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SIMULATING URBAN TRANSITION IN MAJOR SOCIO-ECONOMIC SHOCKS

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ABSTRACT

This paper presents an agent-based model that simulates the dynamic process of urban transition in major socio-economic shocks. The model features the coupled housing and labour markets in heterogeneous neighbourhoods in a city that is going through a major transition in the industrial structure. We consider a scenario where the old or traditional industry is gradually replaced by a new industry. Preliminary results from the scenario analysis are presented. This paper makes several contributions: 1) We introduce feedback links between the housing and the labour market via connecting the choices of individuals and businesses and the evolution of neighbourhoods; 2) We introduce links between the local workers, businesses and the overall industrial structure in a complex urban system; 3) Finally, we propose a complex system approach to major socio-economic transitions in an urban system.

1 INTRODUCTION

One of the main drives of a city's rise and fall is the development and decline of its main industries. Historically, the decline of a city or region is often associated with the decline of the city's main industries. Shrinking cities as a result of industrial decline are seen in both developed countries, including the U.S., Europe, Japan and Australia (Martinez-Fernandez, Weyman, Fol, Audirac, Cunningham-Sabot, Wiechmann, and Yahagi 2016) and developing ones, including China (Long, Wu, and Wang 2015) and Brazil (Moraes 2007). The decline of a dominant industry in a city, however, does not mean that the city will necessarily see a reduction in population and economic activities: many cities have successfully reinvented themselves in different formats after the once-important industries decline, such as New York City after the decline of the garment industry and London after the decline of manufacturing and port industries. Jacobs (1961) attributes the success of these big cities to the density and diversity in people and urban infrastructure that their sizes can afford. There are also smaller cities that are formerly manufacturing towns that have successfully transitioned by specialising in one area (e.g. research for Cambridge). While successful urban transition can take many forms, unsuccessful ones almost always lead to undesirable social consequences, including inequality, segregation, long-term unemployment, crime, mental health issues in those 'locked in' within declining cities. Its social, economic, and political implications are profound.

Researchers have been using agent-based models (ABMs) to study the phenomenon of 'shrinking cities'. Haase, Lautenbach, and Seppelt (2010) develop an agent-based model of Leipzig, a city in Eastern Germany that has been shrinking after the collapse of its manufacturing sector in the 1990s. Jiang, Crooks, Wang, and Xie (2021) develop an agent-based model to explore the housing market in the shrinking city of Detroit after the collapse of its car manufacturing industry. Both studies focus on the residential sector in a shrinking city, and analyse the impact of population decline and vacant houses on the housing market

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and urban planning. While ABMs have been developed to simulate the phenomenon of shrinking cities and its impact on the residential sector and urban planning, few have looked at the underlying mechanism of shrinking cities (or cities in major transitions for that matter).

While the labour market can affect the housing market by altering the local demand for housing, the housing market can also affect the local labour market by restricting mobility and the labour supply. Research show that high housing prices and limited housing supply will limit labour movement and prevent people from moving to areas with more job opportunities and higher productivity (Hsieh and Moretti 2019; Glaeser and Gyourko 2018). On the other hand, low housing price may prevent people from leaving areas with few job opportunities for those with more job opportunities and higher productivity. The reason is that the resale value of the house is so low that people cannot afford to move elsewhere, and are thus 'spatially locked in' in the rundown neighbourhoods (Chan 2001). Neighbourhoods with a higher rate of long-term unemployment tend also to have a higher rate of crime, homelessness (in vacant houses), mental health problems, and other issues (Austin, Glaeser, and Summers 2018), which could further suppress the housing price in the area, starting a vicious circle. Moreover, the self-reinforcing effect among neighbourhoods can be further strengthened if new industries and businesses are more likely to locate in 'nicer' neighbourhoods, providing more jobs and services there, which further increases the inequality across neighbourhoods.

