Analysis of the boundaries and a possible extension of Jay Forrester's 'Urban Dynamics'

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Abstract

This short article evaluates Forrester's Urban Dynamics book and model in the light of some of the major urban challenges in the emerging economies. The article poses the hypothesis that the Urban Dynamics model is feasible to address these problems, albeit with a few changes in model structure. These structural changes might have significant impacts on the effectiveness of Forrester's proposed policies. Future research questions are posed as an invitation to further study the enormous urban challenges affecting large shares of the world population.

Introduction

In 1969, Jay W. Forrester published a book about the dynamics of urban growth, aging and revival. The study addressed the problem of economic stagnation in the urban centers of American cities such as Boston and Detroit. His model represents "*the central processes common to all urban areas rather than that of a specific area*" (Forrester, 1969, p. 14). Thus, with the appropriate initial conditions and parameters, the model should be able to generate the history of cities as different as New York, Chicago, Beijing and Calcutta. Forrester explains that the behavior of any city is mostly dependent on its internal economic merit and the dynamics between industry, housing and population (Forrester, 1969).

Surprisingly, there has been very little interest within the SD community to test and build on the Urban Dynamics modeling work. Over the 35 years that the System Dynamics Review has been published, only two papers have done some sort of evaluation of its results and usefulness (Alfeld, 1995; Ghaffarzadegan, Lyneis, & Richardson, 2011); both of those papers not classifying as thorough testing and critiquing of the model. Forrester himself seems to have endorsed such endeavors when he wrote, "*the theory (model) of urban behavior presented in this book has so far been subjected to the scrutiny of only a few people who are professionally competent in the urban field… Only with a wider comment and criticism can the methods, the assumptions, and the results be adequately evaluated*" (Forrester, 1969, p. 2). Specifically, he proposed to evaluate the basic assumptions of the model

against experience and data, the behavior of the model against real system behavior and policies in the model against those in the real world.

This Research Problem article provides preliminary evidence for the applicability of Forrester's Urban Dynamics to address some of the major urban problems in emerging economies. Some promising research questions are proposed in the end of the article for future research on this important topic.

Urban problems in the emerging economies

One of the major issues in emerging economies today is the growing number of people living in slums. Recent numbers from the United Nations (UN) Habitat program estimate the total number of people living in slums worldwide to 1 billion, meaning one out of every eight persons. Although there are many different types of slums, the definition used by the UN Habitat program defines a slum as a group of individuals living under the same roof in an urban area who lack one or more of the following (United Nations, 2018):

1. Durable housing of a permanent nature that protects against extreme climate conditions
2. Sufficient living space which means not more than three people sharing the same room
3. Easy access to safe water in sufficient amounts at an affordable price
4. Access to adequate sanitation in the form of private or public toilet shared by a reasonable number of people
5. Security of tenure that prevents forced evictions

One of the extreme examples of slum development is Cairo's City of the Dead, where some twenty thousand poor people use ancient pharaonic tombs for their housing needs. The rapid growth of slums is posing a serious challenge to the first sustainable development goal (SDG) of "eradicating extreme poverty for all people everywhere by 2030". With only 8 years left, the number of people living in poverty-stricken slums keeps increasing, for example in Manila (Table 1).

	Slum Population (millions)	Metro Population (millions)	Share of Metro Population
1946	0.03	1.4	2%
1956	0.09	1.87	5%
1960	0.28	2.5	11%
1970	1.2	3.9	31%
1980	1.6	5.3	30%
1990	2.8	7.4	38%
2000	3.9	9.9	39%

2010	4.6	11.6	40%
2020	6.3	12.9	49%

Table 1 Slum population in Metro Manila (Garrido, 2018)

Within the sustainable development literature dealing with slums, there are two opposing threads. The neo-liberals see slums as transitionary objects that are the result of a developing economy (Frankenhoff, 1967; The World Bank, 2009). On the other hand, a study from MIT argues that there is "no clear pattern between economic growth and slum growth" and that "the type of poverty observed in contemporary slums of the developing world is characteristic for poverty traps" (Marx, Stoker, & Suri, 2013).

