AGENT-BASED MODELING OF URBAN TROPICAL GREEN INFRASTRUCTURE INVESTMENT

Brown, S.*, Ferreira, C.

Department of Civil, Environmental and Infrastructure Engineering, George Mason University, United States

*Corresponding author: sbrowb@gmu.edu

ABSTRACT

This document describes a conceptual methodology to investigate the dynamics of "bottom-up" green infrastructure (GI) investment in tropical urban areas. This approach seeks to develop a methodology of study to understand what policies may lead to more efficient investment policies that lead to a sustainable urban setting. Agent-based Modeling (ABM) was used to replicate a stylized tropical urban environment setting and employed to investigate the emergent patterns of increased GI and greenspace through investments at the local level. Initial modeling results illustrate the generalized methodology developed produces outputs consistent with expectations, thus validating the approach. Further, modeling output illustrates typical policies and conditions necessary to produce a sustainable tropical urban setting using the "Green City" metric. Current modeling efforts employed a stylized spatial setting and synthetic behavioral data for agents and their environment. Similarly, the modeling presented in this paper is not temporally-dynamic. The ability to transfer findings from this research is limited by the conceptual nature of the modeling. Findings from the work is applicable to the development of future modeling efforts employing real-world spatial data, economic behavioral rules based upon literature or surveys, and temporal dynamism reflecting realistic urban growth and investment. Increasing greenspace in urban settings improves the health, well-being and economic condition for tropical urban dwellers. Further, investments in GI can have direct benefits to air and water quality, particularly in addressing impacts from uncontrolled stormwater runoff. To date, no other efforts have been found to study private investment in green infrastructure using an ABM approach.

Keywords: *Greenspace, agent-based modeling, cellular automata, green infrastructure, sustainability, Tropical climate, ultra-urban, Netlogo, stormwater, investment*

1 INTRODUCTION

1.1 Urbanization and Green Infrastructure

A landscape comprised primarily of hardscape (impervious surfaces), which is closely associated with typical urban development, leads to increased flooding, reduced air and water quality, loss of aesthetic value, and increased temperatures through the "urban heat island" effect (Konrad, 2003, Vingarzan and Taylor, 2003, Kloss, 2008). The use of green infrastructure (GI) in the urban environmental has been shown to mitigate these effects by reducing runoff through infiltration, reducing airborne particulates, reducing energy costs, lowering ambient air temperatures, and enhancing the social and economic value of urban areas (Miller 2007, Wise 2007, Currie and Bass, 2005, Wise et al. 2010). Differing types of GI practices reflect varying treatment levels and provide unique benefits. Green roofs can reduce temperatures on building rooftops in the summer and help retain heat in the winter as well as capture small amounts of precipitation. For instance, green roofs have been shown to reduce rooftop temperatures between 40-60 degrees Fahrenheit (Gaffin, et al, 2010). Bioretention facilities capture runoff and provide enhanced water quality treatment while also providing aesthetic value to landscapes. Permeable pavements allow water to soak through paved areas, such as parking lots or basketball courts, which reduce runoff volume. Disconnecting downspouts and other direct drainage connections with the sewer system can mitigate volumetric-driven dynamics for drainage systems. Urban forest canopy, associated with street trees and other deciduous covers used in GI practices, can have direct impacts as well. Berkeley, California and Cheyenne, Wyoming showed an energy benefit of \$11-\$15 per tree (McPherson, et al, 2005) while Washington DC reduced energy consumption costs by \$2.65 million annually because of their trees (Casey Trees, 2002).

1.2 Green Infrastructure and Greenspace in the Tropic Context

Said and Mansor (2011) outline the current condition of green infrastructure in Southeast Asian countries as well as future potential benefits from increased investment in GI. They point out that urban development in tropical countries is growing significantly, such as Malaysia, which is expected to increase its urban population by 78 percent by 2030. Studies are highlighted regarding the current state of urbanization in Southeast Asia by pointing that, “almost all cities in the region (Southeast Asia) have inadequate and poor quality greenspace, which are associated with poor social conditions, economic and environmental deterioration”(ibid.). For instance, it is noted that one major cause for Jakarta’s environmental degradation is the loss of greenspace. They also point out that one of largest barriers to GI investment is the competition with other physical developments and land use pressures. on the other hand, there are many environmental and social benefits of increased greenspace. For instance, “views of nature can reduce psychological and indicators of stress, improve mood, decrease aggressive feeling and promote community bonding” And “green infrastructure improves the quality of urban environment through…improvements in ambient environmental quality” (Said and Mansor, 2011). Economic benefits associated with increased GI as highlighted by their work includes increased housing prices, creation of jobs, urban revitalization and enhanced tourism potential.

Sing et al. (2010) have found that that cities with adequate greenspace should provide between 20 and 30 percent of urban area as greenspace, and Aldous (2010) has noted that a “green city” must have “sufficient greenspace to account for its environmental sustainability.” Lastly, the UN Food and Agriculture Organization suggest a minimum of 9 m2 of greenspace is needed per urban inhabitant for proper urban sustainability (Kuchelmeister, 1998). Singapore, with 46.5 percent of urban area covered by greenspace (and 20 m2 per capita) and Bankok (39% green coverage) are held up as positive examples of a green city in this context, while the green coverage of other cities, such as Jakarta (9.6%) and Kuala Lampur (15.5%) illustrate the need for stronger policies of green infrastructure growth in the Tropics (Said and Mansor, 2011). Considering this information, we will use a threshold of 20 percent greenspace coverage as a minimum for an idealized ‘green city’ in this document, which will be used in the analysis of varying modeling scenarios.

