share-low-inc-hh] of patch -3 2
set Low-33 [d-share-low-inc-hh] of patch -3 3
set Low3-1 [d-share-low-inc-hh] of patch 3 -1
set Low3-2 [d-share-low-inc-hh] of patch 3 -2
set Low3-3 [d-share-low-inc-hh] of patch 3 -3
set Low-3-1 [d-share-low-inc-hh] of patch -3 -1
set Low-3-2 [d-share-low-inc-hh] of patch -3 -2
set Low-3-3 [d-share-low-inc-hh] of patch -3 -3

set total00 [d-hh-number] of patch 0 0
set total01 [d-hh-number] of patch 0 1
set total02 [d-hh-number] of patch 0 2
set total03 [d-hh-number] of patch 0 3
set total0-1 [d-hh-number] of patch 0 -1
set total0-2 [d-hh-number] of patch 0 -2
set total0-3 [d-hh-number] of patch 0 -3
set total10 [d-hh-number] of patch 1 0
set total11 [d-hh-number] of patch 1 1
set total12 [d-hh-number] of patch 1 2
```

```
set total13 [d-hh-number] of patch 1 3
set total-10 [d-hh-number] of patch -1 0
set total-11 [d-hh-number] of patch -1 1
set total-12 [d-hh-number] of patch -1 2
set total-13 [d-hh-number] of patch -1 3
set total1-1 [d-hh-number] of patch 1 -1
set total1-2 [d-hh-number] of patch 1 -2
set total1-3 [d-hh-number] of patch 1 -3
set total-1-1 [d-hh-number] of patch -1 -1
set total-1-2 [d-hh-number] of patch -1 -2
set total-1-3 [d-hh-number] of patch -1 -3
set total20 [d-hh-number] of patch 2 0
set total21 [d-hh-number] of patch 2 1
set total22 [d-hh-number] of patch 2 2
set total23 [d-hh-number] of patch 2 3
set total-20 [d-hh-number] of patch -2 0
set total-21 [d-hh-number] of patch -2 1
set total-22 [d-hh-number] of patch -2 2
set total-23 [d-hh-number] of patch -2 3
set total2-1 [d-hh-number] of patch 2 -1
set total2-2 [d-hh-number] of patch 2 -2
set total2-3 [d-hh-number] of patch 2 -3
set total-2-1 [d-hh-number] of patch -2 -1
set total-2-2 [d-hh-number] of patch -2 -2
set total-2-3 [d-hh-number] of patch -2 -3
set total30 [d-hh-number] of patch 3 0
set total31 [d-hh-number] of patch 3 1
set total32 [d-hh-number] of patch 3 2
set total33 [d-hh-number] of patch 3 3
set total-30 [d-hh-number] of patch -3 0
set total-31 [d-hh-number] of patch -3 1
set total-32 [d-hh-number] of patch -3 2
set total-33 [d-hh-number] of patch -3 3
set total3-1 [d-hh-number] of patch 3 -1
set total3-2 [d-hh-number] of patch 3 -2
set total3-3 [d-hh-number] of patch 3 -3
set total-3-1 [d-hh-number] of patch -3 -1
set total-3-2 [d-hh-number] of patch -3 -2
set total-3-3 [d-hh-number] of patch -3 -3

set status00 [d-district-upgraded?] of patch 0 0
set status01 [d-district-upgraded?] of patch 0 1
set status02 [d-district-upgraded?] of patch 0 2
set status03 [d-district-upgraded?] of patch 0 3
set status0-1 [d-district-upgraded?] of patch 0 -1
set status0-2 [d-district-upgraded?] of patch 0 -2
set status0-3 [d-district-upgraded?] of patch 0 -3
set status10 [d-district-upgraded?] of patch 1 0
```