Already since the 1950s, a variety of urban strategies attempts to deal with the growth of slums. In the 1950s, slum clearance was still the norm, although this did not deal with the core of the problem for why slums are growing, and it led to new slums growing up in different areas of the city. From the 1960s, policy makers shifted from slum clearance to slum neglect, and the number of slums continued to grow. The 1970s saw a shift in policy to the upgrading of slums, whether in the form of increasing access to water and/or sanitation or improving the safety of the houses in the slum. These improvements, however, often only lasted until there was money in the upgrading program and they were generally only in certain pilot areas. In the 1990s, the policy of 'land titling' became more popular, as international NGOs like the World Bank claimed that giving slum residents formal ownership of their houses would strengthen their financial position and willingness to make longer term investments in the neighborhood. This policy, however, neglected that slum residents often already have non-formal ownership of their houses and that this informal organization is often stronger than the official rule of law in the slum. As all policy opportunities seem to have been exhausted since the 1950s, the latest policy recommendation of the UN-Habitat program (2012) is that a more holistic approach to the slum problem is advised (e.g. a combination of land titling with other policy instruments).

Slums in Forrester's Urban Dynamics model

Forrester models slum growth through a stock of underemployed housing, which can increase either through the decay of former labor housing or through the low-cost housing programs by public authorities. The number of underemployed people in the city, in Forrester's model, can grow either through people in labor that lose their job or through immigration from outside of the urban area. This process of migration is driven by the 'attractiveness-for-migration multiplier', which is based on five factors (Forrester, 1969):

1) The readiness with which the underemployed move into the skilled-labor class

2) The number underemployed housing vacancies in the city

3) The amount of tax money spent per capita in the city

4) The amount of jobs available for underemployed people

5) The availability of construction programs for low-cost housing

One of the most important conclusions of Forrester's model is that the public policy of developing low-cost housing could have the unintended consequence of making the city more attractive for underemployed people. This, in turn, leads to increased migration, while at the same time taking up space where otherwise new business ventures could settle, and thereby eventually lowering employment opportunities for the underemployed people.

Forrester concludes that a combination of slum demolition and business generation policies could revitalize the economic prosperity within urban centers..

