Investing in the Future

by Encouraging Energy Retrofit Decisions

BY

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THESIS

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TABLE OF CONTENTS

LIST OF ABBREVIATIONS

ABM	Agent-based model
ANT	Actor-Network Theory
ACEEE	American Council for an Energy-Efficient Economy
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BTO	Building Technology Office
DOE	United States Department of Energy
EEv	Energy Efficiency value
EIA	US Energy Information Administration
EPA	Environmental Protection Agency
ERI	Energy Rating Index
ESPC	Energy Savings Performance Contracting
ESCO	Energy Service Company
EUI	Energy Use Intensity
FEJA	Future Energy Jobs Act
GIS	Geographic Information Systems
IECC	International Energy Conservation Code
IoT	Internet of Things
LCA	Life Cycle Assessment
LEED	Leadership in Energy and Environmental Design certification system
NIER	Neighbor-Influenced Energy Retrofit agent-based model
NIR	Neighbor-Influenced Retrofit
NR	Normal Retrofit
NGO	Non-Governmental Organization
NREL	National Renewable Energy Laboratory
PACE	Property Assessed Clean Energy program
PHIUS	Passive House Institute U.S.
RECS	Residential Energy Consumption Survey
ROI	Return on Investment
UML	Unified Modeling Language
USGBC	U.S. Green Building Council
WEF	World Economic Forum

LIST OF FIGURES

LIST OF TABLES

SUMMARY

Cities with aging building stocks and budgetary challenges often have a high number of buildings in need of energy efficiency upgrades. Inefficient residential buildings have a higher energy consumption and its associated negative, unintended environmental and social consequences. One such social consequence is that higher portions of a resident's income is spent on energy costs. This burden is proportionally higher for low-income residents, which raises the importance of addressing this issue. Energy retrofits can mitigate these consequences, but small municipal budgets and capacity hamper such efforts. The split incentive problem in the multi-family residential sector, where owners incur the costs but tenants primarily benefit from the energy savings, poses additional challenges to energy retrofit efforts. This study employs qualitative interviews to explore how municipalities and nongovernmental organizations (NGOs) in Cleveland, Ohio, Detroit and Grand Rapids, Michigan incorporate strategies that leverage neighbor and network peer influences into their approaches to energy efficiency. These cities all have aging building stocks that are the legacy of a history with greater manufacturing employment. Selected interview findings were used to develop the Neighbor-Influenced Energy Retrofit (NIER) agent-based model to further explore the potential of peer influences within networks and among neighbors to amplify the motivation of multi-family residential building owners to reduce energy consumption through retrofits. The following insights emerge from NIER model: small neighbor peer groups successfully motivate different types of building owners to retrofit when there are also large financial incentives. Large peer groups, including a district approach, can achieve large energy efficiency gains in the population of buildings, but may not motivate all building owner types. The combination of a district approach with an approach of bringing buildings up to code at the point of sale can achieve energy efficiency gains broadly across different types of building owners. Planning and policy recommendations are produced from the insights from the NIER model and the interview findings. These are qualitative recommendations that aim to provide new solutions to the challenges that has hampered energy efficiency efforts among multi-unit residential buildings in the selected cities.

Key terms: Agent-based modeling, combined research methods, decision-making, energy efficiency, energy retrofit, multi-unit residential, qualitative research, sustainability

1.0 INTRODUCTION

1.1 Research Problem

The interviews conducted in this study highlighted the reasons that existing approaches to energy efficiency experience challenges in the multi-unit residential sector. Due to the problem of split incentives between owners and tenants, multi-unit residential building owners are not fully receptive to traditional energy efficiency incentives. This research has also found that different types of building owners respond to traditional approaches that are not what would be expected if they were viewed as rational actors. Kontokosta found that multi-family residential buildings owned by individuals or small groups are more likely to implement an energy retrofit than corporate owned buildings (Kontokosta 2016, 12).

While a rational actor framework predominates in approaches to motivating energy retrofits among building owners, the literature has recognized the influence of other factors such as psychology and socio-technical systems (Sorrell 2015), the visibility of the component to be retrofitted (Berkeley Zero Net Energy++ Working Group 2016), ownership type and the economics of the real estate market (Kontokosta 2016), In cases where owners incur the costs, but the tenants reap the benefits of energy savings, which is common in multi-unit residential buildings, split incentives between the owner and tenants can lead owners to perceive even fewer benefits for the cost of investment. These issues of motivation on the micro-level, either the individual building owner or the ownership management group, can lead to macro-level problems of achieving desired rates of energy efficiency in aging, multi-unit residential building stocks.

Municipalities often collaborate with NGOs to implement the energy efficiency strategies identified in their Climate Action and Sustainability Plans. Despite these collaborative efforts, there remains a gap in planning for energy efficiency between the identification of the targets to be achieved and the investment that cities put into programs to achieve those targets (Aznar et al. 2015). Inadequate and inconsistent funding to address the scope of the problem have been noted as causes for this gap (Interview 013, Nov. 15, 2017; Interview 011, Dec. 6, 2017). This has resulted in disjointed efforts and lack a cohesive institutional structure that governs how public and private entities, municipalities and NGOs, plan energy efficiency efforts within a city.

The energy savings from upgrading older building stocks are significant and the need for reducing energy consumption from buildings is becoming more important as the electricity demand is expected to increase with the adoption of technology relating to the internet of things (IoT) and electric vehicles (Buildings Technology Office (BTO) 2016, 127). More needs to be done to leverage behavioral dynamics in energy efficiency decisions. Currently, research on behavioral approaches predominantly focus on modifying energy consumption behaviors, with little attention paid to behavioral dynamics in energy retrofit decisions.

This trend is starting to change as municipalities and NGOs start to incorporate social incentives into their building retrofit strategies. The approaches taken to encourage energy retrofits in the multi-family residential sector are based in normative understandings of which factors building owners value and which motivate them. While research specific to energy retrofits in multi-family buildings is emerging (D. Philbrick, Scheu, and Brand 2016), bridging the split incentive problem and motivating deep retrofits among multi-family residential building owners remains a challenge (Berkeley Zero Net Energy++ Working Group 2016). This study will contribute to the literature on energy efficiency related planning and policy by increasing the understanding of how municipalities and NGOs leverage neighbor and network peer groups to influence building owner retrofit decisions and how building owners perceive and respond to such approaches.

1.2 Research Question

How do municipalities and NGOs effectively leverage neighborhood and network peer influences to motivate multi-unit residential building owners to invest in energy efficiency retrofits?

While this research question is contextualized within the literature on energy efficiency, the question can be rewritten to reveal the social dynamic that can be tested in other contexts (see Figure 1): *How can we convince people to do the right thing for the environment?*

L1: How do [municipalities and NGOs] effectively [leverage neighborhood and network peer
L2: How can [we] [convince]
L1: influences to motivate] [multi-unit residential building owners] to [invest in energy
L2: [people] to [do the right thing
L1: efficiency retrofits]
L2: for the environment]

Figure 1: Research question and social dynamics question

The complete research question includes factors that can vary by municipality, social context, building sector, and energy efficiency approach. Figure 1 demonstrates the importance of describing the underlying social dynamic (L2) of the research question (L1) because this is the core dynamic that connects all of the parts of the first question into an integrated whole.

This project explores how municipalities work with NGOs to improve the energy efficiency of their respective multi-unit residential building stocks through approaches that motivate owners to invest in energy retrofits. The first round of interviews identified an organization that works with building owners to reduce energy consumption. The organization is called a 2030 District. This organization diverges from traditional approaches to reducing energy consumption that are common to municipalities, such as encouraging energy efficiency by the different building sectors: commercial, industrial, municipal, residential. The 2030 District, by contrast, defines a geographical area of the city, typically a downtown area, and engages all building owners within that defined area, called a District, to encourage energy efficiency. Such a spatial approach increases the possibility of information sharing between building owners. The macro-effects of encouraging micro-interactions between building owners has not been fully studied.

This research contributes to the understanding of how the social dynamics influence building owner energy retrofit decisions. The qualitative findings from the interviews are further explored through agent-based modeling to better understand the possible outcomes of micro-interactions between building owners throughout a large population of multi-unit residential buildings.

1.3 Significance of the study

This study contributes to the literature on urban planning and policy relating to energy efficiency retrofits. The methodological significance is the combination of qualitative methods and agent-based modeling to produce insights into energy retrofit decision-making across a large population of multi-unit residential building owners. The theoretical significance is a more robust understanding of the role of peer influences upon investment decisions in energy retrofits, which is an area of study that has mostly been explored through a rational actor framework. The qualitative findings have been formulated into planning and policy recommendations.

2.0 BACKGROUND: PLANNING APPROACHES TO ENERGY EFFICIENCY

2.1 Conceptual framework

The framework for this study encompasses the approaches taken by municipalities and organizations to work with multi-family residential building owners to achieving energy efficiency. It explores their goals, methods, and the assumptions embedded within these approaches. This study is particularly interested in exploring approaches that would be effective in cities challenged with aging building stocks and budgetary challenges and have the potential to bridge the split incentive problem between owners who incur the costs of retrofits and tenants who would receive the gains from lower energy costs.

This is an exploratory study to generate qualitative insights on energy efficiency approaches in the context mentioned above. It is not intended to be a case study, nor an empirical study of specific strategies in a city. Approaches to energy efficiency are explored in different urban contexts (Cleveland, Detroit, and Grand Rapids) because the objective is to understand them as ideal types, while recognizing that they are social constructs that are created and have meaning in context. The concept of the 2030 District overtly recognizes this distinction. The District allows for each local context to employ the particular tactics that would be the most effective with their members, but the overall strategy is the same – taking a spatial approach in working with all building owners within a defined area regardless of building type.

While ideal types are useful constructs to help us identify which approaches should be strengthened and which create negative unintended consequences, Bruno Latour reminds us that such constructs, including scientific facts, are social (Latour and

Woolgar 1986). The social is a product of associations and networks not only with people, but also with technology and other artifacts (Latour 2005). Latour proposes an Actor-Network-Theory (ANT) that incorporates network interaction through such artifacts. Theorizing the influence of networks through existing infrastructure, organizational structures, and technology adds to the understanding of network effects during moments of change as structures are slower to change. Recognizing that institutions are made up of a set of practices by agents and distinguishing the practices that constitute and self-reinforce institutional structures from practices that are based in local context. For example, what is meant by a city having a 2030 District is, in practice, a series of meetings with participation rates, outreach to building owners, the sharing of specific information, et cetera. Then, each of these elements can be described as to how they contribute to the formation of an institutional structure.

ANT becomes a useful conceptual tool in understanding the influence of peer groups. Given this study's focus on how building owners respond to contextual norms that are set by their neighbor or network peer groups, known energy efficiency information, such as certifications, or energy benchmarking data, can itself impart an effect upon building owners. Latour's ANT theory accounts for these types of influences. Thus, the qualitative portion of this study contributes to Actor Network Theory by exploring how stakeholders make meaning throughout the energy retrofit decision-making process and the effect of the network structure of the 2030 District upon assigned meanings.

The work on the decision-making process contributes to the Choice Architecture by exploring how the organizations shape building owner decisions to nudge them towards an energy retrofit (Thaler, Sunstein, and Balz 2012). The behavioral aspects of decision-making are based in the concepts of cognitive biases and heuristics (Kahneman 2011). This study contributes to the behavioral literature on decision-making.

2.2 Related fields of study

2.2.1 Energy efficiency measurements

There is an expansive literature on relevant measures for assessing energy efficiency. Perez-Lombard et. al. (2009) provide a comprehensive overview of measures as they relate to energy efficiency classification. With respect to multi-family buildings, the appropriate measure should have two primary characteristics:

- Ease of calculation. The assessment of the measure should be widely applicable to buildings in varying conditions.
- Actionable output. The measures for energy consumption should easily inform the building owner where improvements are needed and what can be done to improve energy efficiency.

The majority of measures discussed by interviewees in this study discussed energy use intensity (EUI). This is a basic calculation of building level energy consumption per square foot per year (US EPA 2019). It provides a general understanding of energy efficiency level because it does not account for unit occupancy rate or the number of individuals within a household, which are both significant measures for multi-family residential buildings. The EPA uses EUI as a basis for its Energy Star Rating, which assigns a value from 1-100 representing energy efficiency (Energy Star, n.d.). Building EUI data is reported in a system called Portfolio Manager. For buildings that have not been assigned an Energy Star Rating, this system allows the calculation of EUI data that is normalized for weather during the year.

Other measures are more accurate. EECalc is an energy calculator that was developed by Argonne National Laboratory in collaboration with the Georgia Institute of Technology for the Chicago Loop Energy Efficiency Retrofit project (Guzowski et al. 2014). It is an energy modeling methodology that requires a relatively low level of effort and provides an energy usage by fuel type and specific end uses. Tools such as EECalc can provide ways for building owners to get accurate, actionable data without the cost and effort of a full audit.

The rationale for pursuing energy efficiency determines the measure(s) that are selected for use. For example, ASHRAE level 3 uses life cycle assessment (LCA) for major capital improvements (Detroit 2030 District 2018). LCA measures the energy used (or emissions) within a boundary of the life cycle that includes materials, construction, transport and disposal (i.e. cradle to grave; cradle to gate) (Baumann and Tillman 2004). This rationale for measurement would more appropriately use the concept of embodied energy, which includes the energy put into the product's lifecycle (Jarvis 2018). Embodied energy is also being promoted by 2030 Districts.

Another measurement that uses embodied energy is Energy Return on Investment (EROI). This is a way of calculating energy consumption and efficiency within an entire system and can include growth and infrastructure (Jarvis 2018).

It is important to apply the appropriate measure for the purpose because internal differences could be masked. For example, a simple EUI that does not account for occupancy could mistakenly value low occupancy buildings as more efficient than high occupancy buildings. Approaches to upgrade buildings that are inefficient due to gaps in the building envelope, or inefficient heaters, for example would be different than approaches that seek to reduce the operational energy use of buildings. This latter point is a significant issue as occupants use more electronic devices with the Internet of Things (IoT) and shift to electric vehicles.

Motivations to mitigate environmental and health consequences from energy generation require measuring efficiencies in energy generation as well as efficiencies in energy consumption. This would account for urban growth and increases in behavioral energy use. The LEED rating system seeks to account for multiple dimensions of building sustainability. Though it received criticism in the way it calculates values, it does provide a method for assessing buildings across multiple criteria.

Despite the multiple measures, none of the municipalities included in this study had adequate data on multi-family residential buildings to use in designing energy retrofit approaches. There is a need for better data of the residential sector in general. This is more likely to be simplified energy consumption estimates based on virtual energy assessments or models that can be calibrated with specific inputs.

Energy Benchmarking ordinances is one way of requiring reporting, even if they start with buildings of a particular square footage. None of the cities in this study have a benchmarking ordinance. At this point, reporting in Energy Star's Portfolio Manager is voluntary. Benchmarking ordinances can make energy consumption data publicly available and provide useful insight (City of Chicago 2018). While competitions like the Battle of the Buildings encourage voluntary reporting, the buildings that are least likely to participate are often those that need retrofitting (Energy Star 2015). In cases where those who would benefit most from a retrofit, do not voluntarily participate in energy reporting, both carrot and stick approaches to energy efficiency, such as combining incentive programs with energy benchmarking, can improve the available energy consumption data.

This study focuses on retrofit decision-making and how key decision-makers use and share energy-related information. While many of the energy efficiency measures described above were mentioned by the interviewees in this study, some decision-makers can weigh the same information differently than others and may include information that others don't consider. Thus, a general measure called Energy Efficiency Value (EEv) will be used by the NIER agent-based model presented in Chapter 6 to account for the diversity in the information that is important to building owners, municipal and NGO decision-makers in choosing a retrofit. Further research can inform how these decision-makers perceive energy-related information and use that information in their respective decision-making processes.

There is a growing literature connecting data on energy to other datasets such as health and economic productivity, but energy retrofits remain siloed in energy planning or energy engineering fields. There is an analogous struggle with integrating concepts of sustainability into all aspects of building design and construction. Contributions to the literature on energy efficiency and energy planning would include a better understanding of the role of social factors and influences upon energy related investments and, in turn, the impacts of such investments upon society.

2.2.2 Decision-making

"Fluid decisions made today solidify into the fixed built environment of tomorrow" (Zellner and Campbell 2015)

Studies on decision-making have long recognized the influence of factors other than individual benefit cost calculations. This is especially true for consumer products and services (Hill, Provost, and Volinsky 2006). Nonetheless, the idea that consumers are rational actors who objectively weigh the value and benefits against the cost has become normative. In microeconomics, it forms the basis for the assumptions about how potential consumers will behave. Thus, models of rational actor behavior form an ideal type, a theoretical ideal that guides action, and can be seen throughout many incentive programs, from retirement savings to energy retrofits.

However, research has found that decisions are influenced by emotion and heuristic devices (Kahneman 2011), environmental cues (Thaler, Sunstein, and Balz 2012), language and meaning in social context (Latour 2005; Latour and Woolgar 1986). In addition to the factors included in microeconomic models of decision-making, there is increasing recognition of the role of collective influences upon decision-making. Collective influences recognize that individuals are based in networks that provide meaning (Latour 2005). This is the sociological basis for the effect of peer networks. Participation in networks have been shown to have a direct positive effect upon product adoption (Hill, Provost, and Volinsky 2006).

While there has been much work in helping guide action on city-level and multi-family decision-making (Aznar et al. 2015; D. Philbrick, Scheu, and Brand 2016), more research needs to be done to understand how building owners perceive and respond to these approaches. Understanding decision-making processes has an increased significance in the building investments due to the long-term implications. Energy efficiency decisions in buildings get locked in for the lifespan of the components, which can range from 10 years for HVAC systems to the life of the building for the façade.

Some building owners perceive risk in large-scale investments if they are unsure whether they will see a financial return on their investment. Helping owners understand the return on investment over time can influence their energy efficiency decisions (Heo et al. 2015). The owner's confidence that they will get a return on investment is significant for decision-making because individuals weigh potential losses much more heavily than potential gains (Kahneman 2011). For example, one of the reservations that building owners have about participation in energy efficiency programs is the fear of liability for something in their building that is discovered through the process. The way costs are presented also has an impact on understanding risk. In the case of photovoltaic technology adoption, when potential consumers were presented with different ways of viewing costs, adoption rates increased (Drury et al. 2012). While analyses of multi-criteria decision-making can include many potentially significant factors, how these factors are framed becomes significant.

Issues of energy efficiency are framed in multiple ways, each based in a disciplinary approach (Sorrell 2015). Emerging work shows the role that social norms play in framing benefits and costs, including which factors are considered significant.