Currently there are few simulation models that connect the labour market and the housing market in a complex urban system. Li, Li, Liu, Wu, Ai, and Wang (2013) develop an ABM that considers the influence of external population changes as a result of the labour market expansion on the housing market in the city of Dongguan, China, a city that has gone through rapid population growth since 2000. Grinberger and Samuels (2018) study the impact of a natural disaster that causes an immediate exogenous shock to an industry on the local residential and commercial property stock. The authors investigate the sensitivity of the urban system to capital shocks to find out 'how resilient the urban fabric is'. Finally, Ge, Polhill, Craig, and Liu (2018) develop an ABM to study the transition of Aberdeen City, a city in Northeast Scotland that relies heavily on the oil and gas industry, from the oil industry to a green one. The model considers both the labour and the residential sectors, but like Grinberger and Samuels (2018), the residential sector is rather simplified and does not explicitly represent the tradings of properties. Since housing availability and employment opportunity are the two main drives for people's residential and relocation decisions, we will need a model that incorporate and connect the two to understand the dynamic process of urban transition under major socio-economic shocks.

The paper will fill the gap. First, we will develop an urban simulation model that couples the labour and the housing market in a complex urban system. The model will also link businesses and human capital at local and regional level with the industrial structure on a higher level. Second, we will use the simulation model to understand the feedback loops between the labour and the housing market, between individual residential choices and neighbourhoods, and between workers, businesses and industrial structure. Finally, we will use the simulation model to understand the dynamic process of urban transition during a major socio-economic shock.

2 MODEL SETUP

2.1 Agent

2.1.1 Person

A person has the following attributes of id, age, gender, income, skill, industry (in which they work), household (to which they belong), civil partner (none if single), employer (none if unemployed), and time-on-job-market. Apart from standard demographic attributes such as age and gender, a person has labour market attributes such as skill and time-on-job-market if they are unemployed. In this demonstrative model, a person's skill is a number of between 0 and 1, and does not distinguish between industries. People supply labour and skill to businesses, and earn income in return. For simplicity, we only consider working-age people (20-60), for we want to focus on the labour market. When people lose their jobs, they lose their labour income, and will start looking for a new job. They will do ’job search’, which means they will search for jobs that for which their skills meet the requirement, and apply for a few jobs that provide the highest income. Constrained by cognitive capacity and time, a person only search a random subset of the total available jobs and can apply to no more than three jobs per period (week). The matching process between people and businesses in the labour market will be detailed in 2.2.1

2.1.2 Household

People form households. For simplicity, the demonstrative model has only two types of households: households of a couple, and single-person households. The model does not have children. Household has household income, which is the total income of all members in the household. Households are the participating unit in the housing market. They decide where they live, and whether to buy or sell their house. Moreover, the model does not explicitly model the rental market or social housing. We assume that households that do not own a house will live in a rented or social house.

When buying a house, households evaluate all available options on both the house attributes and the neighbourhood attributes. In the current version, house attributes are assumed to be uniform across neighbourhoods. One of the considerations when evaluating houses is distance to work. We assume that households prefer to stay close to work. If there are multiple members in the household, the average distance to work of all members are considered. Households are heterogeneous in the weights they assign to different dimensions of the house and the neighbourhood. In the demonstrative model, the weights are randomly assigned and add up to 1. More details about the neighbourhood attributes can be found in 2.1.4. After evaluating all options, which is public information, households will bid for the house that gives them the highest weighted score within their budget (if any). The maximum budget of a household equals 7 years of household income, which aligns with government guidance in the UK. The value of the bid will depend on households’ maximum budget and time-on-market, which will be detailed in the housing market matching process in 2.2.

Several events can trigger a household to sell their current house: 1) if the household income changes significantly (more than 20%), e.g., due to family members who change their jobs or become unemployed; 2) if the household decide to leave the city for job opportunities elsewhere or for other external reasons.

2.1.3 Industry

There are three industries in the model: old (traditional), new and service. Industries have the attributes of size, defined as the total number of employment in the city, the minimum skill level, average income, income variance and average growth rate. This reflects the overall industrial structure, although individual businesses in the industry might vary in income, growth rate etc.. We assume that the minimum skill level, average income, income variance and growth rate of an industry are determined by competition and technology development in a global market, and are not be affected by changes in the city, thus are external to the model.

We assume that both the old and new industries require a minimum skill of 0.5 (skills are represented by a number between 0 and 1), whereas the service industry requires a minimum skill of 0. We assume the old industry has the highest average income initially, because it is well established compared with the new industry and high-skilled compared with service. In the baseline scenario, both the old and the new industries grow at the same rate. In the industrial transition scenario (see 3), the old industry will grow at the declining rate, while the new industry will grow at an increasing rate. Such industrial transition are observed repeatedly throughout history and around the world during the first, second, third and fourth industrial revolution. In both scenarios, the service industry will growth at the same rate as the population, to reflect the nature of the service industry.