Another dimension of GI investment to consider is connectivity of greenspace and GI resulting from investments. While the amount of green coverage in Singapore is high, a recent effort has been made to connect these areas, as it is recognized that disconnected greenspace limits public usage / engagement and environmental benefits. Other cities, such as Pretaling Jaya and Putrajaya in Malaysia, are proposing to address environmental degradation by reserving large amounts of future development for green infrastructure that is connected in a network-like fashion (Said and Mansor, 2011). The value of green infrastructure is greatly enhanced when it is well-connected, as it provides a synergistic influence on social and environmental benefits of GI investment.

1.3 Background on Funding and Financing of Green Infrastructure

Many financing and funding options exist when considering investments in GI in tropical urban settings. Top-down investment through public investments is the most common form of investment. In the U.K., the U.S., and other countries, there has been an increase of interest in introducing competition and efficiencies into infrastructure investment, including green infrastructure (Wang, 2009), which can be applied for tropical urban areas.

An example of an innovative approach to drive investment in urban areas to the site/local level is Philadelphia, Pennsylvania’s Green City, Clean Waters program, which proposes to utilize GI to reduce the number of combined sewer overflow (CSO) events. Under this 25-year plan, PWD will invest over $1 billion (in 2009 dollars) to convert current impervious surfaces, such as rooftops and roadways, into “Greened Acres”. Considering that nearly 10,000 acres of impervious cover will need to be addressed in this effort, it is evident that GI investment in areas outside of publically-controlled properties is needed to reach this goal. To help meet this goal, PWD has established a parcel-based fee for stormwater services that established a rate for non-residential property owners based upon the amount of impervious cover at the property level. PWD has also established the provision that up to 80% of the fee could be eliminated assuming the installed practice met the requirements of controlling at least the first inch of stormwater runoff on site.

Analysis has shown that when considering avoided stormwater fees as the only metric of project payback the discounted payback periods of most green infrastructure retrofits on private parcels is ten years or greater, which is longer than most investors would be willing to accept (Valderrama, 2013); however, changes to this model may be made to increase the chance for a more viable way to generate significant amounts of GI through private investment. Specifically, if a private investor with technical knowledge and practical experience in GI investment had confidence that a market for GI investment at the site/property level existed with strong demand, this investor could then obtain financing and purchase materials for GI investment on a large scale and contract with service providers (designers and contractors) at lower negotiated prices based upon the promise of a high volume of low-risk demand. Further, the investor could seek out locations where GI investment is favorable (site conditions, property owner interest / willingness to invest, distance to other green space, etc.), and use these locations as a base in which to invest in not only on the site level, but also at the neighborhood level by seeking out other sites/properties in the immediate area that would be equally (or more) favorable for GI investment. By aggregating projects together, not only could capital costs be reduced as discussed above, but other costs reductions could be realized, such as costs associated with construction mobilization and sharing of labor across multiple properties in close proximity. Beyond capital cost savings, a significant amount of cost reduction associated with transaction costs could be realized by aggregating projects. A similar approach (project aggregation) is used in the Energy Service Company (ESCO) model. This approach is to contract with building owners in urban areas to provide energy-efficient appliances and other similar energy saving efforts and services with the understanding that cost savings realized will be shared by the property/building owner. One major driver in ESCO developments is to reduce transaction costs, which can be 10-40% of the total project cost (Valderrama, 2013).

Considerations for Investments in Green Infrastructure in Tropic Cities

Based upon U.N. studies, for the first time ever in world history the urban population surpassed rural population in 2010 (United Nations, 2010). While the needs in the U.S. for GI investment are great (and growing), the needs in regions such as Southeast Area, the Indian Subcontinent, and Oceania are far greater. The World Bank estimates that the current rate of investment by the Chinese is $20B per year (Gleick, 2009), and considering the increased recent interest in China on GI, evident by an increase in technical conferences and academic institutions formed around this topic, the investment will likely continue to increase. In India, a recent report cited a projection of $32B of investments in stormwater infrastructure over the next 20 years (McKinsey, 2010). Considering that seven of the ten fastest growing cities in the world are located in the Tropics, and considering that increased urbanization with little consideration for greenspace leads to environmental, economic and social impacts, it is imperative to find new and creative ways to maximize the investment in green infrastructure while urbanization occurring.

2 AGENT-BASED MODELING AND GREEN INFRASTRUCTURE INVESTMENT THROUGH PROJECT AGGREGATION

2.1 Overview of Agent-Based Modeling

Agent based modeling (ABM) has unique advantages for simulating a "bottom-up" system, such as private investment of GI at the property or site level. ABMs are modeling frameworks that are comprised of an "agents" or decision-makers who interact with their environment and other agents when taking action in a system. Agents in this context may be individuals, groups, firms, or companies who are identified and given decision-making properties that affect how various types of agents interact. Helbing and Balietti (2006) state that ABM is a, "method that (is) suited for the computer simulation of socio-economic systems," and that, "the behaviors and interactions of the agents may be formalized by equations, but more generally they may be specified through (decision) rules, such as if-then kind of rules or logical operations...this makes the modeling approach much more flexible." The goal of ABM is to provide rules of behavior for agents and their environment that are employed at the local level and investigate the patterns and outcomes that emerge at the macro level under varying initial conditions.