The respect that individuals have for the experts shapes how they value the knowledge that is conveyed (Zellner et al. 2014). The value that is given to expert knowledge is weighted differently based on whether the information comes from someone perceived as similar (Siciliano 2017). Consumer research also has a term, Influencer, that can also apply in retrofit decisions as technology adoption. Shalev and Morwitz (2011) found that as long as there is a recognition of similar social status, those identified as Influencers can increase the uptake of new products by making the majority of conformists question remaining with an old product.

Building owner decision-making has been based in their understanding of the cost savings from energy efficiency, the amount of initial investment and the time for the return on investment and their understanding of the motivation to prioritize an energy retrofit over other investments (Berkeley Zero Net Energy++ Working Group 2017). The effectiveness of these social/cultural aspects has not been well explored in the literature.

2.2.2.1 Energy retrofits as consumer behavior

The effect of consumer behavior dynamics upon energy retrofit decisions require further study. The role of consumption in energy has primarily focused on energy usage (Opattern 2019). Research on consumer behavior regarding the long-term investment implications of energy retrofits needs to further explore how consumers interpret value through discount rates and investment risk. A reasonable return on investment would not motivate the decision to retrofit if the potential consumer is not able to make meaning from that information. The work of Brent and Ward (2018) found that financial literacy is positively correlated with choosing an energy consumer durable with the lowest discounted costs over its lifetime. Thus, financial literacy is itself a factor that influences energy efficiency investment decisions. This finding supports the idea that educational approaches with building owners can yield results with retrofit decisions.

One study of retrofits among multi-family residential buildings in Chicago found that for the same cost of retrofit, a building in the Lincoln Park neighborhood would raise its market value by $335,000, whereas the same cost of retrofit in the Austin neighborhood would only raise the value by $12,000 (D. Philbrick, Scheu, and Brand 2016, 20). This kind of finding would imply that assuming a building owner is a rational actor assessing financial information, the net benefit (perceived benefit minus cost) would be significantly different based on housing market dynamics in a neighborhood.

With so many tools for assessing energy efficiency and so many financial incentives from different sources, the role of an organization, and the good facilitators who work within those organizations, is to narrow the options. Building owners can be deterred from making a decision to retrofit by the lack of guidance to navigate the sheer number of options. The act of narrowing options is an aspect of Choice Architecture that facilitates taking a decision (Thaler, Sunstein, and Balz 2012).

2.2.2.2 Social and spatial factors influence decision-making

The role of social factors in technology adoption is understudied. The contexts in which social factors play a role and the extent of the influence in altering traditional benefit cost calculations is being increasingly studied but is not yet normative. In a study on energy retrofit decisions, Constantine Kontokosta concludes that ownership type, tenant demand and spatial factors influence decision-making (Kontokosta 2016, 12). Ownership type looked at the effect of individual as opposed to corporate ownership and found that corporate-owned buildings are less likely to decide to retrofit. Spatial influences is defined as region and market location of the building (Kontokosta 2016, 4). Spatial market dynamics were also found to have a statistically significant influence upon retrofit decisions.

The literature on behavior and decision-making have been applied in studies of energy consumption, but not often to retrofit or infrastructure investments. Infrastructure and building investment decisions are similarly influenced by positive and negative reinforcement and is significant given that those decisions have a longer impact than behavioral energy use decisions. Prospect Theory proposes many insights that are relevant to energy decision-making, including that individuals weigh perceived negative consequences more than perceived benefits (Kahneman 2011). Another relevant insight from Prospect Theory is that individuals make decisions on complex issues based on heuristics, not by weighing the various benefits and costs. These two insights are examples of significant aspects of decision-making that are not addressed in how municipalities and NGOs convey the benefits of energy efficiency retrofits to building owners.

There is increasing literature on decision-making for energy consumption, but more is needed about the process building owners use to weigh behavioral factors, such as the influence of neighbor peer groups, and how they prioritize those factors alongside others. This is especially relevant for building owners in areas with limited resources.

Many Leaders, those who are inclined to implement sustainable technologies even if costly, have the resources that enable them to think about such investments. Building owners in low-income areas provide a challenging context that reveals the decision-making process.

Micro-level decisions have macro-level impacts. Much of the research and subsequent literature remains siloed to very narrow decision-making processes. However, as sustainable approaches become increasingly normative, more research into the nexus between energy and other systems, such as water, will need to be conducted (Lehmann 2018). Further, the effect of global efforts, such as the United Nations' Sustainability Goals upon municipal decision-making also requires further study (UNDP 2018). This is especially the case if the role of the federal government diminishes and municipalities look more directly to global models to shape local energy efficiency efforts.

2.3.3 Municipal rationale for pursuing energy efficiency

The resources that municipalities allocate to energy efficiency are shaped by their rationale for pursuing energy efficiency. Cities are increasingly allocating resources and staff capacity to addressing sustainability issues. Many are establishing sustainability departments and hiring energy managers. The recent focus of cities to reduce their carbon emissions has led to the formulation of Climate Action Plans. Cleveland, Detroit and Grand Rapids all have a document that outlines their energy efficiency efforts and the underlying rationale (City of Cleveland 2015; Detroiters Working for Environmental Justice 2017; Grand Rapids, City of 2016). The state of Michigan also had its own

Climate Action Plan (Michigan Climate Action Council 2009). Detroit just published its Sustainability Action Agenda in June 2019 (Detroit, City of 2019).

NGOs play a key role in collaborating with municipalities to achieve the energy efficiency goals for their respective cities. NGOs support municipalities in multiple ways, from increasing interaction with building owners, disseminating information and training on sustainability, increasing access to resources and often function as an umbrella organization bringing together public and private entities to facilitate energy retrofits. They also work collaboratively with municipalities to establish new organizational arrangements to help building owners invest in energy retrofits. However, many of these arrangements are relatively new and have not been fully embedded in institutions. The NGOs included in this study range from one to seven years of operation.

The National Renewable Energy Laboratory (NREL) research on energy planning found that city staff identified a lack of standardization in measuring impact and prioritizing actions as an obstacle to energy decision-making (Aznar et al. 2015) These metrics are important for measuring progress and providing updates to the energy reduction components of climate and sustainability action plans (Aznar et al. 2015, p.viii).

Collaborations with NGOs are not fully integrated into municipal planning efforts. These collaborations are often disconnected, lack data sharing and coordination, but they present an opportunity to address the challenges of taking action towards the goals in their sustainability documents. Finding a way to implement sustainability in infrastructure is a key issue because infrastructure, according to Bobylev, is "key for urban sustainable development" (Bobylev 2009). The types of infrastructure investment can significantly influence the energy consumption and associated environmental and social impacts of a city. Infrastructure investment can either help the city meet sustainability goals or lead to locked in rates of increased in energy consumption over the long term.

Weak and inconsistent enforcement mechanisms create challenges to coordinating energy efficiency efforts. This increases the need to maximize the voluntary efforts. In Illinois, regional governmental organizations like the Metropolitan Mayors Caucus help to coordinate these efforts. They have produced a document, the Greenest Region Compact (GRC2), to provide guidance on a regional level (Metropolitan Mayors Caucus 2017, 2). The aim of the document is to help coordinate municipal efforts, which is especially important in regions that have a history of municipalities reluctant to work with each other. While the aim can help steer the region towards more sustainable decisions, the work is in implementing the compact to make the big changes that are needed in the short term (Interview 007, Jul. 10, 2017). Just as building owners face other priorities that compete with energy efficiency, decision-makers in municipalities are also faced with other priorities that they may perceive as more pressing, due to public or political pressure, or that are more in line with how they envision the future of their respective cities. Based on these different inputs, the image of the future that emerges will likely depend upon the nature of the coordination between municipalities and other levels of government, NGOs, and private entities.

More work needs to be done to understand challenges to implementation specific to major municipal investments, such as building stocks and infrastructure. Just as this study explores the behavioral effect of neighbor peer groups upon energy retrofits in buildings, similar research on behavioral effects of different social factors should be further studied as they pertain to municipal decision-making.

3.0 METHODOLOGICAL APPROACH

This study uses qualitative and computational methods to gain a broad understanding of approaches that municipalities and organizations are taking to energy retrofits. The initial aim of the study was to understand how municipalities pursue energy efficiency. The methodology of this study takes an inductive approach to gathering data through exploratory interviews, as seen in Figure 2. The second round of interviews include semi-structured interviews exploring how municipalities and non-governmental organizations (NGOs) in Cleveland, Detroit, and Grand Rapids encourage energy efficiency and leverage social incentives among multi-unit residential buildings.

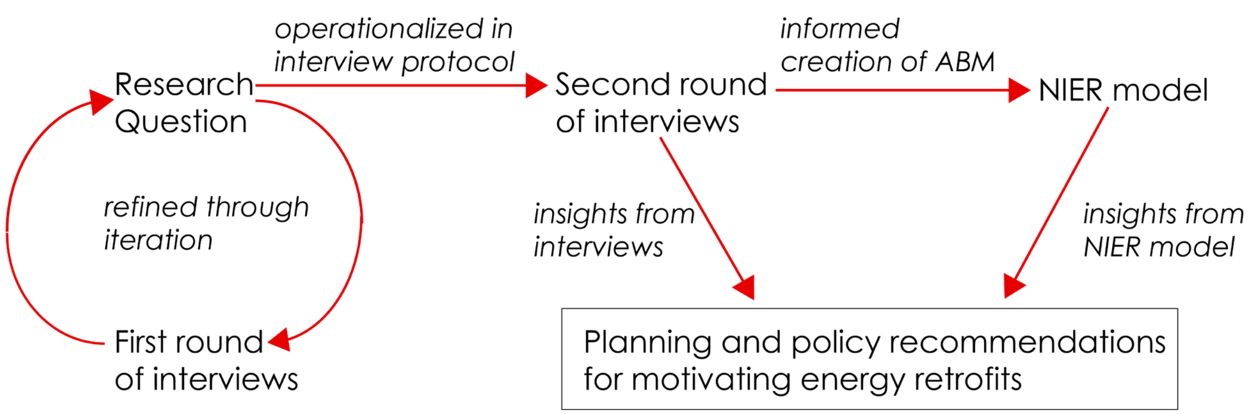

Figure 2: Methodological approach

Interview findings were then used to develop an agent-based model to further explore the approaches mentioned and the possible outcomes if municipalities and NGOs successfully implement what they claim in the interviews. Planning and policy recommendations that emerge from the findings are presented throughout the text and summarized at the end.

3.1 Object of study

The object of study is the approach taken to motivate multi-family residential building owners to invest in an energy retrofit.

This study focuses on the role that municipalities and non-governmental organizations perform in planning that motivates energy retrofits. The findings presented are those that have been raised in multiple interviews in this study. This is method of pattern analysis that increases the likelihood that the factors and dynamics highlighted have a wider applicability (Becker 2017; Weiss 1994).

3.2 Study Design and procedures

3.2.1 Site selection

The criteria for selecting cities to be included in the study were that they had aging building stocks (one of the defining features of Legacy Cities) and a 2030 District. While the original intent was to include cities that had to upgrade aging building stocks, but had limited municipal budgets, Grand Rapids was included because they had a 2030 District. The City of Grand Rapids has been fiscally solvent every year since 2014 (Grand Rapids 2018). Although initially considered, the cities of Chicago, IL and Gary, IN were excluded from the study due to there not being an established 2030 District. Potential subjects from Gary also did not agree to participate in the study. All of the participating cities are in the Midwest and have an industrial legacy, in which they experienced the loss of manufacturing employment and population.

The table below highlights some characteristics of the residential building sector in the respective cities.

City	Housing units	% built 1940-1969	% built before 1939	% vacancy
Cleveland, OH	211,902	30.9	53.7	20.5
Grand Rapids, MI	79,785	35.4	37.3	8
Detroit, Mi	364,900	53.2	34.4	29.2
Chicago, IL	1,200,305	31.1	43.1	12.8
Gary, IN	43,053	26.8	60.8	19.2

Table 1: Housing stock data for selected cities.
Source: (US Census Bureau 2019)

As seen in the table above, all cities have a significant portion of the building stock that is over 50 years old. The age of the building stock is used here as a proxy for the potential need of an energy retrofit. The existing condition of those buildings depends not only on age, but also on how well they have been maintained in the years since construction. However, given the high vacancy rate and that each of these cities have gone through a period of economic downturn, an assumption can be made that there is a wide range of conditions with regards to energy efficiency. Each of these municipalities had mentioned that they are working on compiling a current energy efficiency profile of their building stocks, as of the time they were interviewed.

Pursuing energy efficiency in the multi-family building sector is not only pursued for energy savings, but also as a strategy for maintaining the building stock. Detroit has a land mass greater than Boston, San Francisco and Manhattan combined, without the municipal budget to maintain that expansive infrastructure. The Detroit Climate Action Plan has a section devoted to housing. It identifies 69% of occupied residential buildings having been built on or before 1979, with 12.6% on or before 1939 (Detroiters Working for Environmental Justice 2017, 54). The report views energy efficiency as a strategy to maintain this aging building stock.

3.2.2 Selected participants

3.2.2.1 Inclusion criteria

The criteria for identifying potential subjects to participate in the study is their role in providing some decision-making function relating to either municipal or organizational approaches to energy efficiency or to building-level energy retrofit decisions. Snowball sampling methods were used to identify approximately a third of the subjects interviewed. Potential subjects identified for cold call (unsolicited email and phone call outreach) had at least one of the following criteria:

- Work directly on energy reduction measures.
- Make decisions affecting investment or implementation of energy reduction measures.
- Are able to speak about the issues of implementation with regards to energy reduction measures.
- Are able to speak to policy or implications energy reduction measures.

Interview participants were determined based on three factors: location, network, and position. Potential subjects within Cleveland, Grand Rapids and Detroit who met the criteria were identified and invited to participate in the study.

3.2.2.2 Subject enrollment

Most of the potential subjects were invited to participate in the study through direct outreach, first by email and subsequently by phone. They were identified based on their job position and membership in the selected municipality or organization. Nearly a third were recruited through follow up interviews were conducted with those they recommended, a form of snowball, or convenience sampling (Weiss 1994). Four interviews were scheduled as a result of face-to-face meetings at a Detroit 2030 meeting focusing on multi-unit residential buildings.

Out of approximately 40 requests for interviews, 30 interviews were completed (12 first round, 18 second round). The 18 second round interviews included 21 interviewees. The majority of failed interview requests were municipal employees from the city of Gary, Indiana, which led to that site being dropped from the study. The initial aim for the study was to enroll 5-10 subjects from 3-5 cities, which has been met for Cleveland and Detroit, but only 3 interviewees were able to speak about efforts in Grand Rapids.

Building	Municipality	2030	NGO	Total
4	4	3	7	18

Table 2: Second round of interviews by interviewee association

3.3 Interview instruments

Two questionnaires were developed for the first two phases of this study (see Appendix 13). The initial questionnaire was used in the first round of interviews and is composed of open-ended questions to inform two areas of research: 1. decision-making on approaches to energy efficiency and 2. the implications of energy efficiency planning within municipalities. In-depth interviews with open-ended questions were used to design the questionnaires given the exploratory nature of the study. Open-ended and semi-structured questions of personal and organizational decision-making and behavior can reveal new ideas and details that may not have been included in the original research design (Babbie 1998).

After analysis of the first set of interview findings, the research design was adapted to explore the municipal collaboration with 2030 Districts and their outreach to building owners. A second questionnaire was developed (see Appendix 13.1), which also utilized open ended and semi-structured interviews. This questionnaire was used for interviews 14-28. Interviewees represented the municipalities, energy efficiency related organizations and those who could speak to building owner preferences. The second questionnaire allowed for contextually specific follow-up questions.

3.4 Exploratory interviews contribute to research design

The data collected from qualitative interviews were highlighted when evidence of patterns emerged identifying that feature, or dynamic, across multiple interviews. Evidence is then matched according to existing theories, or if incompatible, contribute to the formation of new ideas. This model of inquiry results in an iterative process where the research design evolves to capture the meanings that emerge from the study participants (Becker 2017).

The initial interview protocol focusing on municipal and organizational approaches to energy efficiency was designed as an exploratory study. The questions regarding the effects of the approach taken by the 2030 District emerged from the first round of interviews and led to the design of the second questionnaire to further understand that approach. The findings from the second round of interviews, which now included the Directors of the 2030 District among the interviewees, were used to inform the development of an agent-based model to explore the strategy of that approach in the context of different policy scenarios.

4.0 FINDINGS FROM THE FIRST ROUND OF INTERVIEWS

The first round consisted of exploratory interviews that helped to define the object of study. It consisted of 12 interviews with individuals from governmental agencies, sustainability organizations, and a utility. These interviews explored how energy efficiency in buildings was approached as a component of broader sustainability goals and how municipalities collaborated with others to define and achieve their goals.

4.1 Drivers of sustainability

An early focus of this study identified who drives sustainability plans. The purpose was to identify who has a voice in defining energy-related sustainability goals and who is responsible for their implementation. The initial interviews with government agencies and quasi-governmental organizations highlighted the role of collaboration in defining sustainability goals, from municipal sustainability plans, to regional sustainability plans, like the Greenest Region Compact 2 (GRC2).

Municipalities are collaborating to develop platforms that can gather and analyze data to assess existing conditions. However, these are often voluntary and lack enforcement or municipal capacity to verify and assess the data reported. Utility companies, on the other hand, are mandated by their respective states to spend the money they earn through a fee to customers on energy efficiency programs. They are also internally driven to increase service reliability by reducing the amount of time energy demand exceeds peak capacity, requiring more expensive and polluting energy plants to come online and supply the difference. Approaches to working with building owners to improve building energy efficiency are commonly parsed by sector (i.e. commercial, industrial, municipal, residential). This parsing is for good reason given the specificities of each building type, but it requires both the capacity and targeted strategies that would be effective in each sector. Municipalities collaborate with organizations to fulfill this capacity gap.

4.2 The role of municipal-organizational collaboration

By recognizing the role that energy- and sustainability-related organizations play in providing municipalities with the capacity they need to implement energy efficiency approaches and achieve their sustainability goals, additional non-governmental organizations (NGOs) were identified. NGOs provide capacity, resources, and are able to apply for funding to implement the energy-related work. NGOs fill a market niche in energy efficiency in areas where the municipality does not have the budget or capacity to perform (Interview 013, Nov. 15, 2017). In another sense, NGOs expand the range of actions and types of services beyond what the municipality would offer if it did have capacity (Interview 018, Dec. 21, 2017). They also serve a facilitator role between municipalities, building owner associations, and utilities.