```
set status11 [d-district-upgraded?] of patch 1 1
set status12 [d-district-upgraded?] of patch 1 2
set status13 [d-district-upgraded?] of patch 1 3
set status-10 [d-district-upgraded?] of patch -1 0
set status-11 [d-district-upgraded?] of patch -1 1
set status-12 [d-district-upgraded?] of patch -1 2
set status-13 [d-district-upgraded?] of patch -1 3
set status1-1 [d-district-upgraded?] of patch 1 -1
set status1-2 [d-district-upgraded?] of patch 1 -2
set status1-3 [d-district-upgraded?] of patch 1 -3
set status-1-1 [d-district-upgraded?] of patch -1 -1
set status-1-2 [d-district-upgraded?] of patch -1 -2
set status-1-3 [d-district-upgraded?] of patch -1 -3
set status20 [d-district-upgraded?] of patch 2 0
set status21 [d-district-upgraded?] of patch 2 1
set status22 [d-district-upgraded?] of patch 2 2
set status23 [d-district-upgraded?] of patch 2 3
set status-20 [d-district-upgraded?] of patch -2 0
set status-21 [d-district-upgraded?] of patch -2 1
set status-22 [d-district-upgraded?] of patch -2 2
set status-23 [d-district-upgraded?] of patch -2 3
set status2-1 [d-district-upgraded?] of patch 2 -1
set status2-2 [d-district-upgraded?] of patch 2 -2
set status2-3 [d-district-upgraded?] of patch 2 -3
set status-2-1 [d-district-upgraded?] of patch -2 -1
set status-2-2 [d-district-upgraded?] of patch -2 -2
set status-2-3 [d-district-upgraded?] of patch -2 -3
set status30 [d-district-upgraded?] of patch 3 0
set status31 [d-district-upgraded?] of patch 3 1
set status32 [d-district-upgraded?] of patch 3 2
set status33 [d-district-upgraded?] of patch 3 3
set status-30 [d-district-upgraded?] of patch -3 0
set status-31 [d-district-upgraded?] of patch -3 1
set status-32 [d-district-upgraded?] of patch -3 2
set status-33 [d-district-upgraded?] of patch -3 3
set status3-1 [d-district-upgraded?] of patch 3 -1
set status3-2 [d-district-upgraded?] of patch 3 -2
set status3-3 [d-district-upgraded?] of patch 3 -3
set status-3-1 [d-district-upgraded?] of patch -3 -1
set status-3-2 [d-district-upgraded?] of patch -3 -2
set total-3-3 [d-district-upgraded?] of patch -3 -3

set IQ00 [d-infrastructure-quality] of patch 0 0
set IQ01 [d-infrastructure-quality] of patch 0 1
set IQ02 [d-infrastructure-quality] of patch 0 2
set IQ03 [d-infrastructure-quality] of patch 0 3
set IQ0-1 [d-infrastructure-quality] of patch 0 -1
set IQ0-2 [d-infrastructure-quality] of patch 0 -2
```

```
set IQ0-3 [d-infrastructure-quality] of patch 0 -3
set IQ10 [d-infrastructure-quality] of patch 1 0
set IQ11 [d-infrastructure-quality] of patch 1 1
set IQ12 [d-infrastructure-quality] of patch 1 2
set IQ13 [d-infrastructure-quality] of patch 1 3
set IQ-10 [d-infrastructure-quality] of patch -1 0
set IQ-11 [d-infrastructure-quality] of patch -1 1
set IQ-12 [d-infrastructure-quality] of patch -1 2
set IQ-13 [d-infrastructure-quality] of patch -1 3
set IQ1-1 [d-infrastructure-quality] of patch 1 -1
set IQ1-2 [d-infrastructure-quality] of patch 1 -2
set IQ1-3 [d-infrastructure-quality] of patch 1 -3
set IQ-1-1 [d-infrastructure-quality] of patch -1 -1
set IQ-1-2 [d-infrastructure-quality] of patch -1 -2
set IQ-1-3 [d-infrastructure-quality] of patch -1 -3
set IQ20 [d-infrastructure-quality] of patch 2 0
set IQ21 [d-infrastructure-quality] of patch 2 1
set IQ22 [d-infrastructure-quality] of patch 2 2
set IQ23 [d-infrastructure-quality] of patch 2 3
set IQ-20 [d-infrastructure-quality] of patch -2 0
set IQ-21 [d-infrastructure-quality] of patch -2 1
set IQ-22 [d-infrastructure-quality] of patch -2 2
set IQ-23 [d-infrastructure-quality] of patch -2 3
set IQ2-1 [d-infrastructure-quality] of patch 2 -1
set IQ2-2 [d-infrastructure-quality] of patch 2 -2
set IQ2-3 [d-infrastructure-quality] of patch 2 -3
set IQ-2-1 [d-infrastructure-quality] of patch -2 -1
set IQ-2-2 [d-infrastructure-quality] of patch -2 -2
set IQ-2-3 [d-infrastructure-quality] of patch -2 -3
set IQ30 [d-infrastructure-quality] of patch 3 0
set IQ31 [d-infrastructure-quality] of patch 3 1
set IQ32 [d-infrastructure-quality] of patch 3 2
set IQ33 [d-infrastructure-quality] of patch 3 3
set IQ-30 [d-infrastructure-quality] of patch -3 0
set IQ-31 [d-infrastructure-quality] of patch -3 1
set IQ-32 [d-infrastructure-quality] of patch -3 2
set IQ-33 [d-infrastructure-quality] of patch -3 3
set IQ3-1 [d-infrastructure-quality] of patch 3 -1
set IQ3-2 [d-infrastructure-quality] of patch 3 -2
set IQ3-3 [d-infrastructure-quality] of patch 3 -3
set IQ-3-1 [d-infrastructure-quality] of patch -3 -1
set IQ-3-2 [d-infrastructure-quality] of patch -3 -2
set IQ-3-3 [d-infrastructure-quality] of patch -3 -3