2.2 Tying Agent-Based Modeling to Green Infrastructure Investment

The goal of the research was to develop a model to investigate the dynamics of GI investment in an effort to explore policies, conditions and behaviors might affect project aggregation. The dynamics of project aggregation occur at a local level involving many decision-makers at the property-owner and investor level using private investment funds, and therefore it is more of a "bottom-up" approach to investment. This is in contrast to a "top-down" framework more closely associated with government mandates and public investments, where investment decision-making occurs at the bureaucratic level by a small number of deciders. Considering this differentiation, it is reasonable to question the applicability of classic economic theory when attempting to understand the behavior and patterns of GI investment through project aggregation. Decision makers at the individual level may not act with perfect knowledge or rationality, for instance, which is inconsistent with the assumptions of classic economic theory. Additionally, analytical methods used in classic economic theory are not spatially-sensitive; however, the characteristics of spatial distribution of GI and green space in the urban setting is significant. Other social and environmental issues, such as environmental justice and environmentally sensitive waters and areas, can only be readily investigated through spatial analysis. On the investor side of project aggregation, locational effects may be significant as well. An awareness of favorable sites for investment within the immediate neighborhood (adjacent lots) as well as those sites beyond the neighborhood-level is critical in the decision-making process for GI investment. Similarly, having a spatial understanding of competitors within potential investment area would likely alter the behavior and criteria for investment decisions. Due to the significance of spatiality in the research as well as the "bottom-up" dynamic of project aggregation, there were clear advantages to using a generative design approach for the work. ABM is particularly well suited to simulate the dynamics of project aggregation for GI investment. Specifically, ABM has the advantage of:

- Accounting for spatial dynamics
- Providing spatial information in results
- Allowing for heterogeneous project/site properties
- Relational analysis locally (in neighborhood) and globally (beyond neighborhood)
- Using a geometry (cells) generally consistent with ultra-urban setting (city blocks)
- Allowing for the integration of decision-makers (investors) in the modeling (agents)

2.3 Model Development

An agent-based model was developed using the Netlogo platform to illustrate project aggregation for GI investment in an ultra-urban setting.

More specifically, this ABM was developed with the intent to capture the basic behavior of how aggregation works at a macro level in order to inform critical system behaviour, such as thresholds of diminishing returns, optimal aggregation scenarios, connectivity, and general patterns of investment emergent behaviour related to project aggregation. Two common neighbordhood configurations are a "Von Neumann" and a "Moore" grouping. Figure 1 illustrates the difference between the two neighborhood types. In this figure, the green cells designate the neighborhood for the center cell, so we can see that Von Neumann neighborhood is comprised of four cells (up, down, left, right) positions while the Moore neighborhood consists of eight cells that include the Von Neumann neighborhood as well as the cells in the upper-left, lower-left, upper-right, and lower-right positions .

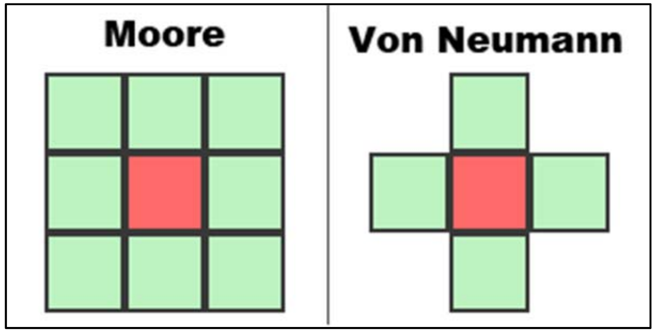


Figure 1: Moore and Von Neumann Neighborhoods (From: Auer and Norris, 2001)

The development of the model focused on the use of variables, elements, parameters, and procedures that best capture the dynamics of the parcel/property aggregation and investment in green infrastructure. Considering the conceptual nature of this model, synthetic data and assumptions were used in the model development. Tables 1 and 2 provide detailed information on model components; however, we will present a generalized overview of the model. (Note the Netlogo-specific notation, such as "patches" for cells, "turtles" for agents, and "procedure" for subroutine) The Netlogo platform is represented by a "world", which is a graphical representation of the algorithms associated with the coding. In the aggregation model, the world is comprised of 775 "patches" (cells), which represent parcels/properties in an ultra-urban setting, along with a user-defined number of "turtles" (agents) representing potential investors in green infrastructure. Patches are assigned colors based upon the favorability of investment in green infrastructure on that patch. These colors represent common site conditions that impact the ability to invest in green infrastructure, such as low-permeable soils, high amounts of existing infrastructure (underground utilities), and a high seasonal groundwater table. A normal distribution of favorability was assumed for patches with a mean of zero (neutral favorability), although the model does allow for the option for a random distribution as well based upon user preference.