Municipalities are also working with organizations to support programs that leverage peer influences. The City of Cleveland has a Sustainable Municipal Buildings Policy that describes two approaches the city has taken that involve information sharing among building owners to improve energy efficiency (Sustainable Cleveland 2013): the Better Buildings Challenge, and the establishment of a 2030 District.

The Better Buildings Challenge was an approach taken by the DOE during the Obama Administration to provide a status incentive for improved energy efficiency (DOE 2019a). It asked for a commitment of a 20% reduction in energy consumption between 2010 and 2020 and required the reporting of energy data along with the strategies taken. Following the conclusion of the Better Buildings Challenge, an analysis can be made of the energy savings associated with each strategy and can help to identify the most successful approaches. However, after multiple requests, the author has found that as of April, 2019, the energy data for this time frame has not yet been made public. This highlights the disconnect municipalities sometimes experience with utilities, which can be due to the availability and quality of data they collect. Utilities are in the process of implementing upgraded technology, including smart meters that can collect more complete and accurate energy consumption data.

In 2012, Cleveland established a 2030 District to work with all building owners in a defined downtown area (Sustainable Cleveland 2013). It subsequently established a second district in University Circle (Cleveland 2018). In August, 2018, Cleveland was also host to the DOE’s Energy Exchange and Better Buildings Summit (DOE 2018), which also hosted trainings. Thus, while there is much emphasis about enabling local capacity to achieve energy efficiency, there is a role for State and Federal support, especially where capacity is limited.

Despite the municipality having authority over regulatory matters, one sustainability department saw themselves as only working on incentives, without any enforcement mechanism:

> *Right, and so we don't have a stick yet in the city. We only have carrots, because again the stick would only come based on compliance I guess -- full compliance and also other things that are more concerned, like safety issues at this point. So yeah that is something we've not been able to do yet from an efficiency perspective. There are also other issues that have dominated the scene in terms of more the priority. Yeah.* (Interview 027, Jan. 25, 2019)

The budgetary challenges of cities like Cleveland and Detroit constrain their respective capacities to fully implement their desired energy efficiency approaches. Such cities also have multiple, competing priorities that further pull from that limited capacity. Multiple interviewees stated that collaboration with NGOs can supplement that limited capacity and hold the potential to bring additional resources to tackling energy efficiency.

4.3 2030 Districts: a spatial approach to motivating energy retrofits

One type of NGO that emerged from the exploratory interviews became a central focus of the second round of interviews. The 2030 District is an NGO that seeks to achieve energy reduction goals by encouraging networking and the sharing of information between building owners within a defined area. This is novel in that it crosses building sectors. Traditional approaches to energy efficiency targets commercial, industrial, municipal, and residential buildings separately. This brings a spatial approach to engaging building owners, which raises the planning questions explored through the second round of interviews and agent-based modeling.

The recent focus of cities to reduce their carbon emissions and the emergence of new organizational arrangements to help building owners invest in energy retrofits provides a new opportunity to address these challenges. One approach municipalities have taken, often with someone in government championing the approach, is a public-private partnership termed the 2030 District. This approach is highlighted in this study because it is a spatial-based strategy to work with all building owners within a defined area encouraging them to implement energy retrofits in their respective buildings.

The 2030 District is a 501c3 nonprofit organization that works with both public and private partners to achieve a 50% reduction in building operational energy use by 2030, which are its challenge goals (Architecture 2030 2018). The long-term strategy is to form a network of high performing building districts. The original building performance focus has architectural origins due to its founder, Ed Mazria being a Seattle-based architect. Thus, 2030 Districts focus on existing buildings with the goal of making them green buildings (Architecture 2030 2018).

The municipalities of Cleveland, Detroit and Grand Rapids collaborate with their respective 2030 Districts through their sustainability departments. Each district is afforded the flexibility to engage in outreach that is specific to their mix of building types, needs and history with building owners, to achieve the 2030 Challenge Goals. The result is that there is a wide diversity in strategies.

The cities included in this study had districts at different stages of development. Grand Rapids is one of the most recent districts to be established, and Cleveland is the oldest. In fact, Cleveland was one of the first cities to join the emerging network. Detroit has one district in the downtown area and another in nearby Ann Arbor.

2030 District	Age of District at time of interview
Grand Rapids, MI	3 months*
Detroit, MI	1 year
Cleveland, OH	7 years

Table 3:Age Range Participating 2030 Districts
**Note: the official launch was in 2014, but they got up and running in 2017.*

The age of the district obviously affects the time to establish activities and increase participation rates. The model presented in Chapter 6 assumes all buildings in the model are participants and share energy related information. It does so to explore the influence of the district, but in practice, not all building owners participate. While all building owners within a defined boundary are invited to participate, some districts are becoming membership based with an annual fee ($100 was reported in an interview). Participation is mapped online for Cleveland's two districts and Detroit. Cleveland and Detroit display participation rates in maps on their respective websites. Participants include commercial, industrial, municipal and residential building types.

Framing participation. Districts are careful in how the benefits are framed to get property owners on board and not fear liability for issues uncovered while being involved in the program. To address this, the framework emphasized:

- A clear understanding of the targets and that they are attainable
- Owners can voluntarily choose whether to implement or not implement the recommended upgrades
- The program is not threatening and not a regulation being imposed. It just provides information to help owners reduce their operating costs and do good for the city
- They are signing on in support of the idea, but participation in the activities is voluntary. There are no punishments for not complying
- Their data is anonymous. While they share energy consumption data, individual building identifiers are removed and they will not be chastised if they have high-energy consumption.

The boundaries of the 2030 Districts in the cities studied were defined in collaboration with their respective municipalities and project partners. All of the existing districts are in the downtown areas.

5.0 MOTIVATING ENERGY RETROFIT DECISIONS

This chapter will highlight the interview findings that inform both the process by which building owners make energy retrofit decisions and how municipalities and organizations encourage building owners to retrofit. This chapter explores the perspectives of municipalities and the approaches they take to working with building owners regarding retrofit decisions and outlines the decision-making process. The final section outlines the planning and policy recommendations that emerge from the interviews.

Given that the findings in this chapter are derived primarily from the interviews, which were conducted with a guarantee of confidentiality, individually identifiable information has been removed from findings that are solely based in interview data. Municipalities and organizations, including and beyond those included in this study, are identified with regards to publicly accessible information.

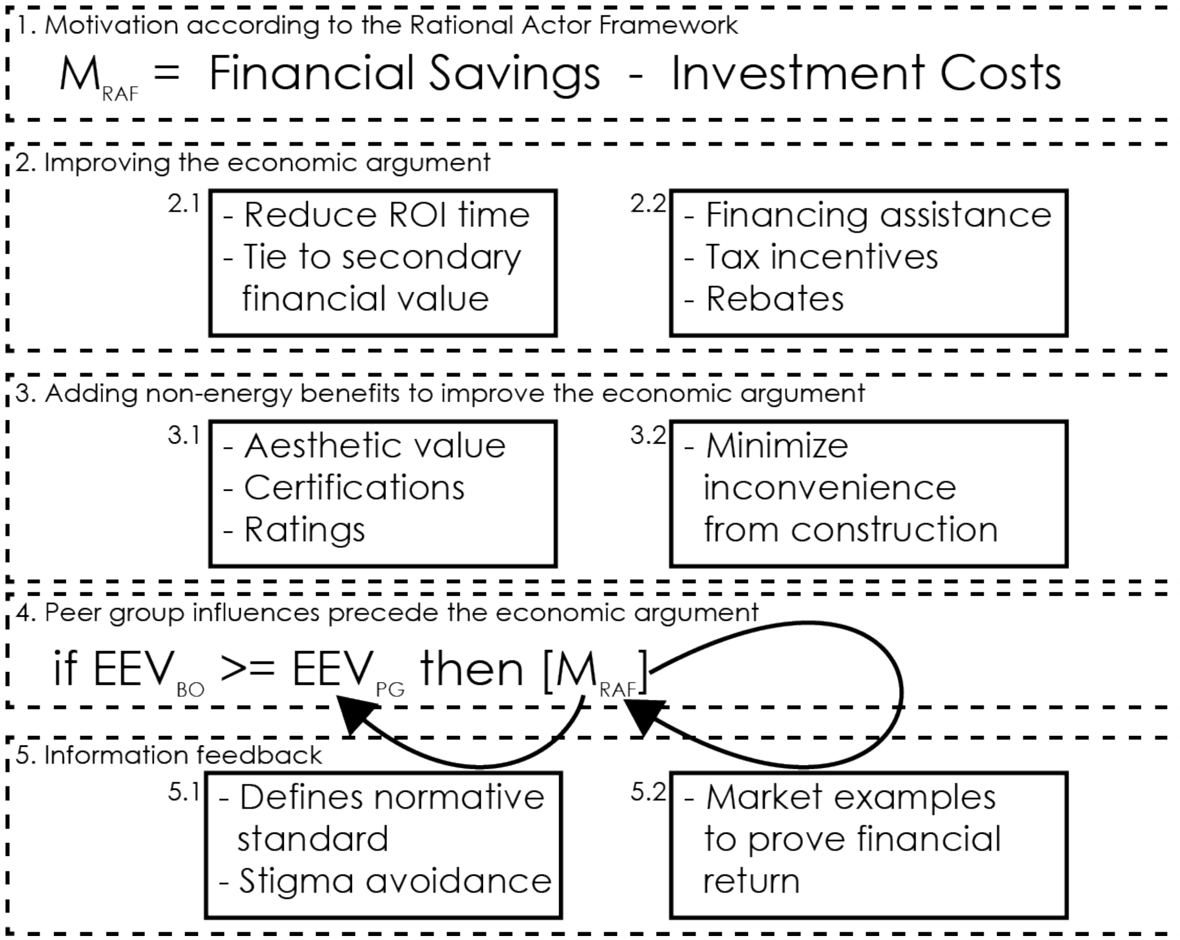

Figure 3: Motivation to retrofit

<u>5.1 Motivation according to the Rational Actor Framework</u>

How energy retrofits are framed shapes energy retrofit decision-making. Motivation in a Rational Actor Framework (M_{RAF}) is often presented as an economic feasibility argument. Framing as an economic argument (boxes 1 and 2 in Figure 3) can constrain the discussion of even non-energy benefits in financial terms (box 3 in Figure 3). Recognition that peer group feedback not only influences retrofit decision-making, but precedes the economic argument (box 4 in Figure 3) changes the discussion from financial feasibility to the motivation to retrofit in the first place. If a building owner does not see an energy retrofit as desirable, or a priority, both of which are strongly influenced by peer groups, then financial feasibility is less relevant to the decision. This ties into the literature on behavioral incentives. One NGO avoids the term sustainability and quantifies all non-energy benefits to be framed in financial terms (Interview 021, Jun. 21, 2018). The rationale is to provide a true benefit cost analysis, including externalities, and then present that in a narrative form to building owners.

When building owners came to the first few 2030 District meetings with the intention of finding ways to reduce their operational expenses. Districts provide information on incentive programs and help building owners identify the programs that would be applicable. For example, the Grand Rapids 2030 District worked with the Consumers Energy utility to pilot a Zero Net Energy Program. They are also working with the city on a Zero Net Carbon initiative to achieve net zero carbon emissions by 2050. Then, in subsequent meetings, those same owners are looking for ways to maximize the benefits of energy efficiency, including other positive externalities.

One example of how 2030 Districts facilitate energy retrofits is the toolkit the Detroit district has prepared for multi-family building owners (Detroit 2030 District 2018). This was prepared in conjunction with other organizations to provide building owners with guidance about the different levels of assessment and how to go about an energy audit. The next step is to inform building owners of existing financial incentive programs at all levels of government as well as utility programs and to help sort through the multiple options to find the appropriate incentives. This practice has a behavioral component for decision-making, as too many options can actually be a deterrent (Thaler, Sunstein, and Balz 2012).

> *So I would say typically, a short ROI is a motivator. We don't necessarily have a specific time identified as, you know, the deal breaker. But what we also add into that is how long we intend to own that asset, so there's a lot of multifamily developers who develop, lease up and sell.* (Interview 024, Jun. 22, 2018)

This initial quote highlights a common finding that building owners do not simply weigh potential energy savings and costs but interpret those factors through the strategy they will use for managing the building. Building owners who are not fully motivated by traditional, rational actor-based approaches are not simply financially challenged, or faced with other priorities, but could also be those with short-term management strategies for the building. The difference with this type of building owner is in how they perceive and respond to energy efficiency messages, which is based on their internal priorities and strategies for managing their buildings. For the purposes of this study, this type of building owner is defined by the terms Stigma-avoiders or Business as Usual (BAU).

The following quote demonstrates how building owner strategy interprets energy efficiency ratings in a way that does not necessarily motivate them to retrofit.

> *When we're looking at our lower performing buildings versus our higher performing building, we're often using energy star portfolio manager as the metric for that. The reason we do that is because, it's fairly simple for the people who are managing these assets internally who don't have the same kind of technical knowledge and detailing rights to be able to have some of these discussions where we can say, okay, we have this suite of buildings that is all energy star certified.* (Interview 024, Jun. 22, 2018)

The first part of this quote identifies the role of convenience. Tools need to be convenient, easy to use and the results easy to interpret because it cannot be assumed that those who run the numbers have the same technical expertise.

> *If it's not a data issue, we've got a serious problem if it's really underperforming to that extent and that's when we typically, you know, figure out what can we do, um, to improve this property's performance, um, and kind of dive into some different options. And then from there look at what the ROI is going to be. Are we going to keep that property for a long period of time or for us as it may be in year nine, and you know, not going to be part of our portfolio much longer anyway.* (Interview 024, Jun. 22, 2018)

In this example, finding out that a building is a low performer can lead to the building not receiving any more upgrades because the management company identified that property as one to remove from their portfolio of buildings. Examples such as these raise the issue that how building owners are expected to respond may not be how they actually respond. More research is needed to assess the correlation between building owners' perceptions of factors and their actions to better inform the approaches that motivate them. In the words of a building owner:

> *I think these cities need to do a better job and not only tracking the data but providing the property owners information on understanding that data and what's that data telling them.* (Interview 021, Jun. 21, 2018)

5.2 Improving the economic argument

Building owners and management groups (herein building owners) are quick to say that if a proposed investment does not make financial sense, they won't consider it. This statement is a good example of how different stakeholders create meaning differently. Municipalities and some organizations repeat this sentiment and focus on making a particular energy retrofit feasible with such financial tools as short returns on investment (ROI) or financial support programs. But when building owners describe this sentence, they talk about revenue that can be generated downstream from this investment. The following description is an example of how a retrofit is seen in terms of a multi-family business model:

> *They just allowed tenants to move in and just with the most basic of upgrades. And then over time, you know, as the money is coming in, now we can put the insulation or more insulation or we can put in more better because we can then raise the rent. Right? You have to establish the economy first, right? and that takes time. You can't just say, okay, we're gonna put all these things up front, which is a lot of money. And then if things don't pan out, then you're stuck.* (Interview 026, Aug. 3, 2018)

While they are also concerned with initial investment costs, ROI and potential energy savings, how they interpret "make financial sense" is in the promise of greater revenue from using the retrofit to raise rent, increased occupancy of building units and increased tenant retention (Interview 026, Aug. 3, 2018). Even when municipalities and organizations mention increased revenue, the priority they give to these factors is quite different than the priority the building owners conveyed. An interesting addition to this point is that this is an idea that may be passed from owner to owner. Those interviewed were unaware of any studies proving that increased revenue follows an energy retrofit. While this is a story of success that is passed through the network, no known studies have proven the financial return from increased occupancy.

One of the programs that was mentioned as having an effect on lowering the financial barrier was the Property Assessed Clean Energy Program (PACE). PACE is a voluntary program that helps property owners finance energy-related investments by adding an assessment to their property tax bill (NASEO 2018). Given that the assessment is a bond that homeowners repay through their property tax bill, it requires governments to set up financing districts. There are versions of PACE applicable to commercial and residential properties. In the residential version of PACE (R-PACE), funds for energy retrofits are made available to homeowners who voluntarily sign up through a municipal, or county level, financing district (DOE 2019b).

5.3 Adding non-energy benefits to improve the economic argument

> *What I will say is that we think that by embedding sustainability as part of our customer service and just part of, again, the lifestyle we're providing, that it does entice people to have a better experience with us. Um, they're saving money, they're living healthier, we're making an easy for them to do that. We do think that's reflected in our renewal rates and in our rent.* (Interview 024, Jun. 22, 2018)

Contractors work with building owners to raise energy retrofits up their list of priorities. Building owners who are identified as Leaders place a high value on comfort and aesthetics (Interview 018, Dec. 21, 2017). This is how a building owner described aesthetic value of a retrofit to potential tenants:

> *So if you want the long term, you have to really take stock of it and I can explain the stuff that's going to last for a long, long time or how it make huge [energy savings] benefits in the end and that becomes its own aesthetic.* (Interview 026, Aug. 3, 2018)

For this reason, organizations argue for energy efficiency upgrades to be aesthetically pleasing and be careful about disrupting comfort levels. One example that was given was to place more priority on equilibrating temperature throughout a house, to avoid running the heat higher because of one cold room, than on a smart thermostat reducing the temperature setting and risk stirring displeasure about energy saving technology. This same interview also warned that the focus on comfort and aesthetics is only a significant motivator among certain clientele who know that they will gain or lose tenants based on the extras offered in their building. Other building owners do not see that direct tie to revenue and, accordingly, do not place the same value on those factors. Aesthetics also connect with other factors that may be valuable for tenants:

> *Doing a refresh of lighting, especially moving up to led when done correctly, it can really, you know, promote that feeling of security. And also I think it just sort of refreshes and gives the product a little bit more of an updated look. But we do talk about it as well as a selling feature for our residents.* (Interview 024, Jun. 22, 2018)

Here, the building owner describes achieving comfort even considering the diminishing returns of added insulation.

> *if you were able to do it by insulating, just by installing it, a small amount is going to have a huge impact in terms of energy efficiency. Then, incrementally as you add more and more, the economics get less and less, but the comfort goes up.* (Interview 026, Aug. 3, 2018)

5.4 Peer group influences precede the economic argument

Interviewees identified the role of neighbor peer influences. While the forms neighborhood groups take can vary by context, for example Chicago has more building owner associations than Detroit, there is a general theme that some form of local comparative group exists and has influence. As mentioned in the quote below, influence can be both word of mouth as well as from building owner associations.