Slums in the emerging economies compared to United States

The New York metro area is by far the largest urban area in the United States and it reached a population of close to 19 million inhabitants in the year 2020. It took the metro area about 120 years to grow from 4 million inhabitants (in 1900) to that 19 million. If we look at some of the urban metro growth in the developing world, as shown in Figure 1, we find growth that is much faster as compared to American cities in their growth phase today, like Houston, Phoenix and Seattle. The rate of growth seems to better resemble that of New York in its former growth phase. However, even compared to New York's growth, the metro areas in the developing world grow more rapidly. It takes Sao Paulo, Cairo, Mexico City and Mumbai only some fifty years to grow from 4 million to 19 million inhabitants.
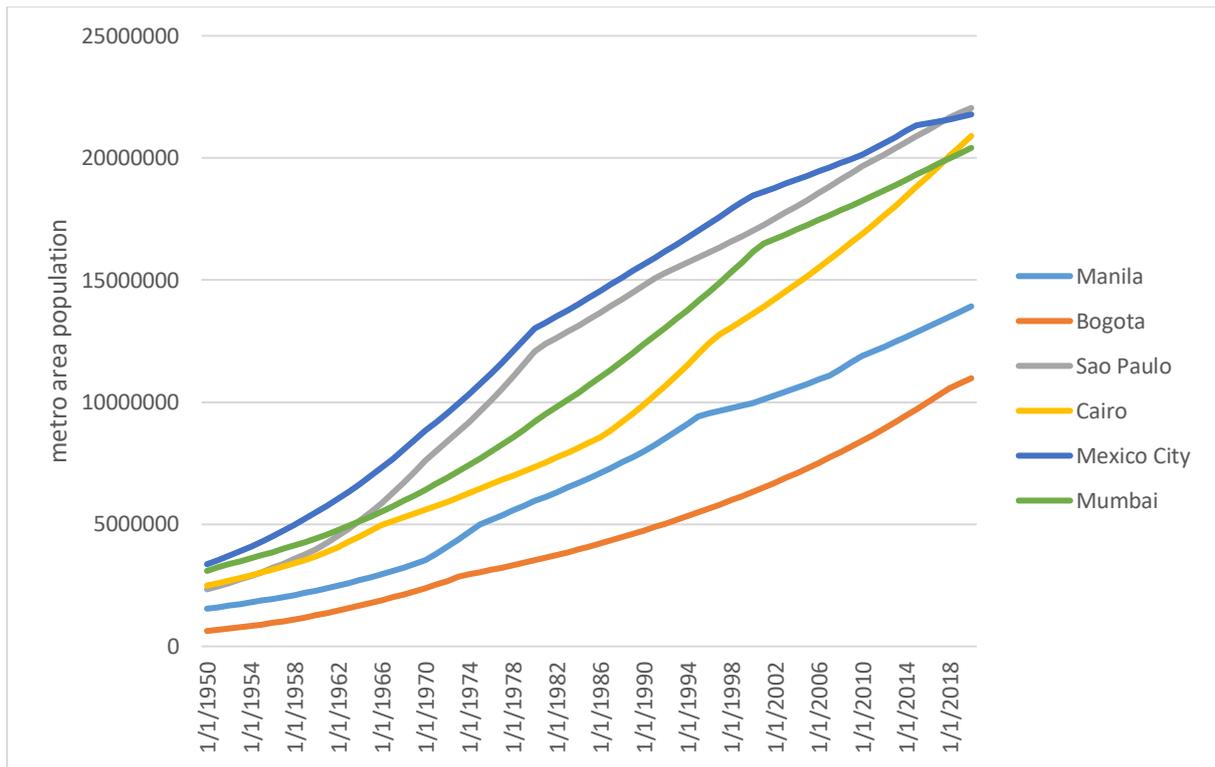
Figure 1 Metro area growth of cities in the developing world

As compared to growing American cities of today, the obvious explanation for their lower growth rate is the difference in birth rates. The fertility rate in the United States (e.g. births per woman) have been below two for most of the growth period of cities like Houston and Phoenix, shown in Figure 2. Thus, urban growth would have mainly come from migration. In the developing countries, birth rates were