A number of user-defined parameters were included in the model that impacts investment dynamics. "Favorability Threshold" (FT) is a parameter that is intended to represent the level of risk accepted by a potential risk. "Favorability Need" (FN) is simply the summation of FL values between a patch with an "active investor" and each patch within a Moore neigbhorhood. An "active investor" is an agent (turtle) who is randomly placed on a patch that has a FL value that is equal to, or less than, the FT value for that simulation. In this circumstance, the patch becomes an "invested" patch, and the investor becomes an "active investor". The Number of Turtles (Investors) (TU) simply reflects the amount of interest in the investment community to invest in this area – the higher the investment interest, the higher the number of investors. The "Level of Competition" (LoC) reflects the tolerance of investors to competition in local area (Moore neighborhood) around a patch hosting an active investor. The "Growth Capacity" (GC) parameter is intended to reflect conditions or policies favourable to growth in investment globally (i.e., beyond the local, or Moore neighbourhood level), and is defined as the number of other invested patches surrounding a patch without an active investor located beyond the local reach (Moore neighbourhood) of an active investor required to grow. Lastly, the "Limit of Investment Radius" (IR) reflects the aggressiveness of active investors to seek investment opportunities beyond the local scale. The radius term here is defined as the radius of a patch, so a radius of 1 means the distance between the center of one patch to the center of an patch within a Von Neumann neighbourhood.

Four procedures are included in the model; Set Up (SU), Determine Competitors (DC), Neighbors Test (NT), and Growth (GR). The SU procedure establishes the world, populates it randomly with normally-distributed patches of varying FL values (and colors reflecting these values). Further, this procedure randomly populates the world with a user-defined number of agents (potential investors), which is represented by yellow trees. The DC procedure randomly reduces the number of potential investors to be consistent with the user-defined LoC parameter. The NT procedure transforms potential investors to active investors (blue trees) by comparing the FT value with the FL value of the patch on which the potential investor is located. Further, this procedure transforms patches into invested patches locally around an active investor if the computed FN value is equal to or greater than the user-defined FN value for each local patch and if that local patch has an FL value above the user-defined FT value as well. Lastly, the GR procedure transforms patches beyond the local scale (global) into invested patches if they are within the Investment Radius, have a FL value equal to or greater than the user-defined FT value, and if the number of locally invested parcels is equal to or greater than the user-defined GC value.

3 RESULTS

In a generalized view, the modeling output shows the number and distribution of active/inactive investors as well as invested and uninvested parcels based upon initial conditions. Figure 2 shows two examples of outputs based upon varying initial conditions. For a formal analysis of model performance, the model was run in a batch process with ten runs performed per scenario, and results analyzed for thresholds, significance of variables and parameters, connectivity of invested patches, and general relationships between initial conditions and resulting investment conditions.
A two-ANOVA test was run to discern which variables were significant and if interaction or auto-correlation exists between variables (results are presented in Table 3). Considering an alpha of 0.05, three variables were found to be significant to the 95th percentile (listed as bold values in Table 3): Number of Potential Investors, Favorability Threshold, and Favorability Need. These results are consistent with expectations, since these parameters have direct impacts on the number of invested patches. To contrast, the remaining parameters (Growth Capacity, Investment Radius and Limit of Competition), have secondary impacts on investment outcomes. An interesting significant interaction exists between a pairing of Investment Radius - Favorability Threshold and Number of Potential Investors-Limit of Competition. This interaction can be interpreted by the dependency of invested patches and the paired variables. For instance, the number of invested patches for IR is correlated with the FT, which may limit or expand the population of investable patches within the Investment Radius. Similarly, the amount of patches invested for TU will depend upon the LoC set. For instance, a high investor population will be reduced greatly by a low tolerance of competition. The larger interaction speaks to global investment growth capacity being related to the investor population, which again is consistent with the expectation that global investment growth cannot occur without active investors present.

Thresholds relationships were found to exist that can help to inform future work. For instance, high rates of growth in invested patches occur across all relationships when initial investor population is varied between 25 and 200. However, instability and diminishing returns begin to occur when investor population reaches approximately 25 percent of total patch population (about 200 investors), and this diminishing return matures at 40 percent of total patch population (about 300 investors). This diminishing return likely points to a saturation point of investment within the model, where an increase in the population of investors becomes less meaningful in terms of invested patches. A similar diminishing return occurs for various parameters. For instance, when tolerance for competition is relaxed, allowing LoC values to increase from 1 to 9, we see marked increases in invested parcels; however, this growth diminishes quickly above the value of 2 and continues to degrade through 9. This dimishing growth indicates a “crowding out” of investors and limits the marginal impact of growth gained by additional investors as more are allowed. In other words, much of the growth that could possibly occur related to investors' tolerance for competition can be realized when 1 other investor is located locally (in Moore neighborhood), and that allowance for additional investors locally has less and less of an impact on overall investment. Output results shown in Figure 3 illustrate examples of instability, and diminishing return related to both initial investor population and investor tolerance for competition.