> *The vast majority of work that [NGO} gets is word of mouth from other owners to owners. … they've all these landlord neighborhood associations …in these different neighborhoods get together all the time. … word of mouth spreads in those little associations, and then they get more work.* (Interview 025, Jun. 27, 2018)

A key finding of this study was the difference between types of building owners in their priorities for energy efficiency, and sustainability in general, in the strategies they use to manage their buildings.

> *Not everybody is an early adopter, right? I mean people … being an innovator and the adopter and also leaders and followers. So certainly, there are a lot of people who rely on information that has worked for their neighbors and then jumped on it.* (Interview 027 Jan. 24, 2019)

Interviewees who were building owners or management groups reported having a wide range of priorities that were based in their strategies for managing buildings. These strategies greatly affected their receptiveness to information about energy efficiency. These differences in management strategies may explain why some building owners seem reluctant to respond to conventional approaches, while others are easily motivated with very little incentive. The traditional approaches that municipalities and NGOs take in motivating energy efficiency are not currently designed to address these differences.

Interview findings from this research revealed that people could respond to programs and policies in ways that undermine their intended outcomes. For example, in response to information on a building's energy efficiency level and options to retrofit and lower consumption, some types of building owners perceive that message differently and can instead react by disinvesting in that building – the opposite of the intended outcome.

The reason these types of reactions are unexpected is due to faulty assumptions underlying how building owners are thought to make decisions. Conventional planning and policy approaches assume that building owners are rational actors. The rational actor framework values information that is knowable, accessible, and quantifiable. Both municipalities and non-governmental organizations (NGOs) apply this framework by quantifying the benefits and costs of energy-related investments in financial terms and sharing this information with building owners with the assumption that they will be motivated accordingly.

While in other contexts, emotional, sociological, and other non-rational factors have been recognized to influence consumer behavior significantly, these factors have not been widely applied to motivating energy retrofits in buildings. The challenges to motivating multi-unit residential building owners include large numbers of owners to motivate, different types of management strategies, and the problem of split incentives between those who incur the retrofit costs and those who receive the benefits.

Planning for energy efficiency among multi-unit residential buildings can serve as a test case to uncover and verify new approaches that will prove effective in motivating diverse types of building owners to retrofit.

Interviewees reported lacking the capacity, resources, and information feedback to properly evaluate the performance of their efforts, which may contribute to limited or converse results from owners who are not receptive to those approaches.

However, an emerging approach employing a spatial strategy to engage building owners is being implemented. This approach magnifies neighborhood and network peer influences and conveys information from respected peers, which building owners have reported that they factor into their retrofit decision-making.

The 2030 District Directors actively seek to bring together all property owners within the defined boundaries. While some building owners seek the kind of information and services the District offers, others require a lot of conversation and convincing. One of the outcomes of district meetings that include building owners from different sectors is the idea that some strategies may be applicable across sectors. One director stated that they didn’t know what benefits could be transferred from successes in commercial or municipal buildings to residential buildings, but at least if they are talking to each other, a multi-family building owner may be willing to try something similar – and that is the aim – to create an environment where such conversations can take place (Interview 014, Nov. 22, 2017).

One study found that belonging to an environmental group was positively correlated with residents' favorable attitudes towards renewable energy projects in their city (Knapp et al. 2013, 9). Districts establish the institutional structure that enables information sharing within the network of building owners and facilitate building owner's participation in comparative events such as the Battle of the Buildings competition in Michigan, where building owners can win recognition at the annual event for the building with the greatest improvement in energy efficiency (Energy Star 2015). The Battle of the Buildings is a US EPA nationwide building challenge (DOE 2019a). Cleveland also has a similar social competition called the Green Building Challenge (Cleveland 2018). One 2030 District Director talks about how her city became involved in the Battle of the Buildings:

> *Once I secured enough funding, it had about 50 buildings and 11 million square feet which was phenomenal for year one because my hope was to get a million square feet to join this competition. So blew that way. Year two 22 million. Year three 65 million. And right now, year four, 93 million and 600 buildings across the state are competing in the Battle of the Buildings and it's being referred to by the EPA as a voluntary benchmarking program for the state of Michigan and I'm speaking with the EPA at their events and trying to help them get other states, cities, whatever, to do competitions like this and just kind of sharing that story.* (Interview 015, Nov. 28, 2017)

One director identified the value of large building owners influencing smaller building owners. "Once the big building owners were on board, that further encouraged smaller building owners to join" (Interview 014, Nov. 22, 2017). Literature on consumer behavior shows the influence of those identified as "Influencers" and participation in networks that share information on products as having significant effects in increasing adoption of the product (Hill, Provost, and Volinsky 2006). Influencers can even promote unconventional products as long as the influencer resembles the adopter (Shalev and Morwitz 2011).

5.5 Information feedback

Many municipalities lack the capacity and resources to assess fully the performances of planning and policy approaches. Without feedback on which efforts are effective with different types of building owners, efforts to motivate those who didn't respond to conventional approaches often resort to doing more of the same: education, outreach, and financial incentives.

5.5.1 Feedback within the economic argument

> *When an owner sees someone else doing it, they always want case studies. Who's got the case study? Who's got the data? Who can show me that you've done this?* (Interview 025, Jun. 27, 2018)

The most common feedback mentioned by interviewees is encapsulated by the quote above. Building owners want some form of certainty that a proposed energy retrofit will return the expected financial savings. There are two types of feedback that place value on information; authority derived from hierarchy and authority derived from peers. The former assigns value from a recognized authority, which can be a respected NGO, certification from organizations such as LEED or Passive House (PHIUS certification), or a real estate valuation for specific energy efficiency features, which is the goal of a Green MLS listing. The latter assigns value from peer groups in the form of norms. These are contextually dependent valuations that are fluid over time.

5.5.2 Feedback within peer groups

> *Within the program that I defined, certainly that's really been helpful to spread by word of mouth or by other trusted partners, if you may, and trusted organizations. So when they hear from somebody that they know that it works, the feeling is there, then they can understand the comfort. Then certainly it helps somebody try that out right? So that has been very effective in our residential efficiency program. Beyond that I'm not able to advocate. Or at least to be able to analyze if there is any impact, because I've not worked for any large multi-family type resident.* (Interview 027, Jan. 24, 2019)

The above quote highlights two main points. First, is the role of trust in the partner or organization that is sharing the information. The role of respect in accepting information has been shown to be valuable (Zellner et al. 2014). Trusted networks can be established through many forms of social infrastructure. The 2030 District is one example of a network designed to build trust with building owners. Through these networks, information on the value of energy retrofits are more readily received, which is a theme that was conveyed through multiple interviews.

The end of the quote above raises another point that came through many interviews; there is less understanding about what approaches work among multi-unit residential buildings. There are many assumptions that carry over from other sectors, such as residential, as referenced In the quote above.

5.6 Interview findings on unintended consequences

One of the benefits of qualitative research is the potential to discover unexpected results. The interview findings identified mechanisms whereby building owners respond to traditional energy efficiency approaches in ways contrary to the approaches' intended objectives.

The first mechanism is retrofit fatigue. While interviewees who design energy efficiency approaches reported using a strategy where they will do a relatively easy to implement retrofit, like lighting, to demonstrate value and encourage building owners to invest in deeper retrofits, building owners, and those who work with them, reported mixed motivation to invest in another retrofit. Due to the inconvenience incurred by the construction, some building owners are reluctant to do sequential retrofit projects. This is especially true in the case of multi-unit residential buildings where construction is a burden on tenants. For owners, tenant retention is a motivator for doing a retrofit; that benefit would be undermined if long-term construction affected tenants' decisions to renew a lease.

Another aspect of retrofit fatigue is building owner expectations for the perceived results of an energy retrofit. One interviewee talked about a building owner who was encouraged to do an energy audit and was shocked to hear how his building was rated.

> *He asked me "what's the point? I have been working with you for a year and it didn't make any difference." I had to work with him closely after that to get him back on board".* (Interview 016, Nov. 28, 2017)

This kind of perception is based in how individuals process information. Nudge effects, where inputs, such as policy levers, can motivate an individual to do something they are currently not doing, requires the individual to see the goal as achievable (Thaler, Sunstein, and Balz 2012). Beyond that point, the input no longer has the desired impact. Another factor that contributes to this perception is priming. When the actual result differs greatly from the expected, then it takes a lot more work to accept the result (Kahneman 2011, Ch. 7). For these situations, the role of the facilitator is important (Interview 025, Jun. 27 2018)(Zellner et al. 2014). In *Thinking Fast and Slow*, Daniel Kahneman describes how people understand complex relationships, or statistics they don't fully understand for example, by using simple heuristics. Such heuristics applied over a large population may lead to false conclusions. This again highlights the need for a facilitator to provide a narrative that can explain the values, relationships and identify possible solutions.

The second mechanism is how owners perceive and respond to information. Building owners, like other consumers and decision-makers, are motivated when the next step is within reach. However, if the gap between where they are and their goal is too large, the information can de-motivate owners.

In responding to an energy audit, building owners perceive the gap between their existing state and their goal, depending upon what type of building owner they are. Building owners who derive value from having the most energy efficient building, or technology, in their peer group are easily motivated regardless of the gap. The majority of building owners, however, conform to the norms of their peer group. Normative energy efficiency goals are defined by one's neighborhood and network peer groups. A third type of building owner, represented by ownership groups among the interviewees, are motivated by stigma avoidance – they avoid being the worst performing building among their peers. This type of owner is labeled here as a Stigma-avoider (other studies use Business as Usual, BAU).

Another type of response to energy efficiency information is when building owners who already need to make investments to upgrade to existing energy-related building codes, may respond to higher code standards by stopping investment and selling or abandoning the building. As the interviewees stated, recent upgrades in energy-related codes reflected standards that a large portion of the market was already doing. So, the proportion of building owners who may respond contrarily would likely be a minority of the total building population. However, given that to improve energy efficiency, some NGOs are actively working to encourage the enforcement of energy-related codes (existing incentives highly prioritize building codes relating to life safety), by default that means some buildings are not yet up to existing energy-related codes. The idea conveyed in the interviews is that for buildings that are not yet meeting the existing energy code, increasing energy-related code standards may result in a gap that some building owners may choose a different action than investing in building energy efficiency.

Qualitative findings revealing unintended consequences of energy efficiency approaches are particularly useful because they reveal how the internal dynamics of an approach can produce contrary results. The implication is that owners who are not motivated as a result of these unintended consequences cannot be motivated by just doing more of the same; these results highlight the need for more robust approaches that address these consequences. The next section describes an agent-based model that was created to find robust approaches that effectively motivate the three types of building owners by leveraging neighbor and network peer influences.

5.7 The Value of Facilitators

Interviewees working with NGOs frequently highlighted the value of a skilled facilitator, one who has the social skills to effectively motivate building owners at every step of the retrofit decision-making process. The role of facilitators is especially important in municipalities that face budgetary and capacity challenges, and aging building stocks. Like many municipalities, financing and staff capacity for energy efficiency approaches can sometimes be given a low priority as decision-makers define other issues as more pressing.

> *Our buildings are just really in need of improvement overall not even thinking about energy efficiency. So, we know that our buildings need a lot of investment right now.* (Interview 013, Nov. 15, 2017)

Facilitators serve a key role within NGOs working with building owners to identify the problem, envision the opportunity, and propose a practical solution. The value of a facilitator in achieving consensus has been well established (Zellner et al. 2014). Effective facilitators go beyond framework alignment by working with stakeholders on the judgements they hold that underlie their frame of reference (Milz 2018). A facilitator lacking in the necessary skills to connect with their audience risks further distancing a building owner from taking action.

> *The things we know that they care about is simplicity, beauty, convenience and ease… A lot of times when a sustainability practitioner tries to explain or pitch why they should do it, they try to explain the whole at once. Yeah, yeah. Like we're dealing with this big holistic nightmare. Everything's connected to*

> *everything and we need to be pushing on all these things out once and immediately you've lost, you've already lost.* (Interview 018, Dec. 21, 2017)
>
> *So when you're talking to the owner, and you're improving their bottom line, then they start to trust you, and then you're like, "Well, you're putting in LED lighting in the hallways, you should put it in your tenants spaces, too, when you're doing the retro-fit." Right? "You're putting in new windows, right? Obviously, you want the best windows in your common space, you should put it in your tenant's space, too, right?" They start to see the value in it. Then you've got their ear, and then you start talking about, if you lower the tenants' utility bill, they're more likely to probably pay their rent. They've more cash on hand, right? There's less of a likelihood, If you have a tenant that has a really high bill to cool their space in summer. There's a potential that they've got to figure out how to split that small amount of money they have to pay for the cooling of their space and their bill. And it's really important for owners to have tenants pay their bills on time.* (Interview 025, Jun. 27, 2018)

They saw these individuals as a value for their respective organizations as well as achieving the goal of improving energy efficiency. However, none knew of any training for employees to get the social skills to be a skilled facilitator. When asked, they described these social skills as a natural gift. To the contrary, Dan Milz conducted qualitative research showing that the skills to be an effective facilitator can be systematically studied, learned as a craft, and applied into planning practice (Milz 2018). A skilled facilitator working with building owners in network structures was identified as effective in the diffusion and acceptance of information on the benefits of energy retrofits. Here is how the role of one skilled facilitator was described:

> *We hired Simon[1], a retired code official. Simon drove around the state and saw 300 and some code officials in these one-on-one meetings. Similarly, with builders, did the same thing. The idea was one-on-one, we're going to sit down. I'm going to tell you what we learned from the baseline studies. "Most places do windows well and do lighting badly or whatever it was. What are your questions? How can I help you with the problems you're having?" and respond to them at whatever level they were. It's like, "What really is the energy code?" Or, "What's the difference between ...? Or whatever the question, whatever level you're at,*

[1] The name has been changed to maintain confidentiality

> *that's the level you talk to them at. You're there to help them.* (Interview 020, Feb. 20, 2018)
>
> *Those are your guys in your field who have good language skills, have good negotiating and sales skills and are already have a reason to be there.* (Interview 018, Dec. 21, 2017)

5.8 Planning and Policy to improve energy retrofit adoption

Planning for energy efficiency in multi-unit residential buildings implores examining the assumptions underlying conventional approaches and implementing more robust strategies that account for the potential of negative, unexpected reactions.

Interview findings from this research revealed that people could respond to programs and policies in ways that undermine their intended outcomes. For example, in response to information on a building's energy efficiency level and options to retrofit and lower consumption, some types of building owners perceive that message differently and can instead react by disinvesting in that building – the opposite of the intended outcome.

The reason these types of reactions are unexpected is due to faulty assumptions underlying how building owners are thought to make decisions. Conventional planning and policy approaches assume that building owners are rational actors. The rational actor framework values information that is knowable, accessible, and quantifiable. Both municipalities, NGOs, and other building associations apply this framework by quantifying the benefits and costs of energy-related investments in financial terms and sharing this information with building owners with the assumption that they will be motivated accordingly.

These assumptions need to be tested, but many municipalities lack the capacity and resources to assess fully the performances of planning and policy approaches. Without feedback on which efforts are effective with different types of building owners, efforts to motivate those who didn't respond to conventional approaches often resort to doing more of the same: education, outreach, and financial incentives.

While in other contexts, emotional, sociological, and other non-rational factors have been recognized to influence consumer behavior significantly, these factors have not been widely applied to motivating energy retrofits in buildings. The challenges to motivating multi-unit residential building owners include large numbers of owners to motivate, different types of management strategies, and the problem of split incentives between those who incur the retrofit costs and those who receive the benefits.

Planning for energy efficiency among multi-unit residential buildings can serve as a test case to uncover and verify new approaches that will prove effective in motivating diverse types of building owners to retrofit. It requires a shift in many interconnected components including norms and the social and financial institutions, as stated in the following quote:

> *You have to get the builders on board. You have to get the appraisers on board. You have to get the real estate agents on board. It has to be that feedback loop. The banks. The banks have to know about that better. Get the lenders on board so that they know that, oh, these people, they have an energy-efficient house, that means ... I know that their payments are probably more likely to be on time and that kind of stuff. That's one policy mechanism that theoretically should work but everybody has to know and it has to ... It's like where do you jump in the cog to make it start? It doesn't. You have to jump in all at the same time and everybody has to work with it.* (Interview 020, Feb. 20, 2018)

5.8.1 Practical moments for energy retrofits.

While the preceding section identified multiple, interconnecting planning and policy changes that can encourage energy retrofits, this section presents three moments when an intervention can be made. Given that retrofits and building construction are long-term investments, strategies need to be coordinated with the moments in time when building owners are more likely to consider any investment in the building. The following have been identified as moments when building owners are likely to consider an energy retrofit, or alternatively, when energy efficiency standards requiring a retrofit can be enforced:

Point of sale. A moment in which a building is sold provides an opportunity to either include energy efficiency data in the market listing, as Portland, Oregon does, or to mandate improvements to bring the building up to code (Interview 025, Jun. 27, 2018).

Point of construction permits. When major construction is performed that requires a permit, it also provides an opportunity to encourage building owners to make improvements that exceed code requirements (Interview 018, Dec. 21, 2017).

Point of refinancing. In one study of multi-family buildings in Chicago, over half can refinance (D. Philbrick, Scheu, and Brand 2016). This provides a moment to encourage, or require, energy efficiency improvements (Interview 023, Jul. 13, 2018).

6.0 EXPLORING ENERGY RETROFIT DECISIONS WITH AGENT-BASED MODELING

The interview findings were used to build the Neighbor-Influenced Energy Retrofit (NIER) agent-based model that explored the effect of neighbor and network peer influences upon energy retrofit decisions within a population of building owners (Boria 2020). The model runs scenarios of various planning and policy interventions. The NIER model contributes to the literature on qualitative research informing the construction of agent-based models (Yang and Gilbert 2008; Zellner et al. 2014; Agar 2005).

Agent-based models that are informed by qualitative research findings focus on modeling a process, in this case a social dynamic of motivation to retrofit, into the mechanism of an agent-based model (Yang and Gilbert 2008). Given that the data that informs the model is based on an inductive research methodology, the values of the model are adjusted to reflect the dynamics that emerged from the qualitative data. Reducing the rich, qualitative data to simple social dynamics allows micro-interactions to be modeled on a macro-scale through computer simulation to observe any resulting emergent behaviors. This section will outline the protocol for creating the NIER model and discuss the insights that emerged from testing various scenarios.

Findings of unintended consequences in the interview data raise research questions about how the identified dynamics play out on a larger scale through the interaction of a large number of building owners. Agent-based modeling on energy retrofits has been used to provide useful insight to policy makers by exploring infrastructure, policy and behavioral factors (Ignacio J. Martinez-Moyano 2011), behavioral, economic and environmental factors (Rai and Robinson 2015), and other approaches using calibrated models of technical, financial and behavioral factors to support retrofit decision-making in lieu of the time-intensive energy assessments (Heo et al. 2015). The agent-based model developed here will add to this literature by including the influence of neighbor and network peer groups upon the motivation of building owners to invest in an energy efficiency retrofit.