still between six and seven births per woman in 1960, while consequently starting to decrease.
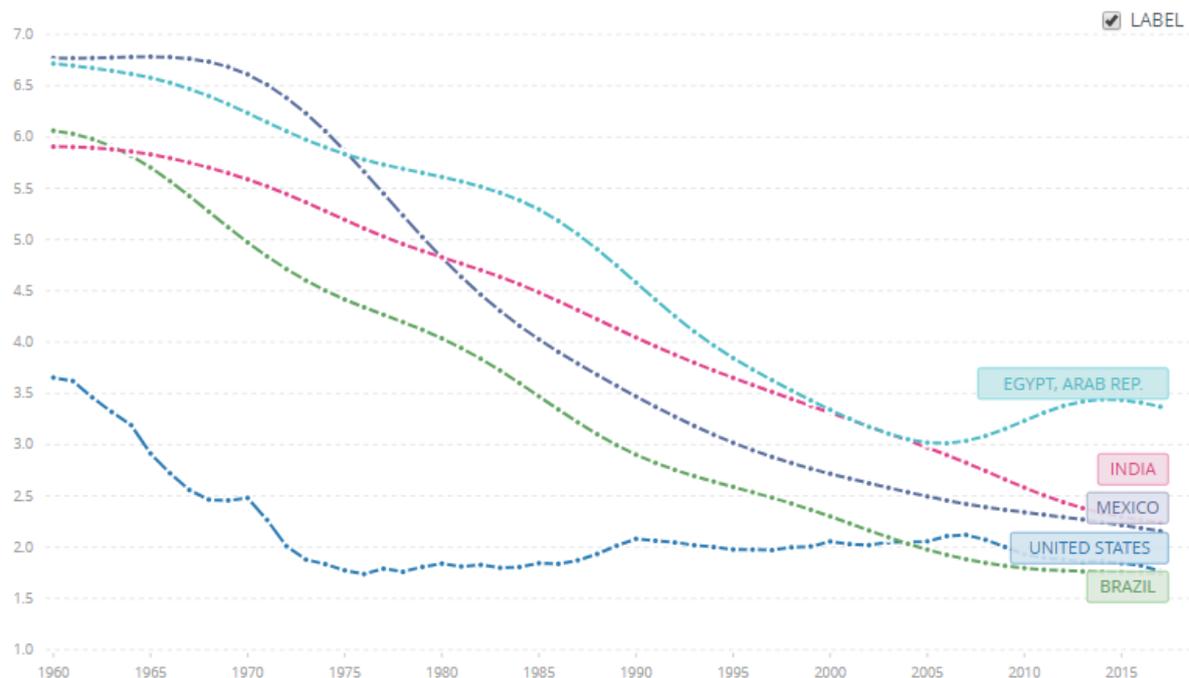

Figure 2 Fertility rate over time (World Bank, 2020)

It will be more interesting to compare birth rates in the developing world with that of New York in its growth period. The birth rate in the United States was 3.7 in 1960 (World Bank, 2020), 4.8 in 1900 and 7 in 1850 (Haines, 2008). Therefore, birth rates in the urban areas in the developing world are comparable to those of New York in its growth phase. The question then remains as to why the metro areas in the developing world are able to grow more than twice as fast in size as that of metro New York. It seems that Forrester's 'attractiveness-for-migration multiplier' is not keeping out migrants as effective as supposed to.

Through expert consultation[1] and a meta-analysis of several studies on urban growth in the emerging economies, from Brazil, Colombia, Egypt, India, Mexico and the Philippines (Davis, 2006; Perlman, 2010; Ragragio, 2003; Ranjan Rout, 2008; The American University in Cairo, 2014) some potential factors were identified that could have produced the rapid growth in urban populations, most notably in urban slums. Firstly, because of rural poverty, climate change and wars, the inflow of people to the urban areas might be higher as compared to how it was for example in New York. Many of the migrants to New York in the 19th century came from abroad, such as the Irish after the potato famine. The effort to reach New York for these overseas migrants is likely much greater compared to domestic rural migrants in the emerging economies.

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[1] In Bogota, Manila and Cairo

Secondly, in the emerging economies, when migrants move to the city, and if there is a shortage of low-cost housing or government initiative to supply them, they build their own low cost housing (e.g. slums). The extent and size of these informal slums being built from scratch seems to be incomparable to that in the times of New York's' growth. In the case of New York, low-cost housing was mainly provided by the market in terms of tenement housing (Lockwood, 1978), while there was also some informal growth in living space, such as in cellars, warehouses, backyards and the adding of floors on top of buildings (History, 2010; Lockwood, 1978). In the emerging economies, complete so-called "shanty towns" are built by the settlers themselves, both within the urban cores as in the fringing wastelands on the urban periphery.

The implications of these findings challenge the boundaries of Forrester's model structure. One of the basic assumptions in Urban Dynamics is that the stock of underemployed housing can only increase through workers housing becoming obsolete and public low-cost housing programs. Non-availability of underemployed housing *should* be a deterrent for migrants, as it decreases the attractiveness of the city for underemployed people. Remember that Forrester's 'attractiveness-for-migration multiplier (AMM)' is based on five factors, one of which is related to the availability of housing and another to the availability of underemployed housing programs. The formulae used for the AMM is multiplicative, so in the model the non-availability of housing would deter immigration altogether. This point is also raised by Rothenberg (1971, p. 18), who mentions that "great international and interregional migration of the unskilled to cities seem to have occurred despite housing conditions".