set MIncome00 [d-mean-hh-income] of patch 0 0
set MIncome01 [d-mean-hh-income] of patch 0 1
set MIncome02 [d-mean-hh-income] of patch 0 2
set MIncome03 [d-mean-hh-income] of patch 0 3
```

```
set MIncome0-1 [d-mean-hh-income] of patch 0 -1
set MIncome0-2 [d-mean-hh-income] of patch 0 -2
set MIncome0-3 [d-mean-hh-income] of patch 0 -3
set MIncome10 [d-mean-hh-income] of patch 1 0
set MIncome11 [d-mean-hh-income] of patch 1 1
set MIncome12 [d-mean-hh-income] of patch 1 2
set MIncome13 [d-mean-hh-income] of patch 1 3
set MIncome-10 [d-mean-hh-income] of patch -1 0
set MIncome-11 [d-mean-hh-income] of patch -1 1
set MIncome-12 [d-mean-hh-income] of patch -1 2
set MIncome-13 [d-mean-hh-income] of patch -1 3
set MIncome1-1 [d-mean-hh-income] of patch 1 -1
set MIncome1-2 [d-mean-hh-income] of patch 1 -2
set MIncome1-3 [d-mean-hh-income] of patch 1 -3
set MIncome-1-1 [d-mean-hh-income] of patch -1 -1
set MIncome-1-2 [d-mean-hh-income] of patch -1 -2
set MIncome-1-3 [d-mean-hh-income] of patch -1 -3
set MIncome20 [d-mean-hh-income] of patch 2 0
set MIncome21 [d-mean-hh-income] of patch 2 1
set MIncome22 [d-mean-hh-income] of patch 2 2
set MIncome23 [d-mean-hh-income] of patch 2 3
set MIncome-20 [d-mean-hh-income] of patch -2 0
set MIncome-21 [d-mean-hh-income] of patch -2 1
set MIncome-22 [d-mean-hh-income] of patch -2 2
set MIncome-23 [d-mean-hh-income] of patch -2 3
set MIncome2-1 [d-mean-hh-income] of patch 2 -1
set MIncome2-2 [d-mean-hh-income] of patch 2 -2
set MIncome2-3 [d-mean-hh-income] of patch 2 -3
set MIncome-2-1 [d-mean-hh-income] of patch -2 -1
set MIncome-2-2 [d-mean-hh-income] of patch -2 -2
set MIncome-2-3 [d-mean-hh-income] of patch -2 -3
set MIncome30 [d-mean-hh-income] of patch 3 0
set MIncome31 [d-mean-hh-income] of patch 3 1
set MIncome32 [d-mean-hh-income] of patch 3 2
set MIncome33 [d-mean-hh-income] of patch 3 3
set MIncome-30 [d-mean-hh-income] of patch -3 0
set MIncome-31 [d-mean-hh-income] of patch -3 1
set MIncome-32 [d-mean-hh-income] of patch -3 2
set MIncome-33 [d-mean-hh-income] of patch -3 3
set MIncome3-1 [d-mean-hh-income] of patch 3 -1
set MIncome3-2 [d-mean-hh-income] of patch 3 -2
set MIncome3-3 [d-mean-hh-income] of patch 3 -3
set MIncome-3-1 [d-mean-hh-income] of patch -3 -1
set MIncome-3-2 [d-mean-hh-income] of patch -3 -2
set MIncome-3-3 [d-mean-hh-income] of patch -3 -3

set BU00 [d-built-up-rate] of patch 0 0
set BU01 [d-built-up-rate] of patch 0 1
```