2.1.4 Business

Businesses belong to different industries. They are the participating unit in the labour market and the employers of individual persons. Businesses have attributes of location, the list of employees, the industries they belong to, and their target number of employees. Businesses' target number of employees will be affected by the overall growth rate of the industries they belong to. If the industry is in decline, businesses in the industry will tend to reduce the size of its employees, and vice versa, although each business may vary in the speed it expands or shrinks. Every period, businesses will compare its employees list with the target number of employees. If they find they have more employees than their target number, they will make some employees redundant; or, if they find they have less employees than their target number, they will try to recruit new workers first from the local labour market and then from outside the city. The matching process of the labour market is detailed in 2.2.1.

2.1.5 Neighbourhoods

Neighbourhoods are localised communities within a larger city. In this demonstrative model, we adopt a stylised, mono-centred urban landscape as shown in Figure 1. There are three rings spreading out from the city centre. Each ring contains six neighbourhoods. The sizes of the neighbourhoods in the innermost ring (1a-f), middle (2a-f) and outer ring (3a-f) are 1x, 2x and 3x the size of the city center respectively. The symmetric and stylised setup has a few advantages: it reflects a typical mono-centred city with more compact and densely populated neighbourhoods closer to the centre with less dense suburbs; with discrete and identifiable neighbourhoods, it is easier to manipulate the spatial distribution of services and industries for different scenarios; with a symmetric setup and without the complications of a real-world city geography, it allows us to isolate the effect of the transition on the neighbourhoods. The model's urban landscape, however, is flexible to accommodate geographic data on any real-world cities, and can be readily adapted for different cities and applications in the future.

Figure 1 also shows the distribution of industries in the neighbourhoods. Both the old (blue) and the new (green) industries locate in the inner ring, with the old exclusively in neighbourhoods 1a-c, and the new exclusively in neighbourhoods 1d-f. The clustered distribution reflect the fact that businesses in the same industry tend to locate closely to each other to share information, supply chain and skilled labour pool, and also to benefit from knowledge spillover. Service industries (orange), on the other hand, are scattered across space. The density of service businesses, however, differ across the neighbourhoods: the city centre has the highest density of services, followed by the inner ring (1a-f) with half of the density, followed by the middle ring (2a-f) with a fourth of the density, and followed by the outer ring (3a-f) with a sixth of the density.

Neighbourhoods have three heterogeneous attributes: 1) location 2) mean income of the residents in the neighbourhood (as a proxy for neighbourhood quality, level of public service, and how 'posh' it is), and 3) the percentage of skilled-worker households in the neighbourhood (as a proxy for class division and school quality). Except for location, which is exogenous, the other two attributes are endogenous and will evolve as people moving in and out of neighbourhoods during the simulation.

2.2 Process and Scheduling

We run the model a number of times (100) with different random seeds and average the results. We have also implemented sensitivity analysis over the parameters to make sure choice of parameters do not interfere with overall robustness of the model. We run the model in python 3.8.

We initialize the agents of the model, that is: industries, workers, households, allocate workers into households, neighbourhoods, businesses, houses and allocate houses to neighbourhoods. The initial configuration characterizes neighbourhoods with average residents' income and skill levels. We then run the model for a number of weeks (520). Each week, the model updates the population with a small number of new comers then runs the labour market.

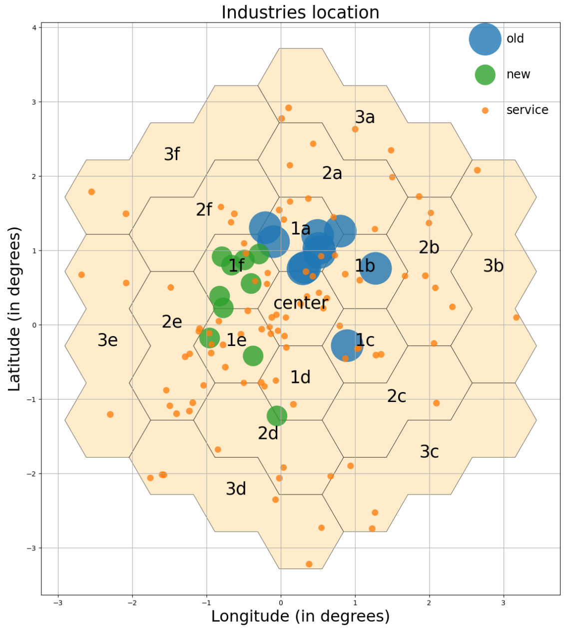


Figure 1: Neighbourhoods and the distribution of businesses in neighbourhoods (size of businesses represents number of employees).