Displaying and sharing energy efficiency information is becoming recognized as a useful tool to motivate building owners to improve their building's energy efficiency performance. While municipal energy efficiency approaches focus on maximizing energy and cost savings from technology and retrofits, more research needs to be conducted into the potential of employing other social factors. Behavioral nudges have been utilized with energy consumption (Opattern 2019), but less so with encouraging energy retrofit decisions. Again, more empirical research is needed to identify which information, when conveyed, has the greatest effect upon building owners and other key decision-makers in the decision to retrofit. Some energy efficiency organizations are already conveying other information with building owners such as aesthetics and comfort (Interview 018, Dec. 21, 2017), tenant satisfaction and retention (Interview 025, Jun. 27, 2018), and intentionally tying energy savings to internal metrics of concern to building owners (Personal communication, Apr. 23, 2019). The 2030 Districts are conveying a wide range of information with building owners, from information about their own building type to codes and standards, to comparisons in competitions such as the EPA's National Battle of the Buildings competition (Interview 014, Nov. 22, 2017; Interview 015, Nov. 28, 2017; Interview 016, Nov. 28, 2017).

There are two insights that emerged from the interviews that are tested with the agent-based model developed here:

Scale of neighbor peer groups. While work has been done on the influence of networks upon the adoption of new ideas (Siciliano 2017; Zellner et al. 2014), the spatial context of peer influence in neighborhoods will be explored here.

Multi-unit residential building owners have different management strategies, which affect their willingness to invest in a retrofit. The way that information is received and interpreted by building owners is not commonly included in research on energy retrofit decision-making.

The hypothesis tested by the NIER model is that neighbor and network peer groups can influence a building owner's energy retrofit decision. The interview findings revealed that building owners not only weigh the financial benefits and costs of a retrofit, but they also take into consideration the state of their building in comparison to the neighborhood they are in and who they consider their network peers to be. These social comparisons for building retrofit investment decisions are largely absent in the literature. Thus, there are no databases of survey values to draw upon. Instead, this model represents the process by which building owners stated that they make decisions and reflects the values as stated by the interviewees.

The following sections describe the Overview, Design concepts and Details (ODD) protocol for the NIER model as adapted from the updated ODD protocol by Volker Grimm and his colleagues (Grimm et al. 2010), its extension to the ODD+D protocol (Muller et al. 2013), and descriptions of ABMS model components by Macal and North (Macal and North 2010).

6.1 Purpose of the Model

The Neighbor Influenced Energy Retrofit (NIER) model was developed in Netlogo (version 5.3.1) to understand how the influence of a building owner's peer group upon the individual decision to retrofit can amplify retrofit motivations throughout the population of building owners. It is important to look at macro-level dynamics from micro-level decisions because cities with aging building stocks and budgetary challenges often have a high number of buildings in need of energy efficiency upgrades. Inefficient residential buildings increase energy consumption and its associated negative, unintended environmental and social consequences. The cities that were selected for the qualitative study have aging building stocks that are the legacy of a history with greater manufacturing employment.

6.2 Entities, state variables, and scales

This section will describe the components of the NIER model, which represents building owner decision-making as operationalized into agents that interact, assess the information of their peer groups, make energy retrofit decisions, and upgrade their buildings. An overview of the components of the NIER model are shown in the Unified Modeling Language (UML) class diagram in Figure 4.

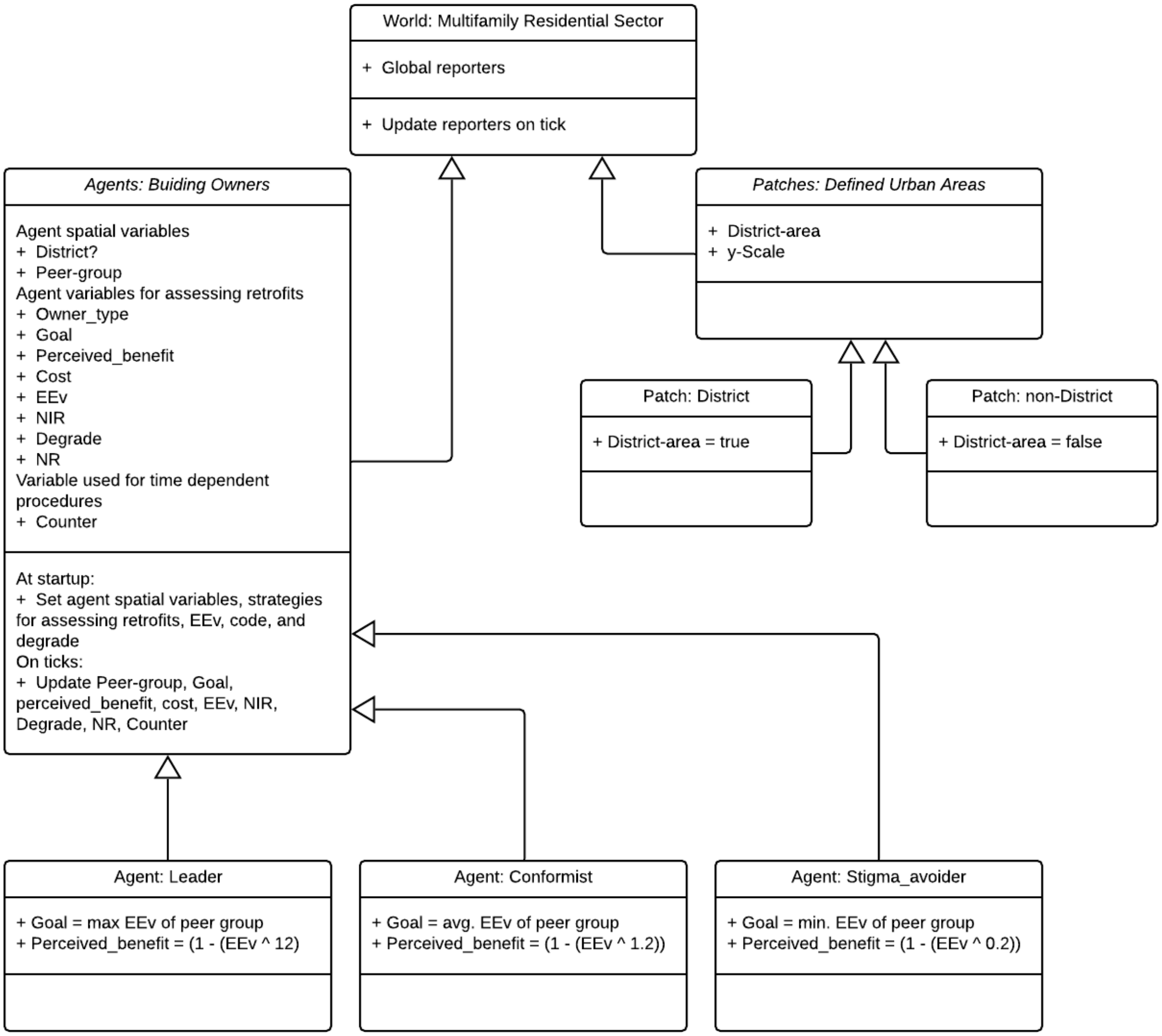

Figure 4: NIER Model UML Class Diagram

6.2.1 Agents: Buildings

For the purposes of this model, building agents contain building owner attributes as well as energy efficiency characteristics of the building itself. Future versions of this model may separate owners from buildings into different agents, but the NIER model does not require them to behave independently.

6.2.1.1 Building owner types

The interview findings identified distinct building owner strategies that made significant, qualitative differences in how owners perceived and responded to energy efficiency information, affecting the decision to retrofit. Underlying the difference in management strategies was their purpose for owning the building and how they view their relationship with tenants. A social constructivist approach to these management strategies can further identify how building owners make meaning of energy efficiency and how that shapes their perception of benefits and costs. For the purposes of this study, building owner strategies can be categorized into ideal types, which provide a useful approach to highlighting differences that can be modeled. The three ideal types are: Leaders, Conformists, and Stigma-avoiders (also termed Laggards and Business as Usual, BAU).

Leaders compare themselves to the buildings with the highest level of energy efficiency among their peer group. Practically, this represents building owners who are the most receptive to success stories among their peer group.

Conformists, instead, compare themselves to the average of their peer group, meaning they conform to normative standards.

Stigma-avoiders (Business as Usual building owners) compare themselves to the lowest energy efficient building in their peer group, applying the motive of stigma avoidance.

The owner types were derived from multiple interviews, mainly focusing on Leaders and Stigma-avoiders in terms of their receptiveness to energy efficiency goals (Interview 014, Nov. 22, 2017; Interview 015, Nov. 28, 2017; Interview 019, Sept. 19, 2017; Interview 020, Feb. 20, 2018). The role of building owner type, defined as individual versus corporate ownership, was found to significantly influence retrofit decisions (Kontokosta 2016).

6.2.1.2 Agent parameters

6.2.1.2.1 Energy Efficiency Value

The Energy Efficiency Value (EEv) represented in this model ranges between 0-100% efficient, represented as 0-1. EEv theoretically encompasses energy efficiency information that is shared between building owners. Practically, it represents a building Energy Use Intensity (EUI), a measure of energy efficiency per square foot. Given that this model represents a packet of energy efficiency information that building owners know about their own building and share with other building owners, it can theoretically include other energy benefits deemed of value by building owners. The value of EEv is also used because building owners may not have an accurate understanding of their building's EUI, thus EEv represents a building owner's perceived energy efficiency value that they will use in the retrofit decision-making process.

6.2.1.2.2 Determining willingness to pay

Even if the building owner has a motivation to retrofit from neighbors, they will only do so if their internal calculation of benefits outweighs the costs. Traditional approaches to retrofit decisions focus strongly on energy savings and additional benefits along with initial costs and return on investments. These calculations are roughly represented in the Perceived Benefit and Cost assessment in the NIER model but are weighed sequentially *after* the motivation to retrofit from neighbor peer groups. The NIER model contributes peer group influences as an addition to the traditional benefit-cost assessment.

Agents calculate the perceived benefits and costs of upgrading at every level of energy efficiency. The curves in Figure 5 have been derived from output values from model runs (for verification purposes), which are based upon curves from environmental economics.

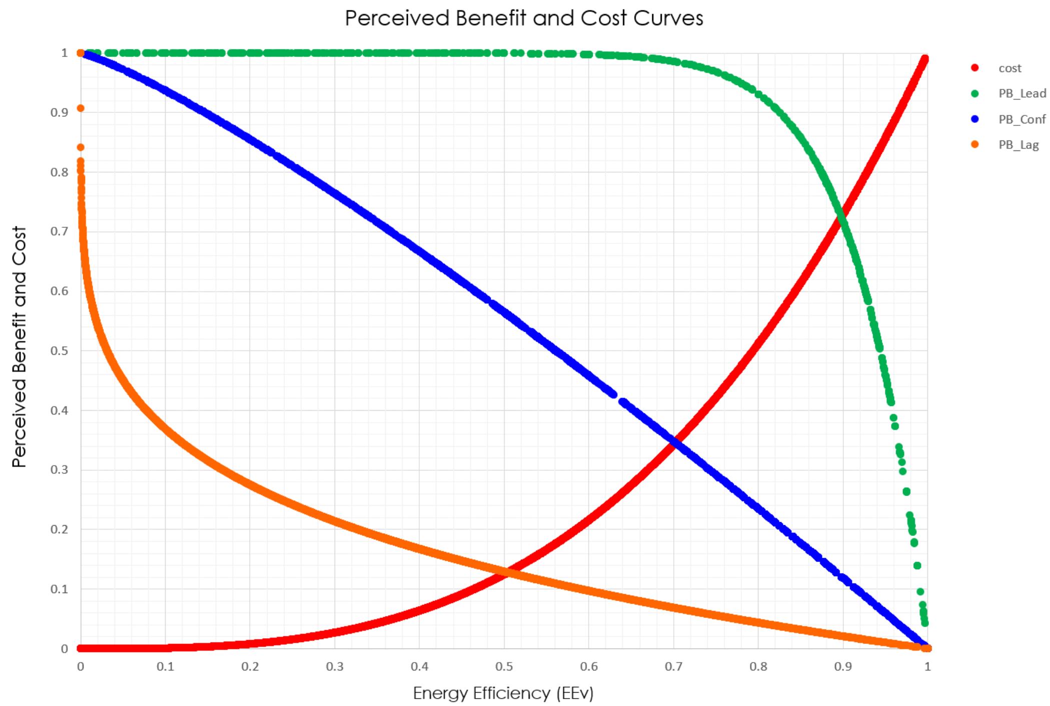

Figure 5: Perceived Benefit and Cost values by building owner type

Source: graph created by author from ABM data output.

Perceived benefit for energy efficiency is represented by the concept of declining marginal returns as the use of any resource, approaches 100%, which is represented by 1 on the x-axis (Field and Field 2006). Thus, for the same energy efficiency upgrade, fixing leaky windows for example, low energy efficient buildings will see a greater percentage increase in efficiency than buildings that are already efficient. The differences in the perceived benefit curves for Leaders, Conformists, and Stigma-avoiders (green, blue, and orange respectively in Figure 5), reflect the differences that emerged from the interview data for the value that different types of building owners have for energy efficiency with respect to their existing state of energy efficiency (EEv). Equations for the perceived benefit curves in Figure 5 are as follows:

Leaders PB_i = (1 - (EEv ^ 12)
Conformists PB_i = (1 - (EEv ^ 1.2))
Stigma-avoiders PB_i = (1 - (EEv ^ 0.2))

A second aspect of diminishing returns represents consumer behavior. The willingness to pay for each additional unit decreases as the quantity purchased increases (Field and Field 2006, 43). This was an issue raised by both interviewees working with building owners and building owners themselves (Interview 014 Nov. 22, 2017; Interview 026, Aug. 3, 2018). Both had mentioned the increased difficulty with encouraging building owners to do another retrofit after they had just completed one, even if the energy savings was clear. The fact of being inconvenienced for the retrofit, and the negative externality of tenants being dissatisfied with that inconvenience, can lead to a discouragement to retrofit. Building owners want to see the benefit of retrofitting extend for a number of years (Interview 022, Jan. 21, 2018).

Conversely, the cost for every unit of energy efficiency improvement (the red curve in Figure 5) rises exponentially as energy efficiency approaches 100% (or a resource nears being 100% used). The marginal cost for every unit of energy efficiency improvement will rise exponentially (Field and Field 2006, 59). For example, the cost of improving 5% for low efficiency buildings could be a simple replacement of light fixtures, but that same percentage increase for high efficiency buildings could require a replacement of the HVAC system and the installation of heat pumps. This is one of the difficulties in encouraging deep retrofits (Berkeley Zero Net Energy++ Working Group 2017). While improvements in technology can lower those costs, the shape of the curve will continue to increase as efficiency increases (Field and Field 2006, 57). The equation for the cost curve in Figure 5 is as follows:

C_i = (EEv^3); Cost is a function of EEv

While cost is an objective value, it is subjectively interpreted. Differences in both how building owners pay and how they understand cost could also affect the shape of the cost curve. In the case of photovoltaic adoption in California, cost was found not to be the only option, but also how the cost was presented (Drury et al. 2012). The study found that policies encouraging third parties were successful in reaching a new demographic of adopters. The third parties allowed the client to see the cost and benefits upfront, within the first month, in contrast to having a long return on investment (ROI) drag out over a decade. Differences in the cost curve are not included in this model but could be explored in future versions.

6.2.1.2.3 Neighborhood scale

Spatial relationships in this model represent social influences from peers, either in the form of neighborhoods or networks. Spatial relationships were also found to significantly impact retrofit decisions in the form of regions or market locations (Kontokosta 2016). The qualitative differences between the nature of interactions and the types of information that is conveyed between different neighbor and network peer groups is beyond the scope of this study. The NIER model tests the spatial component of peer groups, which is the size of the comparison group that a building owner compares energy efficiency information with. Thus, neighbor peer groups are tested by various scales neighbor groups in the non-District side of the model world. The scale of the peer group is tested using in-radius. Figures 6(a,b,c) show the spatial relationship of in-radius 1, 2 and 3, which is how many agents away (in cardinal directions) will a building owner consider as their peer group. Figure 7(d) represents the 2030 District, in that it compares all agents in the model world. This can also symbolize policies that affect large populations of building owners.

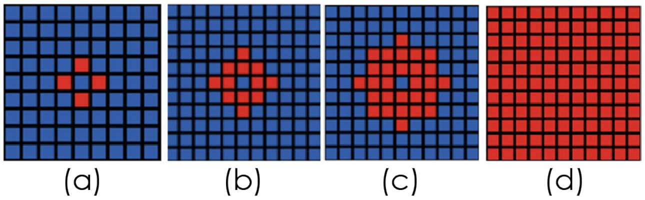

Figure 6: Neighborhood scale modeled

Figure 7 also shows the for In-radius 3 property for “no-wrap” that prevents agents on the edge of the world from assessing agents on the other side, as if the world wrapped. Thus, agents on the edge have a smaller agentset of neighbors than those elsewhere in the world. This represents the edge of residential neighborhoods, or it can also represent the boundary line for Districts.

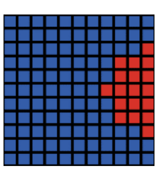

Figure 7: In-radius 3 no-wrap

6.2.1.2.4 Goals

Figure 8 describes how agents assess peers and how they calculate their goal values. Goal is an agent variable that is dependent upon building owner type but is calculated based on values in the agent's peer group.

OWNER TYPE	GOALS	non-DISTRICT NEIGHBOR PEERS CONSIDERED	DISTRICT NEIGHBOR PEERS CONSIDERED
Leaders	High Match Max. EE value of neighbors	Max. EE value of other agents in local neighborhood defined by slider	Max. EE value of all agents in District
Conformists	Average Match Avg. EE value of neighbors	Avg. EE value of other agents in local neighborhood defined by slider	Avg. EE value of all agents in District
Laggards	Low Match Min. EE value of neighbors	Min. EE value of other agents in local neighborhood defined by slider	Min. EE value of all agents in District

Figure 8: Goals by building owner type

6.2.2 Processes and Order of Events

6.2.2.1 Time

The time of iteration represents a year. Based on interviews with energy efficiency organizations, the time between the initial outreach to building owners, their interest in requesting more information and/or scheduling an energy audit and finally being motivated to take a decision on an energy retrofit varies widely, but a typical estimate is a year (Interview 015, Nov. 28, 2017; Interview 021, Jun. 21, 2018; Interview 022, Jan. 21, 2018). The decision to run the model for 100 iterations (years) is to place the end point at the year 2100 (81 years at the time of this publication, rounded up to 100).