```
set BU02 [d-built-up-rate] of patch 0 2
set BU03 [d-built-up-rate] of patch 0 3
set BU0-1 [d-built-up-rate] of patch 0 -1
set BU0-2 [d-built-up-rate] of patch 0 -2
set BU0-3 [d-built-up-rate] of patch 0 -3
set BU10 [d-built-up-rate] of patch 1 0
set BU11 [d-built-up-rate] of patch 1 1
set BU12 [d-built-up-rate] of patch 1 2
set BU13 [d-built-up-rate] of patch 1 3
set BU-10 [d-built-up-rate] of patch -1 0
set BU-11 [d-built-up-rate] of patch -1 1
set BU-12 [d-built-up-rate] of patch -1 2
set BU-13 [d-built-up-rate] of patch -1 3
set BU1-1 [d-built-up-rate] of patch 1 -1
set BU1-2 [d-built-up-rate] of patch 1 -2
set BU1-3 [d-built-up-rate] of patch 1 -3
set BU-1-1 [d-built-up-rate] of patch -1 -1
set BU-1-2 [d-built-up-rate] of patch -1 -2
set BU-1-3 [d-built-up-rate] of patch -1 -3
set BU20 [d-built-up-rate] of patch 2 0
set BU21 [d-built-up-rate] of patch 2 1
set BU22 [d-built-up-rate] of patch 2 2
set BU23 [d-built-up-rate] of patch 2 3
set BU-20 [d-built-up-rate] of patch -2 0
set BU-21 [d-built-up-rate] of patch -2 1
set BU-22 [d-built-up-rate] of patch -2 2
set BU-23 [d-built-up-rate] of patch -2 3
set BU2-1 [d-built-up-rate] of patch 2 -1
set BU2-2 [d-built-up-rate] of patch 2 -2
set BU2-3 [d-built-up-rate] of patch 2 -3
set BU-2-1 [d-built-up-rate] of patch -2 -1
set BU-2-2 [d-built-up-rate] of patch -2 -2
set BU-2-3 [d-built-up-rate] of patch -2 -3
set BU30 [d-built-up-rate] of patch 3 0
set BU31 [d-built-up-rate] of patch 3 1
set BU32 [d-built-up-rate] of patch 3 2
set BU33 [d-built-up-rate] of patch 3 3
set BU-30 [d-built-up-rate] of patch -3 0
set BU-31 [d-built-up-rate] of patch -3 1
set BU-32 [d-built-up-rate] of patch -3 2
set BU-33 [d-built-up-rate] of patch -3 3
set BU3-1 [d-built-up-rate] of patch 3 -1
set BU3-2 [d-built-up-rate] of patch 3 -2
set BU3-3 [d-built-up-rate] of patch 3 -3
set BU-3-1 [d-built-up-rate] of patch -3 -1
set BU-3-2 [d-built-up-rate] of patch -3 -2
set BU-3-3 [d-built-up-rate] of patch -3 -3
```