The labour market starts with each business deciding whether to hire or fire new employees given their exogenous intended target size. When hiring businesses post announcements on a public list, whereas when firing the employees are chosen randomly. All unemployed workers that are not retired go through the job search and apply for some jobs. After the matching process, if the businesses cannot fulfill their needs with locals, they try to bring in workers from out of the city with a probability of success. At this moment, households evaluate whether they want to buy or sell a house, or if they want to leave the city based on their employment status and housing situation. After that the housing market takes place.

2.2.1 The match process in the housing market

The match process in the housing market works as follows: In each period, sellers post 'house for sale' on an open housing market. Information on all houses for sale is open to all potential buyers, including information on the house (e.g. location, number of bedrooms, size etc.), asking price and time on market (TOM). Sellers who list a house for sale also have a 'reservation price', usually lower than the asking price, below which they are not willing to sell. Reservation price is private information and is unavailable to buyers. It depends on past prices of similar properties in the neighbourhood and the property's TOM. The difference between reservation and asking price allow for room for bargaining and a final price lower than asking price.

Information on houses for sale are public to all buyers, who will use the information to evaluate all available options. Since house attributes are uniform in this model, households' choice will be based on their budget and the neighbourhood. Households will only consider houses within their budget. They will then evaluate neighbourhoods by calculating a weighted average on scores of the three attributes of the neighbourhoods: location or distance to work, mean income (as a proxy for neighbourhood quality and amenity) and percentage of skilled households (as a proxy for class division). Households have heterogeneous weights, which are drawn from a random distribution in this model. The weights also depend on the employment status of household members (for unemployed household, the weight is assumed to be zero). We use the percentage of skilled households in the neighbourhood as a proxy for class. Neighbourhoods with a high percentage of skilled households are consider 'knowledge class', and those with a low percentage of skilled households are considered 'working class'. We also assume that high skilled households have prefer 'knowledge class' neighbourhoods, while other households are neutral.

After evaluating the options, the buyer will put in a bid on their most preferred house within their budget. The bid price will depend on the buyer's TOM. A house for sale may get multiple bids from buyers, in which case the highest bid is accepted, given the bid is above the reservation price. The final price equals the winning bid.

2.2.2 The match process in the labour market

The match process in the labour market works as follows: In each period, businesses who are recruiting post job adverts with information on income, required skill level, the type of industry and location. The income of the job would increase with the required skill level for the job. The information is open to all job seekers, although job seekers only assess a random subset of the available jobs due to limitation on time and cognitive capacity. Each week, active job seekers will browse the adverts to look for jobs. There might be more than one job for which their skills meet the requirement, in that case the job seeker will rank the jobs by income and apply for a maximum of 3 jobs in each period, due to cognitive and time constraints.

After job seekers apply for the jobs, businesses will evaluate all the applicants by their skill, and make a job offer to the candidate with the highest skill level who has not already accepted an offer from another business. Job seekers will accept the first offer make to them. Job seekers who do not get any offers in one period will continue to search in the next period. However, their skill level will depreciate by a small percentage for another period they stay unemployed, which is consistent with the literature (Laureys 2021; Görlich and De Grip 2008).

3 SCENARIO & PRELIMINARY RESULTS

3.1 Scenario: Slow Industrial Transition

In the baseline scenario, both the old and the new industry grow at the same (slow) rate of 0.01% over 10 years. In the slow industrial transition scenario, the growth rate of the old industry gradually slows down to zero while the growth rate of the new industry gradually doubles to 0.02% over 10 year. We called it 'slow' because 1) the change in growth rate is small and gradual; 2) although doubled, the growth rate of the new industry is still low; and 3) the old industry slows down but does not shrink or disappear as in many cities in the real world. In the future, we will include different types of transition, including the more radical transitions such as the collapse of the main industry in a city in a relative short time.