Another consequence of the informal slums in the emerging economies is that the slums frequently have their own informal economy. In Forrester's model, slums connect to the formal economy. When the slums in the emerging economies are part of an informal economy, this means that there are no direct costs (e.g. welfare programs) for policy makers, but there are high indirect costs (loss of tax income on income, commerce and real estate, loss of profitable public land and crime-related expenditures).

Discussion

Forrester started out modeling problematic behavior in American cities that started after about 100 years, under an 'overshoot and (undesired) equilibrium' scenario. The urban problem in the emerging economies could potentially be much more unstable. The feedbacks between much larger (and nearer) pools of (rural) migrants, those migrants building their own housing and shanty towns, large shares of the metro urban population living outside of the formal economy and the fiscal impacts on municipalities and related consequences for industrial activity have not been included in Forrester's Urban Dynamics.

Based on an exploratory study into slums in the emerging economies, I have to reject the hypothesis that with the appropriate initial conditions and parameters, Forrester's urban dynamic model can

generate the history of cities in the emerging economies that are facing a rapid growth in slums. While Forrester's model is able to reflect the fact that normal arrival rates are higher and normal departure rates are lower in the emerging economies, the model structure is not able to reflect two important structural mechanisms responsible for slum growth:

1) There is an additional inflow of "informal slum construction", through which underemployed people built their own lost-cost housing when the public/private sector fail to do so

2) The above mechanisms leads to the creation of a secondary/informal economy, which is not reflected into Forrester's model: governments are not able to get tax on informal slum estate, while they are also not able to provide social welfare to its residents

The informal slum model structure interferes strongly with Forrester's desired policy of slum demolition: when governments destroy slums in one part of the city, they might just as easily come back up in other parts. This could potentially lead to a "shifting the burden" archetype.

The informal economy structure interferes strongly with both Forrester's desired policy of business generation but also with the attractiveness of the city for underemployed people. In Forrester's model, underemployed people seem to leave the city if there are no welfare payments. In the emerging economies, they usually stay if they are able to make a small enough living in the informal economy. That means more pressure on the availability (and price) of land for new business ventures, leading to less jobs and consequently a potential poverty trap. Thus, including these feedbacks in Forrester's urban model might provide evidence that contemporary slums in emerging economies can be described as a poverty trap (Marx et al., 2013).

The feedbacks between underemployed people building their own housing, 50% of people living outside of the formal economy, and the fiscal impacts on municipalities and related consequences for industrial activity have not been included in Forrester's prior work. On the other hand, the problem of slums in the emerging economies is still explained by the internal economic merit and the dynamics between industry, housing and population. Furthermore, Forrester's 'attractiveness-for-migration multiplier' seems applicable to the slum problem as well. Therefore, I believe that Forrester's Urban Dynamics still has an important role to play in addressing contemporary urban issues. The addition of some new model structure and some minor modifications will likely help address the problem of growing slums in the emerging economies. However, my hypothesis is that these changes will have significant impacts on the effectiveness of Forrester's proposed policies.

Further research

Further research on the dynamics of slum growth in the emerging economies can, but should not be limited to, focus on the five following topics.

Topic 1 – Parameter updates

Adjustment of parameters in the Urban Dynamics model to reflect specific situation of emerging economies, potentially focusing on a specific case study. This includes changes in birth and death fractions, normal departure and arrival rates, people per house and people per business structure. Changes in the people per house and people per business structure would reflect higher housing density and lower labor productivity in the emerging economies.