```
set Occ00 [d-owner] of patch 0 0
set Occ01 [d-owner] of patch 0 1
set Occ02 [d-owner] of patch 0 2
set Occ03 [d-owner] of patch 0 3
set Occ0-1 [d-owner] of patch 0 -1
set Occ0-2 [d-owner] of patch 0 -2
set Occ0-3 [d-owner] of patch 0 -3
set Occ10 [d-owner] of patch 1 0
set Occ11 [d-owner] of patch 1 1
set Occ12 [d-owner] of patch 1 2
set Occ13 [d-owner] of patch 1 3
set Occ-10 [d-owner] of patch -1 0
set Occ-11 [d-owner] of patch -1 1
set Occ-12 [d-owner] of patch -1 2
set Occ-13 [d-owner] of patch -1 3
set Occ1-1 [d-owner] of patch 1 -1
set Occ1-2 [d-owner] of patch 1 -2
set Occ1-3 [d-owner] of patch 1 -3
set Occ-1-1 [d-owner] of patch -1 -1
set Occ-1-2 [d-owner] of patch -1 -2
set Occ-1-3 [d-owner] of patch -1 -3
set Occ20 [d-owner] of patch 2 0
set Occ21 [d-owner] of patch 2 1
set Occ22 [d-owner] of patch 2 2
set Occ23 [d-owner] of patch 2 3
set Occ-20 [d-owner] of patch -2 0
set Occ-21 [d-owner] of patch -2 1
set Occ-22 [d-owner] of patch -2 2
set Occ-23 [d-owner] of patch -2 3
set Occ2-1 [d-owner] of patch 2 -1
set Occ2-2 [d-owner] of patch 2 -2
set Occ2-3 [d-owner] of patch 2 -3
set Occ-2-1 [d-owner] of patch -2 -1
set Occ-2-2 [d-owner] of patch -2 -2
set Occ-2-3 [d-owner] of patch -2 -3
set Occ30 [d-owner] of patch 3 0
set Occ31 [d-owner] of patch 3 1
set Occ32 [d-owner] of patch 3 2
set Occ33 [d-owner] of patch 3 3
set Occ-30 [d-owner] of patch -3 0
set Occ-31 [d-owner] of patch -3 1
set Occ-32 [d-owner] of patch -3 2
set Occ-33 [d-owner] of patch -3 3
set Occ3-1 [d-owner] of patch 3 -1
set Occ3-2 [d-owner] of patch 3 -2
set Occ3-3 [d-owner] of patch 3 -3
set Occ-3-1 [d-owner] of patch -3 -1
set Occ-3-2 [d-owner] of patch -3 -2
```

```
set Occ-3-3 [d-owner] of patch -3 -3

set RR00 [d-tenant] of patch 0 0
set RR01 [d-tenant] of patch 0 1
set RR02 [d-tenant] of patch 0 2
set RR03 [d-tenant] of patch 0 3
set RR0-1 [d-tenant] of patch 0 -1
set RR0-2 [d-tenant] of patch 0 -2
set RR0-3 [d-tenant] of patch 0 -3
set RR10 [d-tenant] of patch 1 0
set RR11 [d-tenant] of patch 1 1
set RR12 [d-tenant] of patch 1 2
set RR13 [d-tenant] of patch 1 3
set RR-10 [d-tenant] of patch -1 0
set RR-11 [d-tenant] of patch -1 1
set RR-12 [d-tenant] of patch -1 2
set RR-13 [d-tenant] of patch -1 3
set RR1-1 [d-tenant] of patch 1 -1
set RR1-2 [d-tenant] of patch 1 -2
set RR1-3 [d-tenant] of patch 1 -3
set RR-1-1 [d-tenant] of patch -1 -1
set RR-1-2 [d-tenant] of patch -1 -2
set RR-1-3 [d-tenant] of patch -1 -3
set RR20 [d-tenant] of patch 2 0
set RR21 [d-tenant] of patch 2 1
set RR22 [d-tenant] of patch 2 2
set RR23 [d-tenant] of patch 2 3
set RR-20 [d-tenant] of patch -2 0
set RR-21 [d-tenant] of patch -2 1
set RR-22 [d-tenant] of patch -2 2
set RR-23 [d-tenant] of patch -2 3
set RR2-1 [d-tenant] of patch 2 -1
set RR2-2 [d-tenant] of patch 2 -2
set RR2-3 [d-tenant] of patch 2 -3
set RR-2-1 [d-tenant] of patch -2 -1
set RR-2-2 [d-tenant] of patch -2 -2
set RR-2-3 [d-tenant] of patch -2 -3
set RR30 [d-tenant] of patch 3 0
set RR31 [d-tenant] of patch 3 1
set RR32 [d-tenant] of patch 3 2
set RR33 [d-tenant] of patch 3 3
set RR-30 [d-tenant] of patch -3 0
set RR-31 [d-tenant] of patch -3 1
set RR-32 [d-tenant] of patch -3 2
set RR-33 [d-tenant] of patch -3 3
set RR3-1 [d-tenant] of patch 3 -1
set RR3-2 [d-tenant] of patch 3 -2
set RR3-3 [d-tenant] of patch 3 -3
```

```
  set RR-3-1 [d-tenant] of patch -3 -1
  set RR-3-2 [d-tenant] of patch -3 -2
  set RR-3-3 [d-tenant] of patch -3 -3