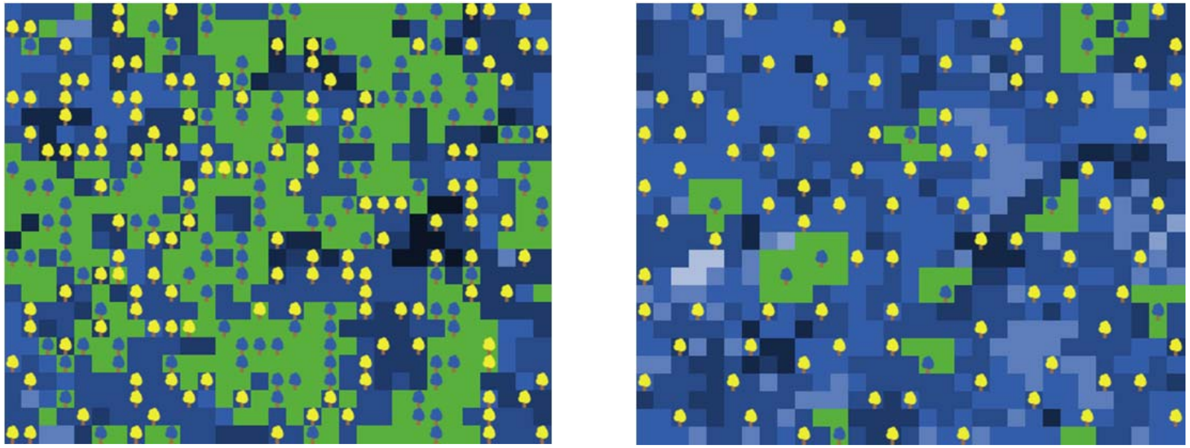
Table 1. Variables and Elements Associated with Aggregation Model (Brown, 2013)

Variable / Element	Properties / Assumptions
Patches	• Cells that represent parcels that can potentially have stormwater management infrastructure built on site.
Turtles	• Agents that represent investors in green infrastructure
World	• Element that graphically encompasses all patches and turtles • Can accommodate a total of 775 possible patches / turtles
Favorability Level	• Assigned value ranging between -2 and 2 • Defines the color of patches (cells) in "world" • Value directly related to favorability of investment
Favorability Threshold	• User-defined input value ranging between -2 and 2 • Tied to Favorability Level of selected patch in analysis • Value inversely related to risk tolerance
Favorability Need	• User-defined input ranging between -4 and 4 • Reflected by the sum of a selected patch and each patch in Moore neighborhood • Represents a threshold for collective investment between an investor and neighboring patches • Value inversely related to risk tolerance
Number of Investors	• User-defined input ranging between 25 and 700 • Defines the number of turtles (agents) in the scenario • Value directly related to the number of potential investors
Level of Competition	• User-defined level between 1and 9 • Reflects the number of turtles (potential investors) in Moore neighborhood • If turtle is surrounded by more than or equal to the user-defined number, it "dies" (is removed from the analysis) • Represents investor tolerance to competitors within local area • Value is inversely related to tolerance of competitors
Growth Capacity	• User-defined value ranging between 0 and 8 • Reflects the number of invested patches in neighborhood • Value inversely related to growth potential

Limit of Investment Radius	• User-defined ranging between 1 and 5 • Represents investment reach / range by active investors • Value inversely related to investor reach / range

Table 2. Procedures Associated with Aggregation Model (Brown, 2013)

Procedure	Purpose / Actions / Output
Set Up	• Purpose: To establish initial conditions through patch and turtle creation and distribution. • Patches are assigned colors using a normal distribution based upon Favorability Level and randomly distributed throughout the landscape • Patches are then assigned a Favorability Level based upon color • Turtles are created based upon user-defined Number of Turtles o Turtles are yellow colored trees and are to represent potential investors
Determine Competitors	• Purpose: To align the number of potential investors with competition policy / tolerance • Reduces the number of turtles based upon the Level of Competition variable • Randomly checks the number of turtles within Moore neighborhood • Randomly eliminates turtles (competitors) within neighbourhood above the Level of Competition
Neighbors Test	• Purpose: To create and signify invested parcels and investors actively investing in GI • Transforms parcels to “invested parcels” within local range (Moore neighborhood) through the following analysis: o If patch selected added with each neighboring patch (separately) is equal or greater than the user-defined Favorability Need level, and if there is a turtle on the selected patch, and if Favorability Level of selected patch is greater than or equal to user-defined Favorability Threshold, then patches meeting these conditions in neighborhood are turned green to signify investment • For turtles left after the Determine Competitors, the following analysis is performed: o If a turtle is on selected patch, and if any turtles in neighborhood are green (invested), and Favorability Level of the selected patch is equal to or greater than Favorability Threshold, then Turtles “die” and a new breed of “Active Investors” is hatched in their place o Active Investors are signified by blue trees
Growth	• Purpose: To create and signify invested parcels globally (beyond Moore neighborhood) • Identifies patches within a range defined by radius value for user-defined Investor Radius centered around Active Investors • Checks the Favorability Threshold of parcels within range • Performs the following analysis for patches within range: o If selected patch is equal to or greater than user-defined Favorability Threshold, and if number of invested parcels in Moore neighborhood is equal to or greater than user-defined Growth Capacity, then patch becomes an invested parcel signified by being turned green



High Investment / Inefficient Policies

Initial Conditions:
GC = 3, IR = 1, TU = 300, FT = 1, FN = 3, LoC = 4
Results: 329 invested parcels, 115 active investors