Topic 2 – Structural adjustment ("informal slum construction")

A new inflow can be added to the Urban Dynamics model, which can be referred to as "informal slum construction", and which is based on the gap between the underemployed population in the city and the availability of housing. Figure 3 shows an example of such a new model.
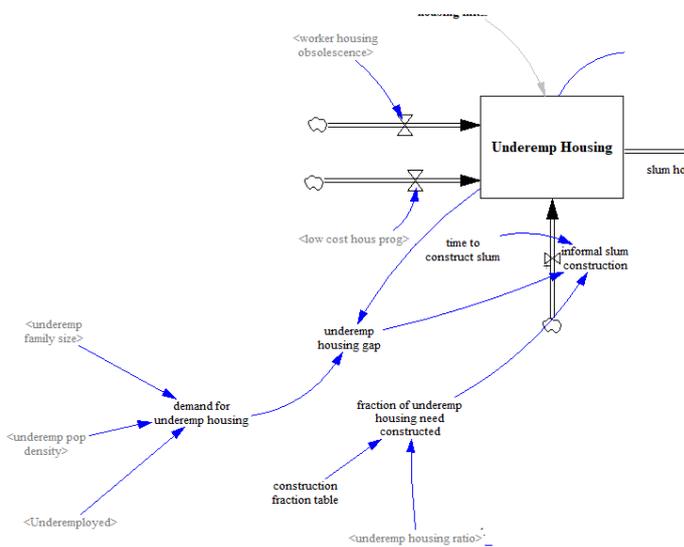

Figure 3 Informal slum construction inflow

The equations can be formulated as follows:

Informal slum construction = (underemp housing gap*fraction of underemp housing need constructed)/time to construct slum

Underemp housing gap = demand for underemp housing – Underemp housing

The demand for underemployed housing is measured in housing units and is a function of the number of underemployed workers times the average family size of an underemployed worker, divided by the number of underemployed people per housing unit (underemp pop density), i.e. Demand for underemp housing = (Underemployed*underemp family size)/underemp pop density

The fraction of the underemployed housing gap that is being constructed can be determined based on a nonlinear function of the crowding of the current underemployed people in the city.

Topic 3 – Structural adjustment ("informal economy")

In Forrester's model, slums connect to the formal economy. To reflect the way in which informal slum economies are decoupled from the formal economy, the following equations can be modified:

Housing assessed value = premium housing assessed value*Premium Housing+ worker housing assessed value*Worker Housing + (underemp housing assessed value*(Underemp Housing*(*1-Informal slum share*)))

Tax needed[2] = (tax spending per manager*manager prof family size* Manager Professional+ tax spending per labor*labor family size*Labor+ (tax spending per underemp*underemp family size*((*1-Informal slum share*)*Underemployed)))* tax collection mult

Topic 4 – Structural adjustment ("Endogenous urban area")

Forrester's Urban Dynamics focused on the problem of decay in urban centers, which continues to be an important issue in its own right. The issue of slum growth requires a wider system boundary. In addition, nowadays expanded and faster transportation networks have expanded the effective size of cities until congestion / tolerable travel times offset this growth.

As Forrester claims that internal dynamics between industry, housing and population produce the behavior of a city, the fact that the workers in urban centers, now often live in 'outside' urban area, poses the need to enlarge the boundary of the model to be able to endogenize the three subsectors. Forrester seems to have left some room for ambiguity. He mentions on the one hand that the urban area is "*a suburban area or the core area of a city but probably not an area containing both*" (1969, p. 2), while on the other hand that the appropriate area is "*small enough so that cultural, economic, and educational interchange is possible between its component populations* (1969, p. 2). To endogenize the urban area reveals the dynamic of the "extending" city, in which the urban area itself grows in absolute size, due to the population moving farther away out of the urban centres, directed by increasing real estate prices, to create space for dense commercial and industrial centres. In that process, former housing stocks are demolished to make way for commercial buildings; which is one of the prescribed policies by Forrester to stimulate urban renewal. Such metro areas will not grow indefinitely (e.g. growth is likely s-shaped and reaches a limit), and this is probably linked to Forrester's argument regarding the impact of distance on the "*cultural, economic and education interchange between component populations*" (1969, p. 2).