  ;; third: update global variables (using updated patch-data)
  set totalHHNumber ( count tenants + count owners ) ;; number of households in the city
  set totalTenantNumber ( count tenants ) ;; number of tenants in the city
  set totalOwnerNumber ( count owners ) ;; number of owners in the city
  set totalHHIncomeLow ( count tenants with [income-level = "low"] + count owners with [income-level
= "low"] ) ;; number of low income households (income less than .25)
  set totalHHIncomeMiddle ( count tenants with [income-level = "middle"] + count owners with [income-
level = "middle"] )  ;;   number of middle income households (income between 0.25 and .75)
  set totalHHIncomeHigh  ( count tenants with [income-level = "high"] + count owners with [income-
level = "high"] )  ;;   number of high income households (income larger than .75)
  set totalOccupiedPlots (count plots with [count my-links > 0]) ;; number of occupied plots
  set totalFreePlots (count plots - totalOccupiedPlots)  ;; number of free plots
  set totalRentedRooms ( sum [p-no-rooms-rented ] of plots)
  set totalRoomsOccupiedByOwners ( sum [ p-no-owner-occupied-rooms ] of plots)  ;;  number of rooms
occupied by owners


  ;; no update-date for totalMoves, as this is being updated by tenants and owners
  set FC financial-capacity
  set meanBuiltUpRate ( mean [d-built-up-rate] of patches ) ;; mean built-up-rate of patches
  set meanInfrastructureQuality (mean [d-infrastructure-quality] of patches) ;;   mean infrastructure-quality
of patches
  set giniHighIncome gini-highinc
  set giniLowIncome gini-lowinc ;;  Gini-coefficient low-income households
  set giniBuiltUpRate gini-built ;;  Gini-coefficient built-up-rate
  set giniInfraQuality gini-infra ;; Gini-coefficient infrastructure quality
  set giniHHDensity gini-density ;; Gini-coefficient HH density
  set builtUpPerDistrict_dist0_0   mean [d-built-up-rate] of patches with [d-normalised-distancexy = 0]
  set builtUpPerDistrict_dist0_236 mean [d-built-up-rate] of patches with [d-normalised-distancexy =
0.236]
  set builtUpPerDistrict_dist0_333 mean [d-built-up-rate] of patches with [d-normalised-distancexy =
0.333]
  set builtUpPerDistrict_dist0_471 mean [d-built-up-rate] of patches with [d-normalised-distancexy =
0.471]
  set builtUpPerDistrict_dist0_527 mean [d-built-up-rate] of patches with [d-normalised-distancexy =
0.527]
  set builtUpPerDistrict_dist0_667 mean [d-built-up-rate] of patches with [d-normalised-distancexy =
0.667]
  set builtUpPerDistrict_dist0_707 mean [d-built-up-rate] of patches with [d-normalised-distancexy =
0.707]
  set builtUpPerDistrict_dist0_745 mean [d-built-up-rate] of patches with [d-normalised-distancexy =
0.745]
  set builtUpPerDistrict_dist0_85  mean [d-built-up-rate] of patches with [d-normalised-distancexy = 0.85]
  set builtUpPerDistrict_dist1_0   mean [d-built-up-rate] of patches with [d-normalised-distancexy = 1]
```

set HHPerDistrict_dist0_0 (count tenants-on patches with [d-normalised-distancexy = 0] + count owners-on patches with [d-normalised-distancexy = 0])
set HHPerDistrict_dist0_236 (count tenants-on patches with [d-normalised-distancexy = 0.236] + count owners-on patches with [d-normalised-distancexy = 0.236])
set HHPerDistrict_dist0_333 (count tenants-on patches with [d-normalised-distancexy = 0.333] + count owners-on patches with [d-normalised-distancexy = 0.333])
set HHPerDistrict_dist0_471 (count tenants-on patches with [d-normalised-distancexy = 0.471] + count owners-on patches with [d-normalised-distancexy = 0.471])
set HHPerDistrict_dist0_527 (count tenants-on patches with [d-normalised-distancexy = 0.527] + count owners-on patches with [d-normalised-distancexy = 0.527])
set HHPerDistrict_dist0_667 (count tenants-on patches with [d-normalised-distancexy = 0.667] + count owners-on patches with [d-normalised-distancexy = 0.667])
set HHPerDistrict_dist0_707 (count tenants-on patches with [d-normalised-distancexy = 0.707] + count owners-on patches with [d-normalised-distancexy = 0.707])
set HHPerDistrict_dist0_745 (count tenants-on patches with [d-normalised-distancexy = 0.745] + count owners-on patches with [d-normalised-distancexy = 0.745])
set HHPerDistrict_dist0_85 (count tenants-on patches with [d-normalised-distancexy = 0.85] + count owners-on patches with [d-normalised-distancexy = 0.85])
set HHPerDistrict_dist1_0 (count tenants-on patches with [d-normalised-distancexy = 1] + count owners-on patches with [d-normalised-distancexy = 1])
set infraQual_dist0_0 mean [d-infrastructure-quality] of patches with [d-normalised-distancexy = 0]
set infraQual_dist0_236 mean [d-infrastructure-quality] of patches with [d-normalised-distancexy = 0.236]
set infraQual_dist0_333 mean [d-infrastructure-quality] of patches with [d-normalised-distancexy = 0.333]
set infraQual_dist0_471 mean [d-infrastructure-quality] of patches with [d-normalised-distancexy = 0.471]
set infraQual_dist0_527 mean [d-infrastructure-quality] of patches with [d-normalised-distancexy = 0.527]
set infraQual_dist0_667 mean [d-infrastructure-quality] of patches with [d-normalised-distancexy = 0.667]
set infraQual_dist0_707 mean [d-infrastructure-quality] of patches with [d-normalised-distancexy = 0.707]
set infraQual_dist0_745 mean [d-infrastructure-quality] of patches with [d-normalised-distancexy = 0.745]
set infraQual_dist0_85 mean [d-infrastructure-quality] of patches with [d-normalised-distancexy = 0.85]
set infraQual_dist1_0 mean [d-infrastructure-quality] of patches with [d-normalised-distancexy = 1]
set meanHHIncome_dist0_0 mean [d-mean-hh-income] of patches with [d-normalised-distancexy = 0]
set meanHHIncome_dist0_236 mean [d-mean-hh-income] of patches with [d-normalised-distancexy = 0.236]
set meanHHIncome_dist0_333 mean [d-mean-hh-income] of patches with [d-normalised-distancexy = 0.333]
set meanHHIncome_dist0_471 mean [d-mean-hh-income] of patches with [d-normalised-distancexy = 0.471]
set meanHHIncome_dist0_527 mean [d-mean-hh-income] of patches with [d-normalised-distancexy = 0.527]
set meanHHIncome_dist0_667 mean [d-mean-hh-income] of patches with [d-normalised-distancexy = 0.667]