6.2.2.2 Decision-making process

Box 1 in Figure 9 describes the model initialization, where agents are created, one on each patch in the world, assigned whether to be in the district or not, and all agent attribute values described above. The Setup assigns fixed energy efficiency values on a scale corresponding to the y-axis. The scale is to represent areas of the city that range from high to low energy efficiency. Randomness is introduced into the counter number that is used to determine when a normal retrofit will occur. A normal retrofit is defined as a retrofit that would normally take place due to normal wear and replacement of materials, without neighbor influence. The counter is also used to determine when a building will be sold, which is used in both the ownership change and energy code enforcement scenarios.

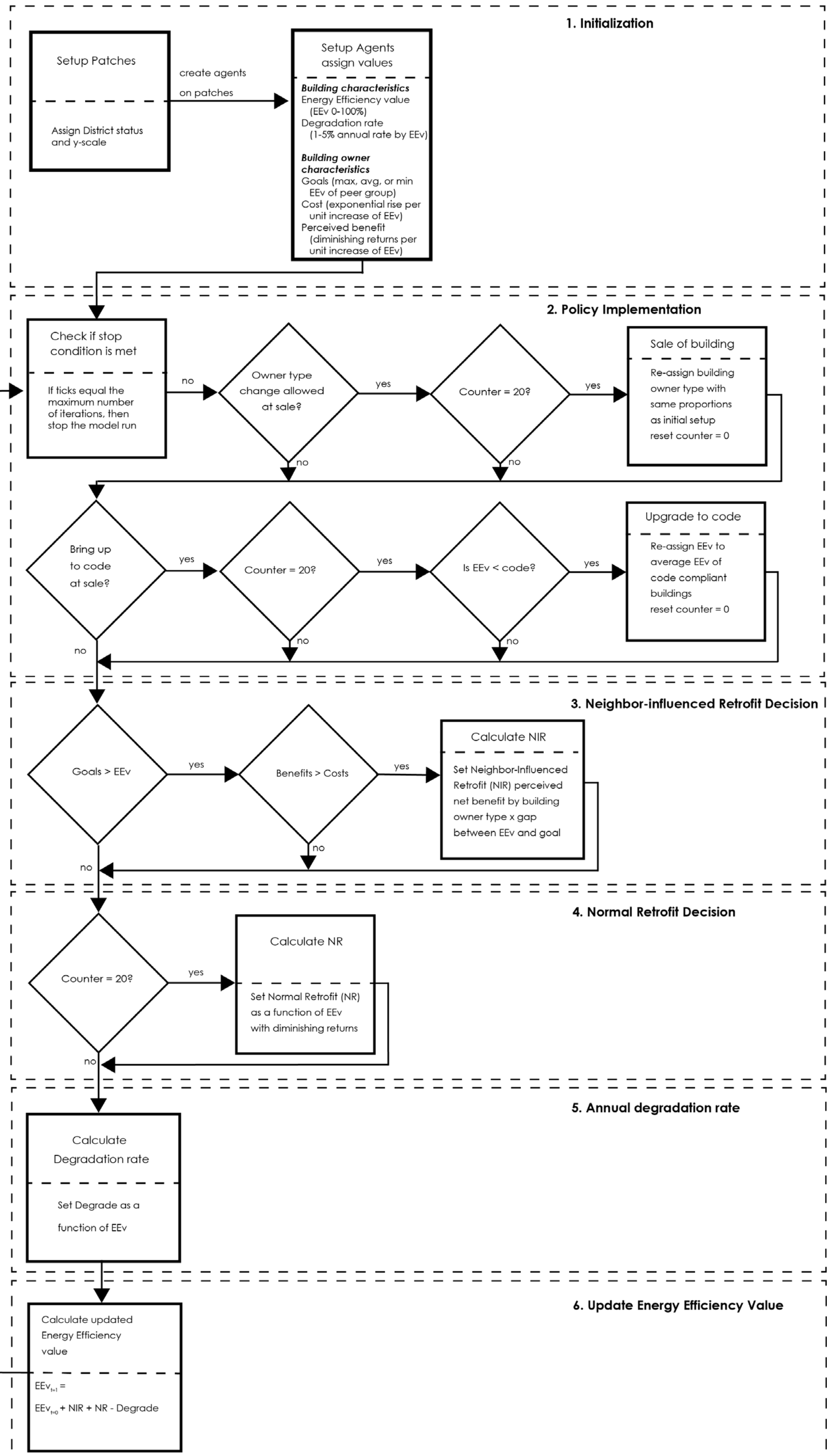

Figure 9: NIER Model Decision Tree

In every iteration, agents perform the following procedures to interact and update values. Following initialization, the model checks two scenarios of planning and policy interventions. Box 2 in Figure 9 outlines the sequence of decisions for these two scenarios. They can be enabled by choosers on the interface. The first determines whether ownership change is allowed. The decision steps for this scenario are shown in Figure 10. When the counter reaches 20, indicating 20 years, the building is sold. Randomness is introduced into the model at this point. The building type of the new owner is a random number draw, while ensuring equal proportions to the initial settings. For example, baseline settings create 80% Conformists, 10% Leaders, and 10% Stigma-avoiders. The random draw for the new building owner type will reflect the 80:10:10 probability. However, if the scenario is not activated or if the counter is not yet at 20, the decision will go to the next step without an ownership change.

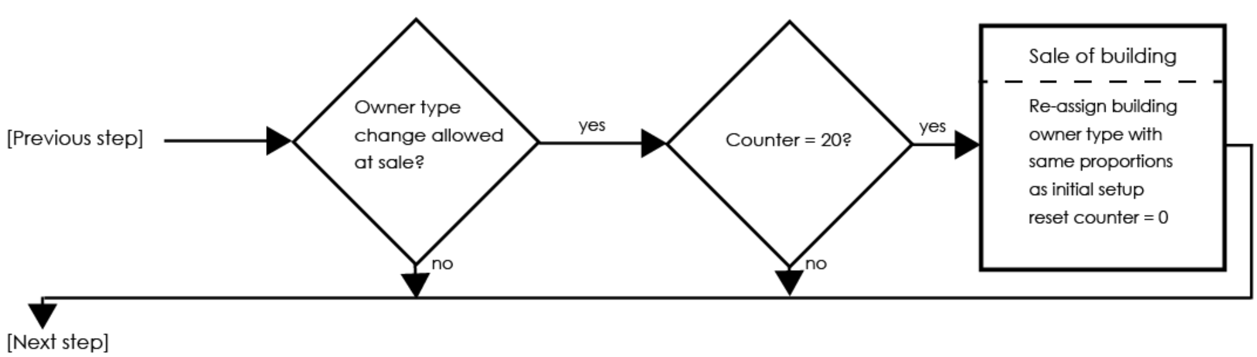

Figure 10: Owner type change allowed scenario

Following ownership change, the next scenario tested in Box 2 is whether the building will be brought up to the energy code at the point of sale. Like the previous scenario, the code scenario must be activated on the interface and the counter must be at 20 (as shown in Figure 11). This scenario represents a policy that takes the moment when a building is sold to ensure that the building meets energy-related codes before it is purchased. In addition to the requirement that the counter indicates 20 years since the last major upgrade, the procedure also checks that the code is greater than the existing energy efficiency value of the building. If the building is already at a higher level of energy efficiency, then code is already met.

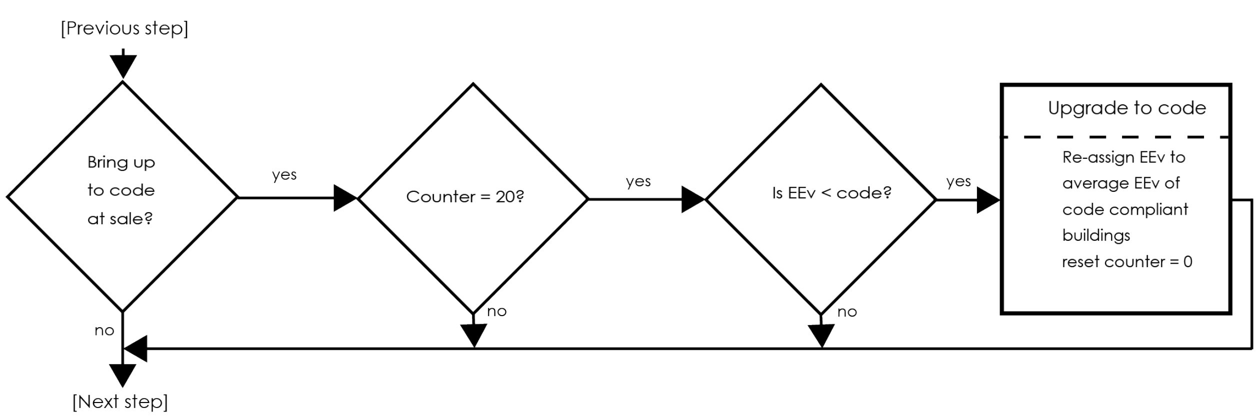

Figure 11: Bring up to code scenario

The neighbor-influenced retrofit decision (NIR) is the key component of the NIER model (Box 3 of Figure 9 and highlighted in Figure 12). NIR represents the only peer group influence in a building owner's retrofit decision-making. The component of the NIR that represents the peer group influence, from both neighbors and networks, is in how an agent determines the energy efficiency goal. The impact of this one variable in the NIER model tests how the simple inclusion of peer influence can result in large-scale differences among the population of building owners.

The value a building owner derives for the goal is derived every iteration from its peer group based on the building owner type, as described in Figure 8. Perceived benefit and costs are also calculated every iteration. These three variables are required to calculate NIR. Peer groups only have an influence if the peer group goals are greater than the building owner's energy efficiency value, which is the motivation component) and if the perceived benefits are greater than the costs, which is the economic feasibility argument (see Figure 12). If both are true, then NIR is calculated with the following equation: **NIR** = $(G_{pg} - EEv_i) * (PB_i – C_i)$. For a detailed explanation, see 6.2.2.3 Equations compiled.

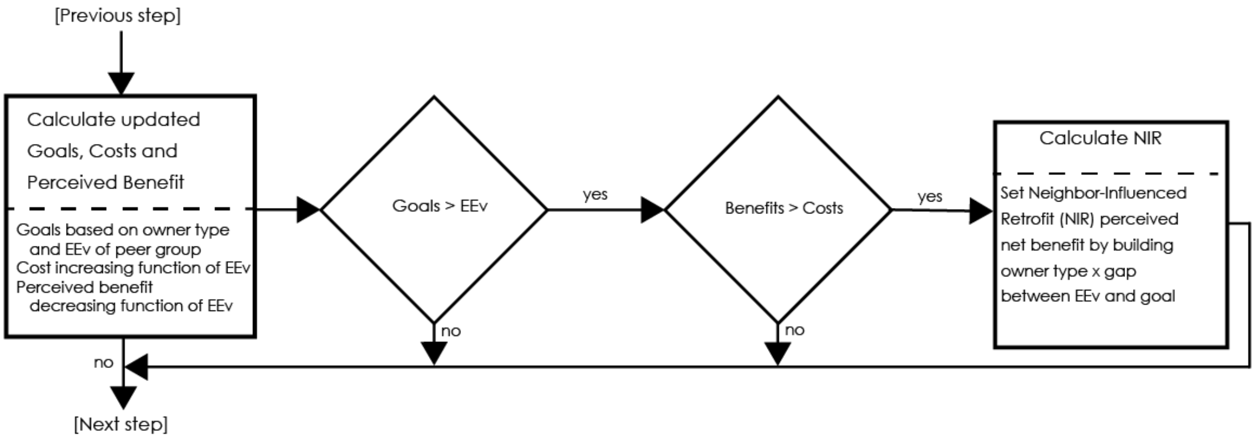

Figure 12: Neighbor-influenced retrofit decision (NIR)

The normal retrofit (NR) decision (Box 4 in Figure 9) only calculates when the counter indicates 20 years. This is to represent the normal replacement of technology. Irrespective of peer group influences, the normal replacement of equipment and materials has led to a 20% improvement in energy efficiency every 20 years. This has been attributed to improvements in technology. For example, even though replacing an HVAC system is infrequent, the newer technology is much more energy efficient. The procedure for NR directly relates to the counter, as shown in Figure 13. If the counter condition is met, NR is calculated with the equation: **NR** = ((%_EEv_upgrade_during_NR * (1 - EEv ^ diminishing_returns_curve)) – NIR). With the baseline values added, the equation is: **NR** = ((0.2 * (1 - EEv ^ 7) – NIR). The curve portion of the equation ensures that the marginal returns diminish as energy efficiency approaches 100%. NIR is also a component of the NR equation because NIR is calculated first in the procedure and can motivate a building owner to invest in a retrofit that the owner would have to invest in anyway when the 20-year counter is reached. Thus, NR ensures that a normal retrofit level occurs when the appliances or materials reach the end of their useful life cycle if NIR has not already covered the upgrade.

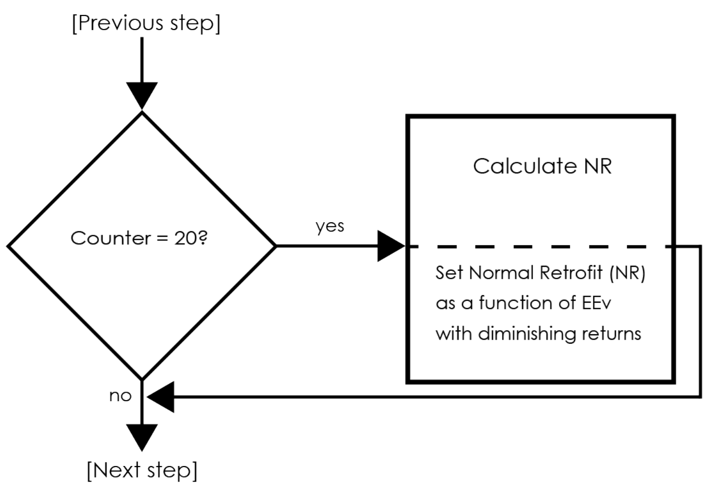

Figure 13: Normal retrofit decision (NR)

The following two procedures are building level attributes. First is the degradation rate, represented by Box 5 in Figure 9. The degradation rate is a function of a building's energy efficiency level. The assumption here is that there is a correlation between energy efficiency level and basic upkeep of the building. Highly efficient buildings are often sound, with a sealed building envelope and are resistant to potential damage from weather events. Conversely, low efficient buildings can often have leaky windows, or other signs of degradation that can make the building even more susceptible to environmental degradation. Thus, as a building loses energy efficiency over time, the rate of degradation increases. The equation for degradation used here is **Degrade** = $(.05 * (.25 \wedge EEv_i))$.

The second building level attribute is the updated energy efficiency value (Box 6 in Figure 9), which is the sum of all of the previous retrofit decisions. Updated value is represented by the formula EEv = **EEv$_i$** + **NIR** + **NR** – **Degrade**. The policy implementations, neighbor-influenced retrofit, and normal retrofit add to the energy efficiency value. The degradation rate is the only way the model represents a loss of energy efficiency.

6.2.2.3 Equations compiled

EEv = **EEv$_i$** + **NIR** + **NR** – **Degrade**

EEv$_i$ is the agent's energy efficiency value at that time step

NIR = $(G_{pg} - EEv_i) * (PB_i – C_i)$

G_{pg} is the goal value calculated from the peer group, as defined by building owner type in Figure 8

Leaders G_{pg} = maximum EEv of peer group agents

Conformists G_{pg} = mean EEv of peer group agents

Stigma-avoiders G_{pg} = minimum EEv of peer group agents

PB_i is an agent's perceived benefit of a retrofit. This differs for each building owner type:

Leaders $PB_i = (1 - (EEv \wedge 12)$

Conformists $PB_i = (1 - (EEv \wedge 1.2))$

Stigma-avoiders $PB_i = (1 - (EEv \wedge 0.2))$

$C_{i\,=}$ (EEv^3); Cost is a function of EEv

NR = ((%_EEv_upgrade_during_NR * (1 - EEv ^ diminishing_returns_curve)) – NIR)

%_EEv_upgrade_during_NR = 0.2 (default level; set by slider on interface)
diminishing_returns_curve = 7 (default level; set by slider on interface)

Degrade = (.05 * (.25 ^ EEv_i))

6.2.2.4 Stochasticity

Randomness is introduced into the NIER model in each agent's initial value for the counter (the counter is used in NR, code, and ownership scenarios). Randomness is also introduced when ownership change is allowed. New owners are selected at random but maintain the population proportions from the initial settings. All other emergent properties result from the interactions in the model.

6.3 Scenarios tested and simulated results

6.3.1 Scale

The section explores the impact of the scale of peer groups. The network between building owners in a district can be understood as a scale effect in that it provides a large group for building owners to compare. The neighborhood scale of the peer group that building owners use to compare increases from in-radius 1, 2, 3 (see Figure *14*).