Low Investment / Disconnected

Initial Conditions:
GC = 8, IR = 1, TU = 300, FT = 2, FN = 3, LoC = 1
Results: 67 invested parcels, 12 active investors

Figure 2: Examples of Model Outputs (Brown, 2013)

Connectivity of greenspace was investigated as well as policies and conditions leading to a "Green City" condition of minimum GI and greenspace coverage of 20-30 percent. This was done by modeling a variety of scenarios qualitatively analyzing results. Some general conclusions are that lower IR values limited connectivity conditions as a very low investor risk tolerance does. Two examples are provided in Figure 4 below that illustrates varying conditions of connectivity tied to the relationships noted above. Both of these examples illustrate conditions that have led to a "green city" condition of 20 percent greenspace coverage; however, the differing connectivity levels are visually apparent. Condition 1 is an example of a fragmented greenspace condition, while Condition 2 shows much higher connectivity, and this is in spite of the fact that Condition 1 begins with six times as many potential investors, a more favorable global growth condition, and almost twice as many active investors. A key difference between these two conditions is that the Investment Radius is larger for Condition 2, allowing the hubs of investment to be larger thereby providing a higher chance for interconnectedness of greenspace.

4 Conclusion

The need for green infrastructure in urban settings is clear: it enhances urban life, provides significant environmental benefits, makes cities more healthy, resilient and sustainable, and brings clear economic benefits to much needed urban landscapes. While many cities in the U.S. and Europe will struggle with the challenges and high costs associated with incorporating GI into cityscapes dense with existing impervious cover and infrastructure, the faster growing Tropical cities in Africa, Southeast Asia, the Subcontinent and Oceania, have a unique opportunity in the coming decades to shape their urban environments using green elements. Cities like Singapore and Bangkok provide hope that cities will take advantage of this opportunity; but others like Jakarta and Kuala Lumpur illustrate that challenges exist in integrating GI into urbanizing landscapes.

Table 3 – Results of Two-way ANOVA Test (alpha = 0.05) (Brown, 2013)

Variable (s)	**P-value**
GC	0.60
IR	0.20
TU	***0.01***
FT	***0.01***
FN	***0.04***
LoC	0.06
GC / IR and TU / FN	0.09
GC / FU and IF / FN	0.07
GC / FT and FN / LoC	0.12
GC / FN and IF / TU and FT / LoC	0.83
GC / LoC and FT / FN	0.90
IR / FT and TU / LoC	***0.04***
IR / LoC and TU / FT	0.08

Outlining the need for GI; however, is only one step in the process of successfully creating a “green city”. Without a strategy of how to pay for this investment, well laid plans for greening may come up short. In the U.S., the topic of private investment in infrastructure is on the rise, which is a reaction to the current economic and political realities limiting top-down public investment in infrastructure, especially in non-transportation related infrastructure. This movement to private investment has spurred interest in studying the dynamics of private investment in GI at the local, site or parcel-level. This generalized model illustrates a methodology that can be applied to simulate the emergent patterns of GI investment at the macro level based upon rules at the local, neighborhood or micro level, which can be applied to urban Tropical environments in an effort to reach the minimum 20% green coverage consistent with the “Green City” metric for a sustainable urban community in the Tropic zone.

5 Future Work

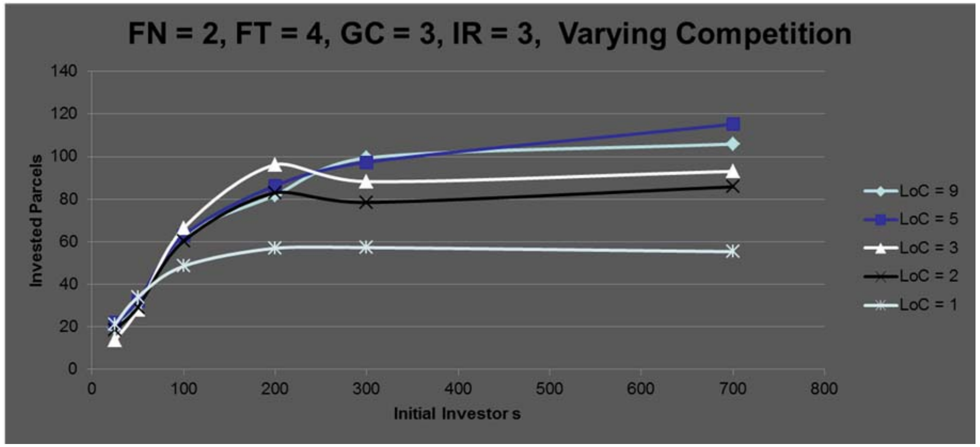
Considering the conceptual and stylized nature of this research, there is a great deal of opportunity to further this work. The most meaningful enhancement of the research presented in this paper will be to incorporate non-synthesized data to describe site favorability tied to a specific city as well as investor and investee decision-making behavior gleaned from interviews and surveys. These are the most significant factors related to the dynamics of localized GI investment. Further improvements of this work will be to capture the spatial and temporal behavior of local investments by taking advantage of the ability of ABM to express these dimensions. This will be done by consideration of using actual city parcel or property data (GIS-based) and placing realistic constraints on annual investments, which will allow for a more dynamic growth of invested parcels. Other future work may consist of:

- Vehicles for private investment in Tropical areas, such as micro-loans;
- Information dissemination on investment possibilities;
- Project aggregation limitations as informed by existing analogues (ESCOs);
- Tying “greened” scenarios to water quality improvements through water quality modeling; and
- Capturing advantages of private/local GI investment over public investment through Value For Money (VFM) analysis

6 Acknowledgments

The authors would like to acknowledge the efforts of Steve Scott and Drs. Thomas Arciszewski, Michael Casey, Mark Houck, and Barry Liner.