```
  set meanHHIncome_dist0_707 mean [d-mean-hh-income] of patches with [d-normalised-distancexy =
0.707]
  set meanHHIncome_dist0_745 mean [d-mean-hh-income] of patches with [d-normalised-distancexy =
0.745]
  set meanHHIncome_dist0_85  mean [d-mean-hh-income] of patches with [d-normalised-distancexy =
0.85]
  set meanHHIncome_dist1_0   mean [d-mean-hh-income] of patches with [d-normalised-distancexy = 1]

    if (export-everyting? = true) [
    file-open (word "/results/IC-patches-hhdensity-per-ha_run" behaviorspace-run-number "_tick" ticks
".csv")
    ask patches [file-show d-hhdensity-per-ha]
    file-close
    file-open (word "/results/IC-patches-hhmeanincome_run" behaviorspace-run-number "_tick" ticks
".csv")
    ask patches [file-show d-mean-hh-income]
    file-close
    file-open (word "/results/IC-patches-infraquality_run" behaviorspace-run-number "_tick" ticks ".csv")
    ask patches [file-show d-infrastructure-quality]
    file-close  ]

end
to-report compute-high-total
 let temp ( count tenants with [income-level = "high"] + count owners with [income-level = "high"] )
report temp
end

to-report compute-low-total
  let temp ( count tenants with [income-level = "low"] + count owners with [income-level = "low"] )
    report temp
end

to-report compute-index
  let temp compute-high / compute-high-total - compute-low / compute-low-total
    report temp
end

to-report compute-hh
 let temp ( count tenants-here + count owners-here )
  report temp
end

to-report compute-tenants
 let temp ( count tenants-here  )
  report temp
end
```