3.2 Preliminary Results

This section shows preliminary results from the model. We have run the model for 520 periods, which represents 10 years in real-time. We test the two scenarios, the baseline and the (gradual) industrial transition. We have run a preliminary sensitivity analysis by altering some key parameters in the model systemically. A full sensitivity analysis will be carried out in the future.

Figure 2 shows the population in the baseline and the slow industrial transition scenarios. For the preliminary sensitivity analysis, We run the model 100 times, and the shaded areas represent the range of values from 95% of the runs. We see that the industrial transition does lead to a slow-down in population growth. The slow-down of the old industry has caused more people to leave the city (due to job loss and external reasons) and less people to enter the city (due to less job vacancies), compared with baseline. We find that the increased growth rate in the new industry has attracted more workers to the city, for the population still grow (albeit at a slower rate) in industrial transition scenario. However it is insufficient to replenish all the loss of workers in the old industry.

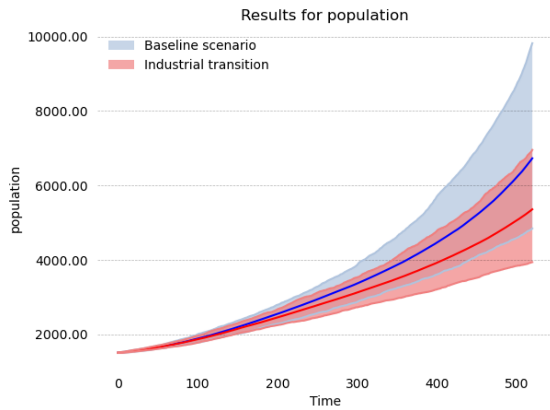


Figure 2: Population in baseline and slow industrial transition.

Figure 3 shows the number of job vacancies in each period in the three industries and in total. We find that, as expected, the number of job vacancies decreased in the old industry and increase in the new industry in the industrial transition scenario. Since the size of the service industry is positively linked to population, it increases at slower rate in the industrial transition. Compared with changes in population, which is relatively moderate, changes in new job vacancies are more pronounced. By the end of the 10-year period, there is almost no new jobs in the old industry, and the number of new jobs has doubled in the new industry. Hence, even under very slow transition, the influx of new workers into the old industry almost stops, and new jobs are exclusively in the new and service industries. It can be expected that, in the long run, the slow change will eventually lead to major structural change in employment structure, the skill stock and population demographics in the city. We also observe a 'trickle down' effect in the service industry, which grows at a slower rate due to the slow-down of the old industry.

4 DISCUSSION & FUTURE RESEARCH

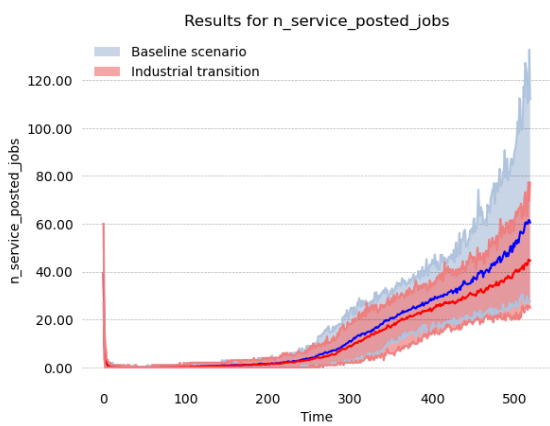
4.1 Discussion

In this paper we present an agent-based model of an urban system with the coupled housing and labour market. The framework is novel in the following aspects:

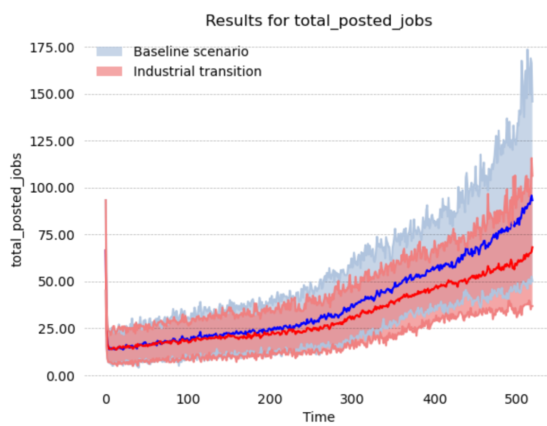
- We introduce feedback links between the housing and the labour market via connecting the choices of individuals and businesses and the evolution of neighbourhoods. By choosing a certain job and with it comes the income, class and workplace location, an individual implicitly adopt constraints on and preferences for their ideal residence and neighbourhood. On the other hand, by choosing to buy a house in the city, the individuals and their households have made a big commitment and investment in the city, which will limit their mobility to leave the city for opportunities elsewhere. People could potentially be stuck in declining neighbourhoods with a house of low value, and cannot afford to move to places where their service and skills are needed. Furthermore, a neighbourhood with a high percentage of unemployed workers will be considered unfavourably by house buyers, which will further depress the housing price and intensify the issue.
- We introduce links between the local workers, businesses and the overall industrial structure in a complex urban system. By doing so, we connect local businesses and human capital with the technological and industrial transition at a global scale. When discussing technological development and industrial transition at a higher level, a common mistake is to view the local workers and businesses as fluid resources that can be moved and reallocated as needed, just like capital. How does such a major socio-economic change affect the local people, families, neighbourhoods and

(a) Old

(b) New



(c) Service



(d) Total

Figure 3: Job vacancies in different industries in baseline and industrial transition.

businesses is often lost in the high-level discussion. The decline of a city can have many chained consequences. People can be stuck in long-term unemployment and crime-ridden neighbourhoods with little hope of getting out. Businesses can struggle to find qualified workers and thus unable to upgrade and innovate. Cities can become more unequal and segregated. Without an integrated model that incorporate and connect all these elements, it will be hard to grasp the whole picture of urban transition.

- We propose a complex system approach to major socio-economic transitions in an urban system. Urban transitions are path-dependent, evolutionary processes emerging from the complex interaction of heterogeneous individuals and businesses in a changing environment. Traditional macroeconomic models often assume that transitions tend to be smooth in the long-run: regions suffering a shock or gradual economic decline will eventually adjust and find a new equilibrium (Simmie and Martin 2010). However, empirical studies of regional transitions show that these models fail to capture important dynamics that often lead to far more dramatic processes of socio-economic transition at the regional level. For example, weaker economic prospects reduce the attractiveness of a region to new skilled workers, while local less skilled workers are often less mobile. As a result, the gradual deterioration in the quality of local human capital makes it harder for companies to innovate, leading to lower profit and further brain drains. These negative feedback interactions tend to lock down regions in declining trajectories that are difficult to overcome. The model presented in the paper is a first step towards an complex urban system approach to major socio-economic shocks and transitions.

4.2 Future Research

In the future, we will consider the following extensions to the model. We will enrich the representation of skills by distinguishing skills for different industries. Individuals can transfer their skills when changing between industries. The transfer rate of skills will depend on the nature of the industries and how related they are. We will also enrich the representation of industries by distinguishing them by the level and type of skills needed.

We will add the effect of long-term unemployment on individuals. In addition to the loss of skills from unemployment, individuals may also quit searching for job. Long-term unemployment can also lead to crime and health issues (Nichols, Mitchell, and Lindner 2013), which will have rippled effect on the neighbourhood. We will consider the effect of vacant or abandoned houses in extreme cases of urban decline.

We will consider different types of scenarios, including more radical changes. For example, there can be a sudden collapse of a major industry in a city (such as the oil price collapse in 2014 and its effect on the city of Aberdeen (Ge, Polhill, Craig, and Liu 2018)), as well as asymmetric changes, where the collapse of old industry is sudden and the growth of the new is gradual. Other scenarios include a large-scale replacement of low and middle-skilled jobs by AI technologies, and the creation of many more high-tech jobs; the outsourcing of the production industries altogether, leaving the city with only the very high-tech and service industries.

Finally, we will conduct a full sensitivity analysis on the model to understand the role of each parameter in the model. We will then use the model to conduct case studies with data on real-world cities. The model will then be calibrated and validated using data for those cities. The model is also flexible to be tailored to addresses various issues in urban transitions faced by cities across the world.

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