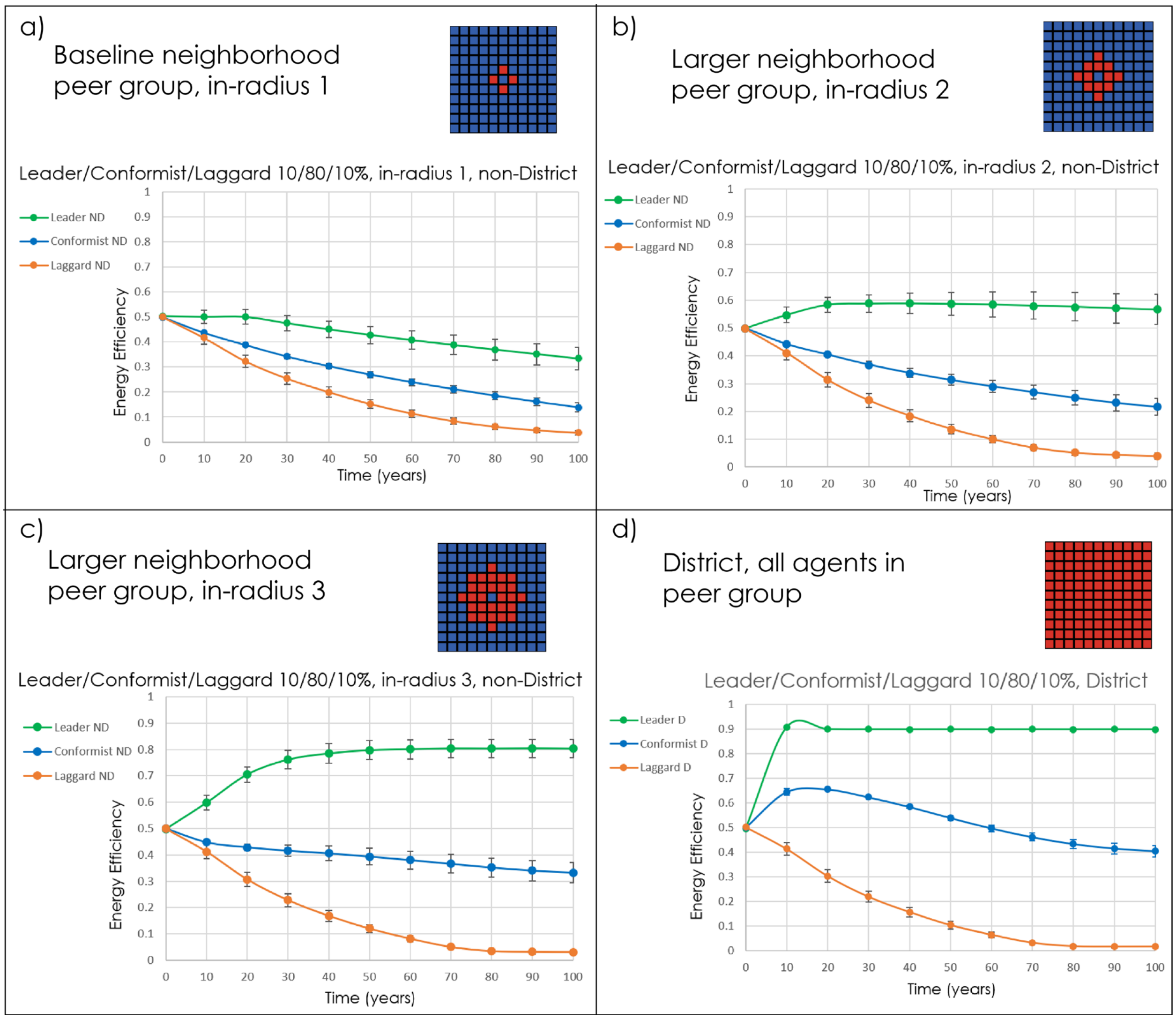

Figure 14: The effect of scale

Figure 15 shows the spatial distribution of buildings by energy efficiency. One of the key findings of scale effects that persist throughout all version of model runs is that non-district (scale = in radius 1) results in clustering by energy efficiency values. High and low energy efficient islands emerge. As the scale increases to the District, on the right of the graph (scale = all agents in District), the spatial distribution is random.

Comparing the spatial distribution from in-radius 1, 2, 3 to the district-wide comparison on the right side of Figure 15, the clustering of buildings by energy efficiency that was seen in the non-District baseline runs start to approximate the random spatial distribution of the district. The non-District plots of energy efficiency also start to approximate the shape of the plot from the District, with Leaders and Conformists rising in energy efficiency value. The mechanism describing the results from the District is that the greater number of agents in the comparison group, the greater chance of Leaders and Stigma-avoiders finding others with extreme values and the system tends towards homogeneity of values around building owner goals (maximum, average, and minimum).

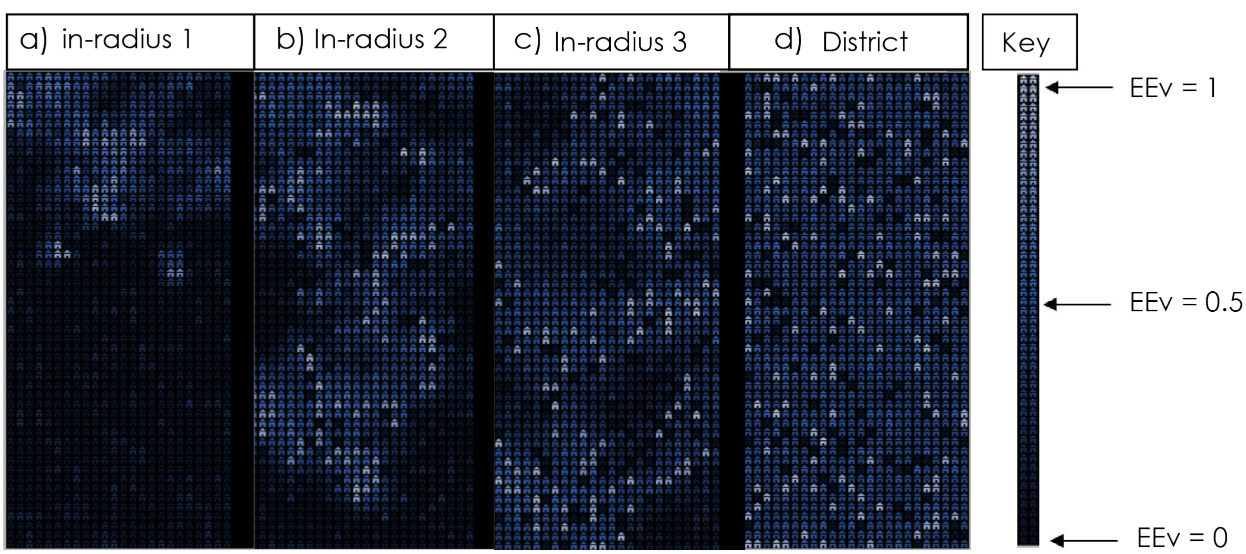

Figure 15: Spatial output from baseline run 10% Leaders, 80% Conformists, 10% Stigma-avoiders

The mechanism for neighborhood scale effects is that as the peer group expands, interaction in the model loses the stability of hybridity of small neighborhood peer groups and Stigma-avoider owners of low efficient buildings do not upgrade because they meet the lowest value in the larger peer group. Stigma-avoiders lose the small group influence that can otherwise raise their energy efficiency values locally. In practice, this may be seen with outlier dilapidated buildings in gentrifying neighborhoods.

Small spatial scales produce hybridity in neighborhood clusters. There are benefits to the hybridity of non-districts that are created by encouraging local neighbor comparisons. These benefits are good for equity because they have spillover effects that can improve Stigma-avoider owned buildings. However, the benefits of interaction from local energy efficiency clusters takes time. So, it can be useful if municipal goals are to improve energy efficiency over the long term, but not so if the goals are short term results

By contrast, the benefit of the homogeneity in Districts at large spatial scales are in promoting broad energy efficiency goals. Given the implications of the mechanism at large spatial scales, the results seen in the District may be analogous to raising standards nationally. Future research could study similar dynamics in national standards.

6.3.2 New owner at point of sale

The mechanism that keeps buildings at low energy efficiency levels is that Stigma-avoider ownership (low goals, low Perceived Benefit) and high degradation rates (degradation rates increase as building energy efficiency decreases) lead to no retrofit decision being made. The mechanism that allows Stigma-avoider-owned buildings to lose efficiency over the time (over the model run) is that they are not motivated to meet any goal other than the minimum. Figure 16 models a random change of ownership, which is enough to break the negative cycle for Stigma-avoider building owners in Districts, because they are no longer comparing themselves to a global minimum, but is not enough to break a negative cycle in non-Districts because all building owner types are losing efficiency. Thus, in non-Districts, there is no local peer group to bring the minimum up. The planning and policy recommendation is that a combination of District approaches with efforts to encourage turnover among Stigma-avoider-owned low-efficiency buildings, could lead to energy efficiency gains in the building stock overall.

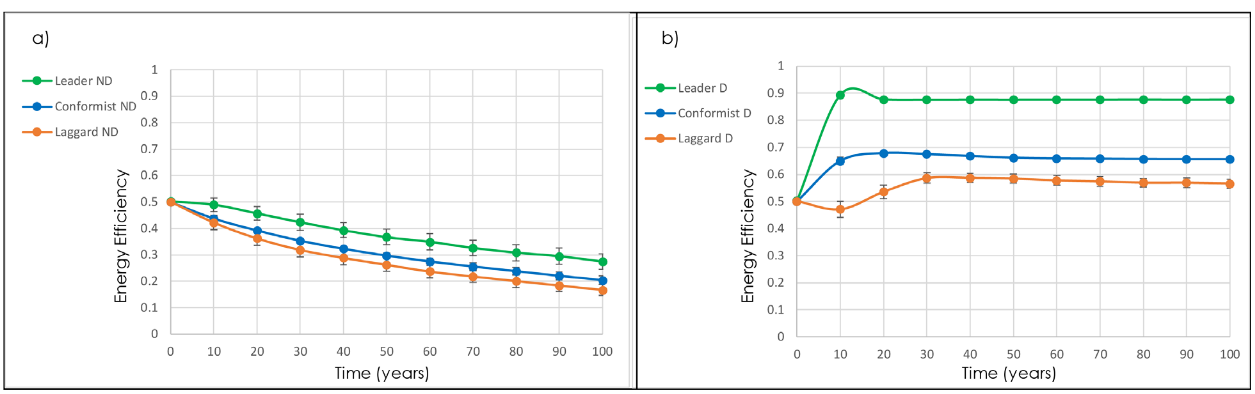

Figure 16: New building owner type allowed at point of sale, a) non-District, b) District

6.3.3 Upgrade to code at point of sale

Figure 17 shows the results of a 50% energy efficiency upgrade at the point of sale. This is a planning and policy intervention that is being discussed in many cities. Point of sale is one moment when a municipality can require upgrades. This is also a practical intervention because it often does not require a change in policy, though code standards also play a role. NGOs have been working with officials to enforce the energy-relevant portions of the building code. Figure 17 a shows that code enforcement and local neighborhood peer influences can stabilize the average energy efficiency levels of all building types, whereas code enforcement in District approaches have the greatest impact upon Stigma-avoiders. The reason for this is that the mechanism for code enforcement is to raise the base level and provide an energy efficiency floor, thus the impact will be primarily on those with low energy efficiency levels. The planning and policy recommendation from these results is that code enforcement can be used as the stick to motivate building owners who do not respond to traditional approaches. In isolation, it will raise the base, but needs to be combined with incentives to achieve high energy efficiency gains among the population of multi-unit residential building owners.

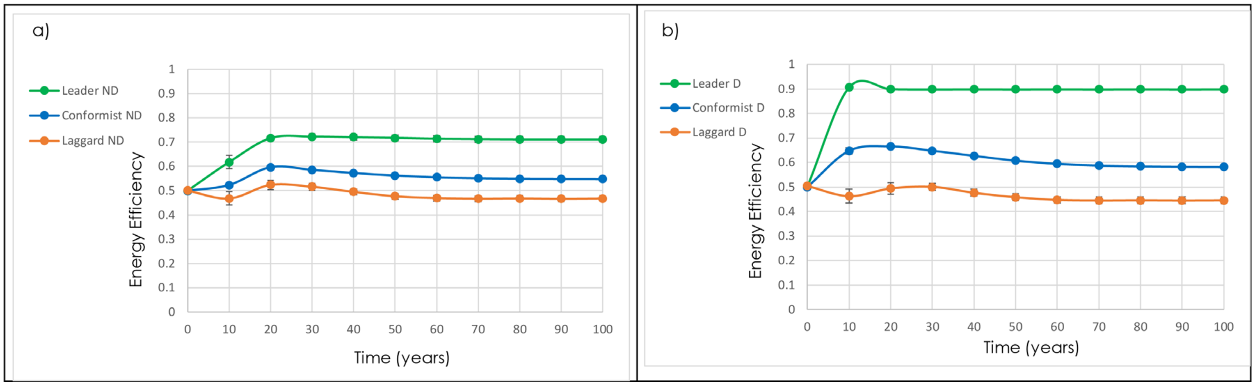

Figure 17: 50% upgrade to code at point of sale a) non-District, b) District

7.0 INTEGRATED PLANNING AND POLICY IMPLICATIONS FROM THIS STUDY

This research contributes to more robust energy efficiency planning that can motivate reluctant building owners with effects beyond the initial intervention. Planning for energy efficiency in multi-unit residential buildings implores examining the assumptions underlying conventional approaches and implementing more robust strategies that account for the potential of negative, unexpected reactions. This study included cities with aging building stocks and budgetary constraints to identify effective approaches to promoting energy efficiency retrofits approached in challenging contexts.

The main contribution of the NIER model is to identify if, and how, influences from neighborhood peers can amplify existing approaches to energy efficiency. This would be especially useful in the multi-unit residential sector where those who incur the costs of a retrofit may not be the same as those who reap the benefits of energy savings. Given that neighbor influences upon the motivation to retrofit may include factors beyond costs and expected energy savings, these factors have the potential to bridge the problem of split incentives.

The NIER model explore approaches to achieving energy efficiency in multi-unit residential buildings and identified those that can produce unintended consequences. A broad summary of the insights from the NIER model include: Large peer groups can achieve quick energy efficiency gains but abandon reluctant owners. Small peer groups successfully motivate all types of building owners but takes time and requires large financial incentives. A combined approach with bringing buildings up to code at the point of sale improves retrofit outcomes.

Both, the interviews and the NIER model indicate that a combination of carrot and stick approaches would be the most effective in achieving the greatest returns in energy efficiency and in reaching all of the building owners. The use of carrots, positive incentives, can benefit from leveraging neighbor and network peer influences. These are low resource intensive approaches to amplifying energy efficiency benefits throughout a population. However, as the qualitative portion of this study showed, some building owners would be more motivated by sticks, which can be enforced regulations such as energy-related building codes. For example, multiple interviewees brought up the case of Portland, Oregon municipal code requiring a Home Energy Score to be included when selling a residential property (Interview 020, Feb. 20 2018; Interview 025, Jun. 27 2018)(EIA 2019).

Below is an example of an effective combination of planning and policy recommendations that are derived from the findings of this study.

	Interview-based findings	NIER model insights
Carrots	• Promote Green MLS listings • Train facilitators to work with building owners and associations • Share energy efficiency data, improve data quality, and make certification ratings visible • Integrate disconnected efforts into a social infrastructure coordinating goals, strategy, and resources to improve energy efficiency	• Leverage neighbor peer effects through building owner associations • Leverage network peer effects through energy efficiency organizations • Combine strategies to quickly improve energy efficiency and motivate reluctant owners
Sticks	• Fund work to improve energy benchmarking data and its use • Require reporting of energy efficiency data upon sale	• Enforce energy efficiency upgrades to code

Table 4: Planning and policy recommendations

The recommendations are a combination of approaches because more robust approaches are needed to account for building owners who respond contrary to an incentive's objectives. A common theme from the interviews is that approaches to energy efficiency are too often disconnected and lack capacity to properly assess the performance, verify data, and conduct the needed engagement with building owners. This study calls for a more integrated approach to energy efficiency. One step towards integration would be to make formal institutional bridges between municipalities, NGOs, building associations, and utilities where they can openly share information and coordinate efforts and resources. The developing networks and platforms that are emerging between municipalities and organizations also create an opportunity for greater involvement from building owners.

As municipalities achieve energy efficiency with their current approaches and move into the more numerous and diverse buildings in the residential sector, finding a way for building owners to estimate their energy efficiency profile becomes increasingly important. Including such attitudinal and behavioral questions could also be joined with existing energy assessments and full energy audits, but this strategy may be limited by making such practices even more time and labor intensive. The goal of improving the accuracy of building energy profiles and identifying the types of retrofits needed are important. For planning and policy approaches to be effective in the multi-family residential sector, factors beyond energy savings need to be leveraged with building owner decision-making processes. Factors such as the influence of neighbor and network peer groups provide a promising first step in the direction of an energy efficient future.

8.0 LIMITATIONS AND FUTURE RESEARCH

The exploratory approach taken by this research calls for future research to conduct broad surveys to evaluate the effectiveness of the energy efficiency approaches identified by the interviewees. Future research could explore the detailed meanings that building owners and municipal employees assign to energy efficiency. Municipalities and NGOs assume that energy efficiency is inherently desired by building owners and they would do so if given the appropriate conditions. This research showed that this assumption is not always held by building owners.

Further, this study is based on qualitative interviews. There is often a distinction between what interviewees say and what they do. Future research is encouraged to compare beliefs with actions and identify the factors that are correlated with their energy retrofit investments. These could depend on social context or region. Thus, future research could explore diversity between regions or between sub-groups within a city.

Multiple interviewees stated that a motivation for multi-unit residential building owners to retrofit is the potential revenue that can be generated from increased occupancy and tenant retention. However, a question to be studied is if building owners see an increase in revenue after a retrofit. Theoretically, as the percentage of multi-unit building owners implement energy retrofits and expect a financial return in tenant revenue, and the number of potential tenants in a city do not increase, then there will be a tipping point where there will not be enough tenants to meet the building owners' expectations, and they will not see a return from this potential revenue. If that is the case, then will building owners may not continue to share information of positive experiences with energy retrofits. Surveys of building owners and tenants would need to be conducted to quantify their perceived benefits, externalities, and their actual energy costs and savings.

Extensions of the NIER model could include a comparison of perceived net benefit and actual benefit. Given that many building owners are promised additional benefits from tenants, future models could explore the neighborhood effects if those effects are successful or do not materialize.

Information sharing is crucial to this study. Future research can extend this study by determining how building owners make meaning of their retrofit experience and translate that into positive or negative feedback that they share with neighbors. Agent-based models are capable of modeling both positivist and social constructivist mechanisms, though ABMs are rarely modeled with the latter (Yang and Gilbert 2008). This could include more detail on the actual information that is conveyed to peers as well as how that information is received, can influence whether the information is trusted and acted upon.

This study takes the perspective of how municipalities and NGOs can motivate building owners to retrofit and how building owners perceive and respond to these attempts at motivation. Research taking a bottom-up perspective can be enlightening. Such a perspective can include cases where tenants put pressure on building owners to upgrade. This example was suggested by an interviewee.

While this study focused on energy retrofits, future research can include rebound effects. Improving a building's energy efficiency could change behavioral energy consumption within that building, thus negating any energy efficiency gains when building-level energy consumption is measured. Future models would account for both energy efficiency and behavioral energy consumption effects. The NIER model can be extended by including additional variables to the retrofit decision-making process such as return on investment (ROI), various financial incentive programs, and how benefits and costs can be perceived differently based on various social factors.