```
to-report compute-owners
 let temp ( count owners-here  )
  report temp
end


to-report compute-low
  let temp ( count tenants-here with [income-level = "low"] + count owners-here with [income-level =
"low"] )
  report temp
end


to-report compute-middle
 let temp ( count tenants-here with [income-level = "middle"] + count owners-here with [income-level =
"middle"] )
  report temp
end

to-report compute-high
 let temp ( count tenants-here with [income-level = "high"] + count owners-here with [income-level =
"high"] )
  report temp
end



to-report compute-share-low-inc-hh-on-patch
  let temp 0
  let sum-low-inc ( count tenants-here with [income-level = "low"] + count owners-here with [income-
level = "low"] )
  if (sum-low-inc > 0) [set temp ( sum-low-inc / ( count tenants-here + count owners-here ) ) ]
  report temp
end

to-report compute-share-high-inc-hh-on-patch
  let temp 0
  let sum-low-inc ( count tenants-here with [income-level = "high"] + count owners-here with [income-
level = "high"] )
  if (sum-low-inc > 0) [set temp ( sum-low-inc / ( count tenants-here + count owners-here ) ) ]
  report temp
end

to-report compute-mean-hh-income-on-patch
  let temp 0
  let inhabitants ( count tenants-here + count owners-here)
```

```
  if (inhabitants > 0) [ set temp (( sum [income ] of tenants-here + sum [income ] of owners-here ) /
inhabitants ) ]
  report temp
end


to-report gini-lowinc
  let gini-upper 0
  foreach [d-share-low-inc-hh] of patches [ [x] -> ask patches [ set gini-upper (gini-upper + (abs (x - d-
share-low-inc-hh))) ] ]
  let gini 0
  if (mean [d-share-low-inc-hh] of patches > 0) [ set gini (gini-upper / ( 2 * count patches * count patches
* mean [ d-share-low-inc-hh ] of patches ) ) ]
  report gini
end

to-report gini-highinc
  let gini-upper 0
  foreach [d-share-high-inc-hh] of patches [ [x] -> ask patches [ set gini-upper (gini-upper + (abs (x - d-
share-high-inc-hh))) ] ]
  let gini 0
  if (mean [d-share-high-inc-hh] of patches > 0) [ set gini (gini-upper / ( 2 * count patches * count patches
* mean [ d-share-high-inc-hh ] of patches ) ) ]
  report gini
end

to-report gini-built
  let gini-upper 0
  foreach [d-built-up-rate] of patches [ [x] -> ask patches [ set gini-upper (gini-upper + (abs (x - d-built-up-
rate))) ] ]
  let gini 0
  if (mean [ d-built-up-rate ] of patches > 0 ) [ set gini (gini-upper / ( 2 * count patches * count patches *
mean [ d-built-up-rate ] of patches ) )  ]
  report gini
end

to-report gini-infra
  let gini-upper 0
  foreach [d-infrastructure-quality] of patches [ [x] -> ask patches [ set gini-upper (gini-upper + (abs (x - d-
infrastructure-quality))) ] ]
  let gini 0
  if (mean [ d-infrastructure-quality ] of patches > 0 ) [ set gini (gini-upper / ( 2 * count patches * count
patches * mean [ d-infrastructure-quality ] of patches ) ) ]
  report gini
end

to-report gini-density
  let gini-upper 0
```

```
  foreach [d-hhdensity-per-ha] of patches [ [x] -> ask patches [ set gini-upper (gini-upper + (abs (x - d-
hhdensity-per-ha))) ] ]
  let gini 0
  if (mean [ d-hhdensity-per-ha ] of patches > 0 ) [set gini (gini-upper / ( 2 * count patches * count patches
* mean [ d-hhdensity-per-ha ] of patches ) ) ]
  report gini
end

to final-output-upgrading
    file-open (word "/results/IC-patches-timeupgrading_run" behaviorspace-run-number "_tick" ticks
".csv")
    ask patches [file-show d-tick-upgrading]
    file-close
end
```

8.3. Heatmap for Gini Coefficient for low-income

	Baseline	Subsidy 100	Subsidy 0	Subsidy 20	Subsidy 40	Subsidy 60	Subsidy 80	Verticalise
Baseline	0.446							
Financial Capacity 2		0.435	0.439	0.436	0.446	0.435	0.441	
Financial Capacity 5		0.498	0.488	0.5	0.491	0.491	0.475	
Financial Capacity 7		0.499	0.488	0.5	0.491	0.491	0.475	
Financial Capacity 10		0.499	0.488	0.498	0.491	0.487	0.475	
Verticalise								0.446

Figure 20 Heatmap of the Gini coefficient of low-income households at time-step 21