Invested Parcels vs. Initial Potential Investor Population with Varying Limits of Competition



Invested Parcels vs. Initial Potential Investor Population with Varying Growth Capacity

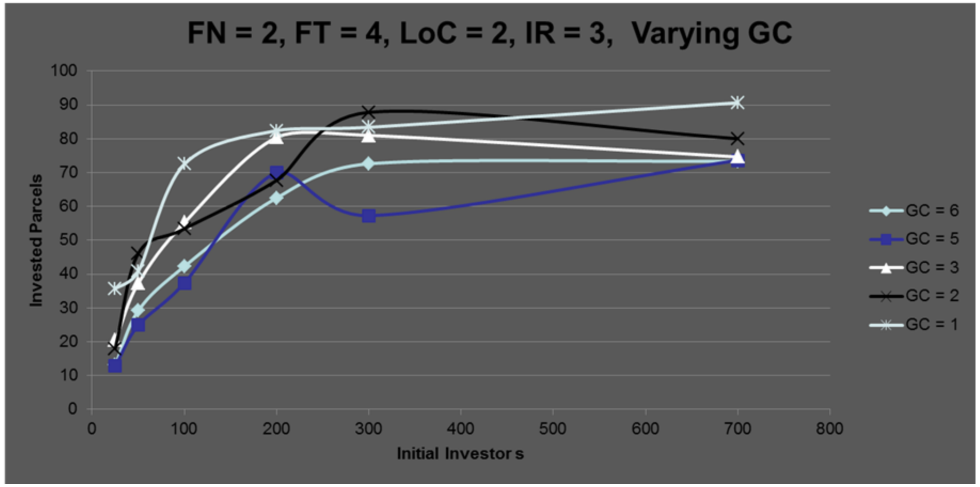
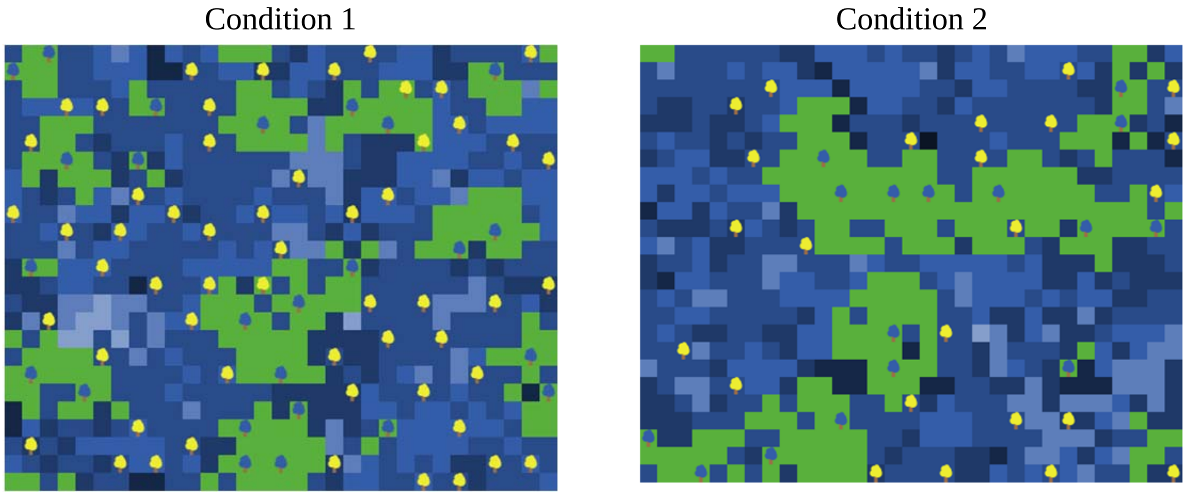


Figure 3: Model Output for Varying Limits of Competition and Growth Capacity (Brown, 2013)



Initial Conditions:
GC = 3, IR = 1, TU = 300, FT = 1, FN = 3, LoC = 1
Results: 189 invested parcels, 28 active investors

Initial Conditions:
GC = 2, IR = 2, TU = 50, FT = 1, FN = 2, LoC = 1
Results: 199 invested parcels, 16 active investors

Figure 4: Examples of Varying Green Infrastructure Connectivity (Brown, 2013)

REFERENCES

Aldous, D. E. (2010). "Greening South East Asian Capital Cities". 22nd IFPRA World Congress, 15-18 Nov, Hong Kong. Accessed November 3, 2013. Available online at http://www.lcsd.gov.hk/specials/ifpra2010/download/paper/david.pdf

Auer, K. and Norris, T., (2001). "'Arrieros Alife' a Multi-Agent Approach Simulating the Evolution of a Social System: Modeling the Emergence of Social Networks with 'Ascape'". Journal of Artificial Societies and Social Simulation. Vol. 4, No 1., Accessed November 5, 2013. Available online at http://jasss.soc.surrey.ac.uk/4/1/6.html.