Topic 5 – Exploration ("Rural carrying capacity and push migration")

Topic one proposed to increase the parameter value of normal departure and arrival rates to reflect differences in migration in the emerging economies. However, further research is required to identify

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[2] I have excluded the effect of crime-related expenditures from the informal slum, which would ideally be implemented as a separate effect

whether Forrester's 'attractiveness-for-migration multiplier' is really the dominant explanation for changes in flows in and out of the city. Slum growth might be less driven by attractiveness of the city and more by specific causes that happen within the rural environment. There might be a large external reservoir of rural land that is less attractive due to limited employment opportunities. Thus, it might be worthwhile to experiment with modeling a dedicated rural area and some of the model structure that is producing the push migration. Adding that model structure will be helpful in answering the question of whether the leverage is within the urban zone (providing more employment, fixing slum land allocation) or within the rural zone (improving land fertility, and access education).

References

Alfeld, L. E. (1995). Urban dynamics—the first fifty years. *System Dynamics Review*, *11*(3), 199–217. https://doi.org/10.1002/sdr.4260110303

Davis, M. (2006). *Planet of Slums* (2017 ed.). London, UK: Verso.

Forrester, J. W. (1969). *Urban Dynamics* (1999 ed.). Waltham, MA: Pegasus Communications.

Frankenhoff, C. A. (1967). Elements of an Economic Model for Slums in a Developing Economy. *Economic Development and Cultural Change*, *16*(1).

Garrido, M. (2018). *The Patchwork City: Urban Fragmentation and Populism in Manila* (manuscript). Chicago, US: the University of Chicago.

Ghaffarzadegan, N., Lyneis, J., & Richardson, G. P. (2011). How small system dynamics models can help the public policy process. *System Dynamics Review*, *27*(1), 22–44. https://doi.org/10.1002/sdr.442

Haines, M. (2008). Fertility and Mortality in the United States. Retrieved February 12, 2020, from EH.Net Encyclopedia website: https://eh.net/encyclopedia/fertility-and-mortality-in-the-united-states/

History. (2010). *Tenements*. Retrieved from https://www.history.com/topics/immigration/tenements

Lockwood, C. (1978, July 23). Quintessential Housing Of the Past: Tenements. *The New York Times*. Retrieved from https://www.nytimes.com/1978/07/23/archives/quintessential-housing-of-the-past-tenements-quintessential-housing.html

Marx, B., Stoker, T., & Suri, T. (2013). The Economics of Slums in the Developing World. *Journal of Economic Perspectives*, *27*(4).

Perlman, J. (2010). *Favela: Four Decades of Living on the Edge in Rio de Janeiro*. New York, NY: Oxford University Press.

Ragragio, J. M. (2003). Urban Slum Reports: The Case of Metro Manila , Philippines. *Understanding Slums: Case Studies for the Global Report on Human Settlements*, 1–21.

Ranjan Rout, N. (2008). Slum Growth in Bhubaneswar: A Problem or Solution? In *ITPI JOURNAL* (Vol. 5). Retrieved from www.itpi.org.in

Rothenberg, J. (1971). *Problems in the modeling of urban development: A review article on Urban Dynamics, by Jay W. Forrester* (No. 81). Cambridge, Massachusetts.

The American University in Cairo. (2014). *Egypt's Strategy for Dealing with Slums*. Cairo, Egypt.

The World Bank. (2009). *Reshaping Economic Geography*. Washington, DC.

United Nations. (2018). UN-Habitat: For a Better Urban Future. Retrieved March 28, 2018, from https://unhabitat.org/

World Bank. (2020). Fertility rate, total (births per woman). Retrieved February 12, 2020, from Data website: https://data.worldbank.org/