Black and Veatch, (2013). "2012 Stormwater Utility Survey: A Black & Veatch Report". Black & Veatch, Overland Park, KS. Accessed November 2, 2013. Available online at http://bv.com/docs/management-consulting-brochures/2012-stormwater-utility-survey.

Brown, S. (2013). "Project Aggregation" Model posted at Netlogo Modelling Commons at http://modelingcommons.org/browse/one_model/3919#model_tabs_browse_applet

Casey Trees, (2002). "The Street Trees of Washington, DC: Structure and Benefits of Urban Forests", Accessed 10 January 2012, Available online at <http://www.caseytrees.org/ geographic/key-findings-data-resources/quantified-benefits/documents/ TheStreetTreesofWashington.pdf>.

Currie, B. A. and Bass, B. (2005). Estimates of Air Pollution Mitigation with Green Plants and Green Roofs Using the UFORE Model. Environment Canada - Adaptation and Impacts Research Group.

Gleick, P. (2009). "China and Water". The World Water Institute. Accessed November 8, 2013, Available online at: http://www.worldwater.org/data20082009/ch05.pdf .

Helbing, D. and S. Balietti (2011). "How to Do Agent –Based Simulations in the Future: From Modeling Social Mechanisms to Emergent Phenomena and Interactive Systems Design", Sante Fe Institute, Working Paper #11-06-024.

Kloss, C. (2008). "Green Infrastructure for Urban Stormwater Management." Proceedings: Low Impact Development for Urban Ecosystem and Habitat Protection. Seattle, Washington, November 16-18, 2008.

Kuchelmeister, G. (1998). Urban Forestry: Present Situation and Prospects in the Asia and Pacific region, FAO Asia-Pacific Forestry Sector Outlook Study, FAO Working Paper No: APFSOS/WP/44, Food and Agriculture Organization of the United Nations, Rome.

McKinsey Global Institute, (2010). "India's Urban Awakening. Building Inclusive Cities, Sustaining Economic Growth". Accessed November 3, 2013. Available online at http://www.mckinsey.com/mgi/reports/freepass_pdfs/india_urbanization/MGI_india_urbanization_fullreport.pdf .

McPherson, G. et al., (2005). "Municipal Forest Benefits and Costs in Five US Cities," Journal of Forestry 103(8):411–416, 2005. Accessed 10 January 2012, Available online at http://www.fs.fed.us/psw/programs/uesd/uep/products/2/cufr_646_Muncpl%20For%20 Bnfts%20Csts%20Five%20Cty.pdf.

S. R. Gaffin, et al, (2010). "A Temperature and Seasonal Energy Analysis of Green, White and Black Roofs", Columbia University, Center for Climate Systems Research., New York, NY., 2010. Accessed 10 January 2012, Available online at http://www.coned.com/ newsroom/pdf/ Columbia%20study%20on%20Con%20Edisons%20roofs.pdf.

Said, I. Universiti T.M. & Monsor, M. (2011). "Green Infrastructure in Cities and Towns in Southeast Asian Countries: Question for Research," In Second International Seminar on Sustainable Development. Johor, Malaysia: Universiti Teknologi Malaysia. Available at: http://www.medinanet.org/index.php/articles/uplanning/211-green-infrastructure-in-cities-and-towns-in-southeast-asian-countries-quest-for-research.

Singh, V. S., Pandey, D. N. and Chaudhry, P. (2010). "Urban Forests and Open Green Spaces: Lessons for Jaipur, Rajasthan, India". Rajasthan State Pollution Control Board, Occasional Paper No. 1/2010, 1-23.

United Nations, (2010). "World Urbanization Prospects: The 2009 Revision, Highlights". Population Division. Accessed November 28, 2013. Available online at http://esa.un.org/unpd/wup/Documents/WUP2009_Press-Release_Final_Rev1.pdf

Valderrama, A. et al., (2013). "Creating Clean Water Cash Flows: Developing Private Markets for Green Stormwater Infrastructure in Philadelphia", Natural Resources Defense Council, Philadelphia, PA. Accessed October 14, 2013. Available online at http://www.nrdc.org/water/stormwater/files/green-infrastructure-pa-report.pdf.

Vingarzan, R. and Taylor, B. (2003) Trend Analysis of Ground Level Ozone in the Greater Vancouver / Fraser Valley Area of British Columbia. Environment Canada – Aquatic and Atmospheric Sciences Division.

Wang, X.Y. (2009). "Comparative study of Chinese and foreign infrastructure investment and financing system." China Urban Economy, 8, 76-83.

Wise, S. (2007). Cities & Green Infrastructure: Examples from Chicago, Milwaukee, & Philadelphia. Center for Neighborhood Technology. Presented at U.S. EPA Wet Weather and CSO Technology Workshop Florence, KY, September 2007.

Wise, S., et al. (2010). "Integrating Valuation Methods to Recognize Green Infrastructure's Multiple Benefits". Proceedings: Low Impact Development 2010: Redefining Water in the City. San Francisco, April 11-14, 2010.