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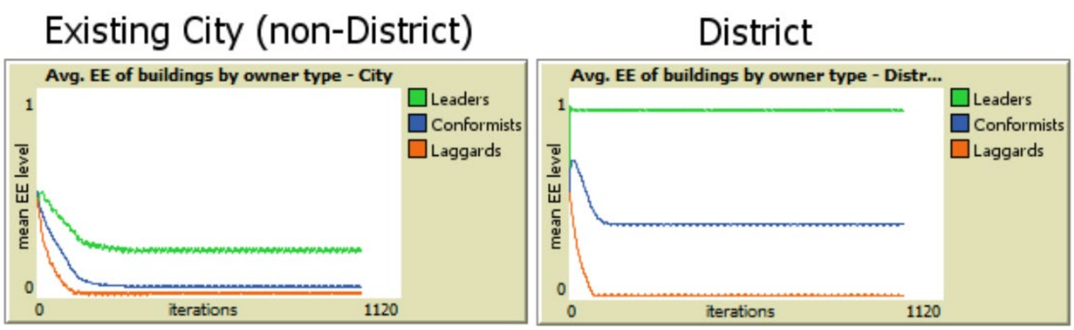
10.0 APPENDIX 1 MODEL RUNS - PARAMETER EXTREMES

<u>10.1 Run length 1000 iterations</u>

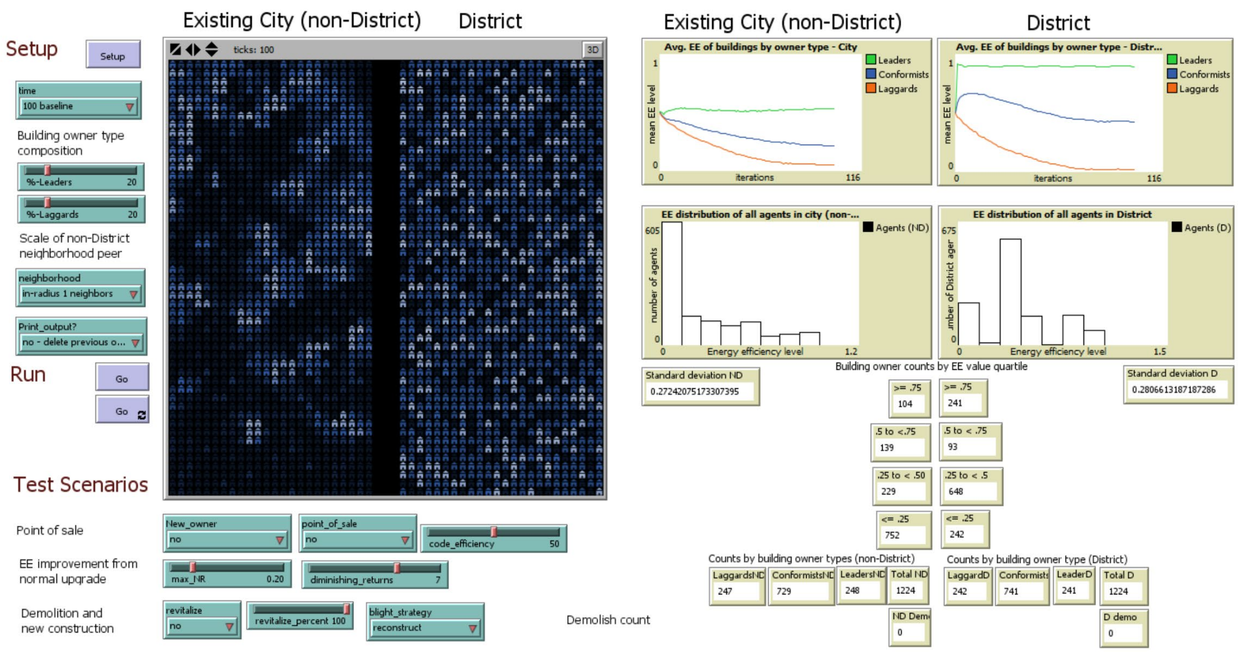
Stabilization in the baseline is reached at approximately 100 iterations for the District and approximately 170 iterations for the non-District.



<u>10.2 Building owner type compositions</u>

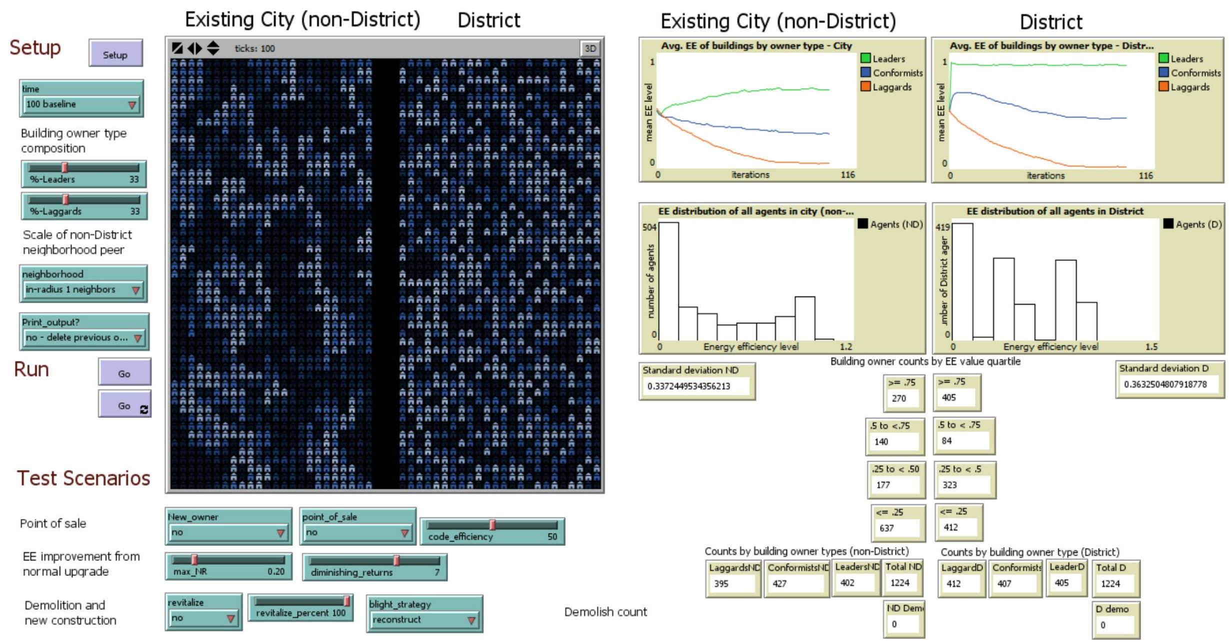
20% Leaders 60% Conformists 20% Stigma-avoiders

In cases where the baseline is 20% Leaders, 60% Conformists and 20% Stigma-avoiders, the non-District Leaders perform better



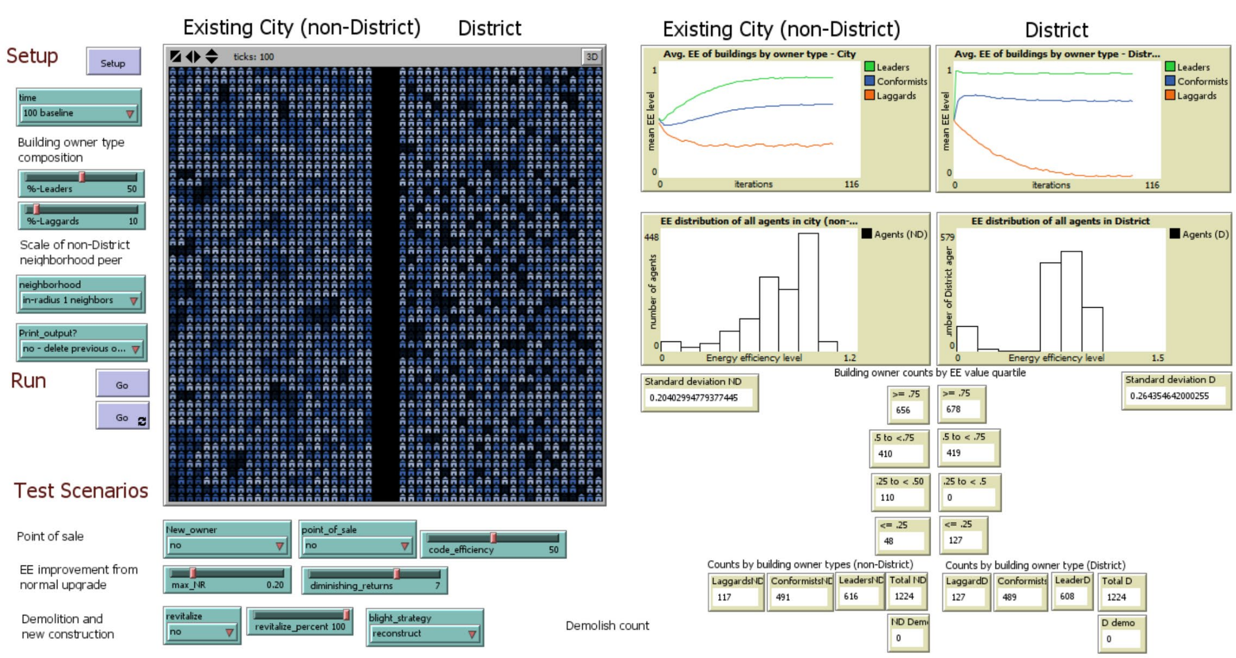
Existing City (non-District)
District
Setup
Setup
time
100 baseline
Building owner type composition
%-Leaders 20
%-Laggards 20
Scale of non-District neighborhood peer
neighborhood
in-radius 1 neighbors
Print_output?
no - delete previous o...
Run
Go
Go
Test Scenarios
Point of sale
New_owner
no
point_of_sale
no
code_efficiency 50
EE improvement from normal upgrade
max_NR 0.20
diminishing_returns 7
Demolition and new construction
revitalize
no
revitalize_percent 100
blight_strategy
reconstruct
Demolish count
ticks: 100
3D
Existing City (non-District)
District
Avg. EE of buildings by owner type - City
Leaders
Conformists
Laggards
mean EE level
iterations
Avg. EE of buildings by owner type - Distr...
EE distribution of all agents in city (non-...
Agents (ND)
number of agents
Energy efficiency level
EE distribution of all agents in District
Agents (D)
Standard deviation ND
0.27242075173307395
Building owner counts by EE value quartile
Standard deviation D
0.2806613187187286
>= .75
104
>= .75
241
.5 to <.75
139
.5 to < .75
93
.25 to < .50
229
.25 to < .5
648
<= .25
752
<= .25
242
Counts by building owner types (non-District)
LaggardsND
247
ConformistsND
729
LeadersND
248
Total ND
1224
ND Dem
0
Counts by building owner type (District)
LaggardD
242
Conformists
741
LeaderD
241
Total D
1224
D demo
0

33% Leaders 34% Conformists 33% Stigma-avoiders



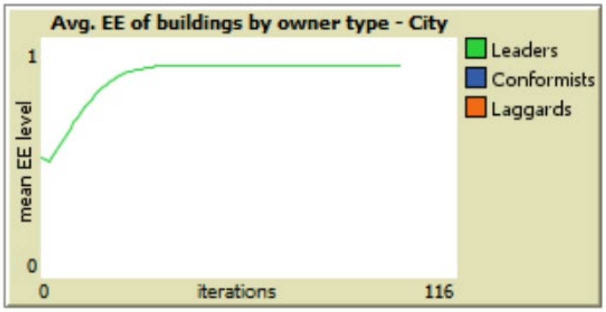
50% Leaders 40% Conformists 10% Stigma-avoiders

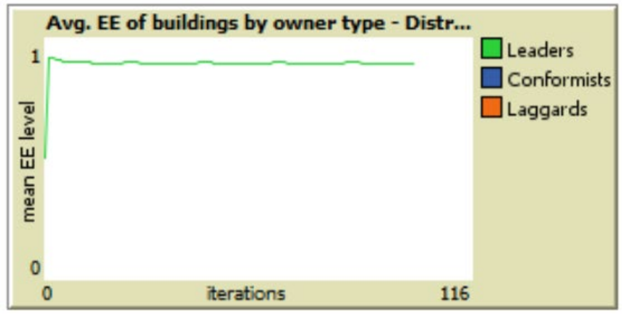
It takes 50% Leaders to stabilize non-District Stigma-avoiders



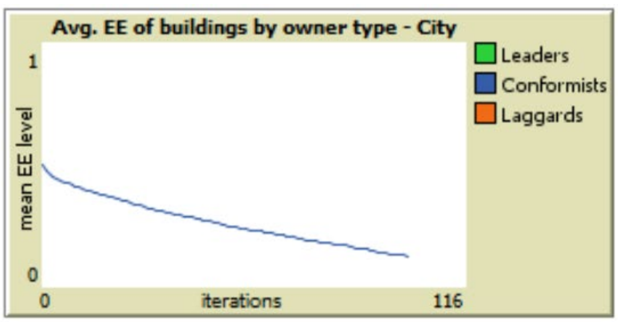
10.3 Building owner type parsed

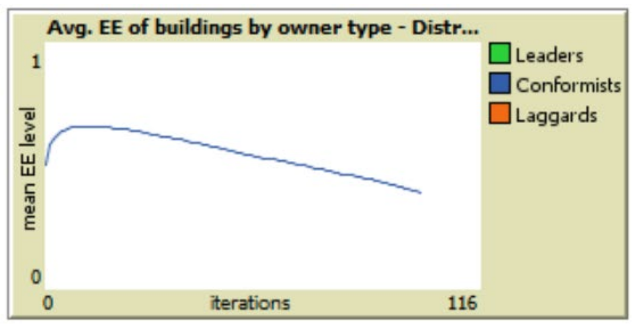
Leaders



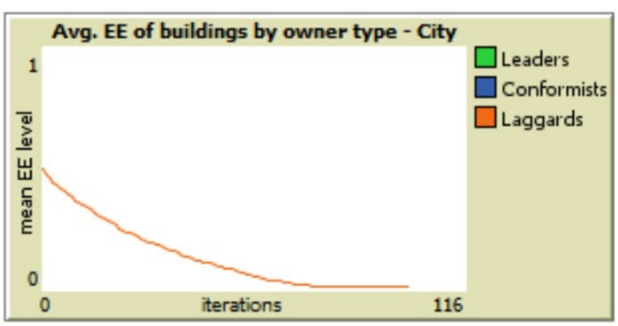


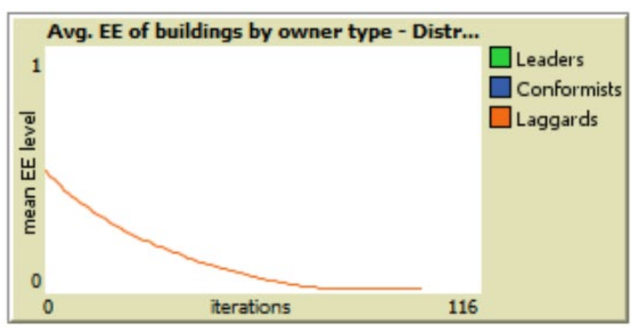
Conformists



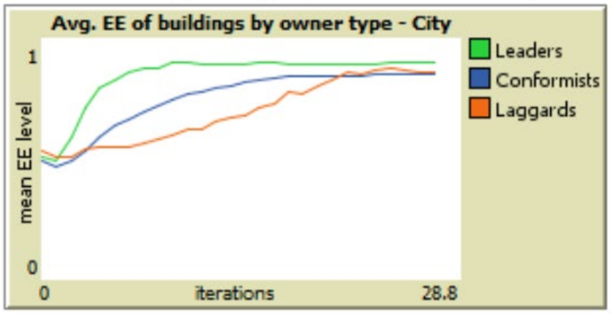


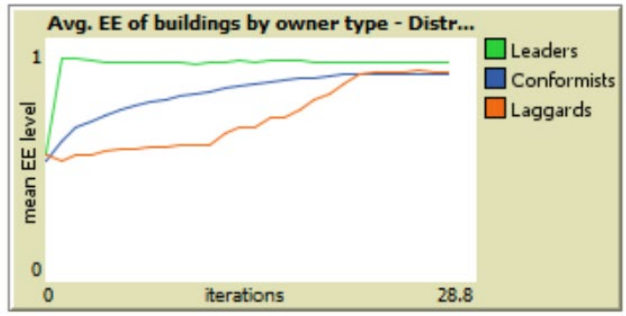
Stigma-avoiders





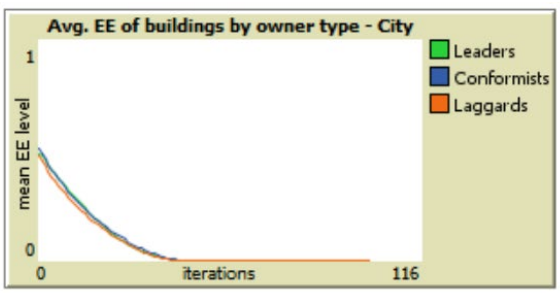
10.4 Code efficiency 100% code

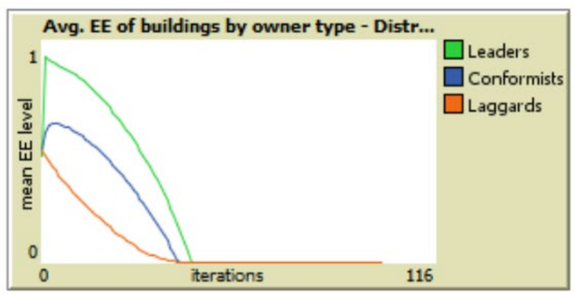




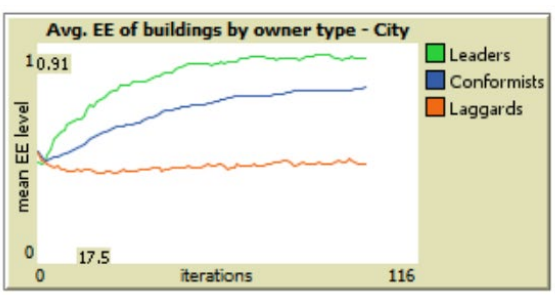
10.5 Max_NR

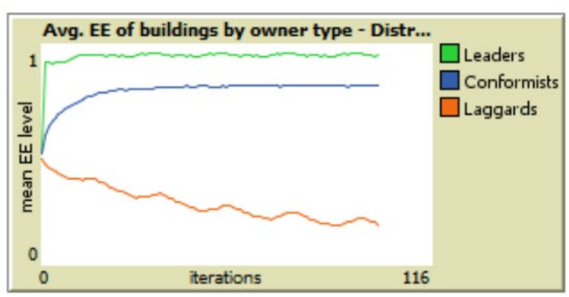
0% no Normal Retrofit



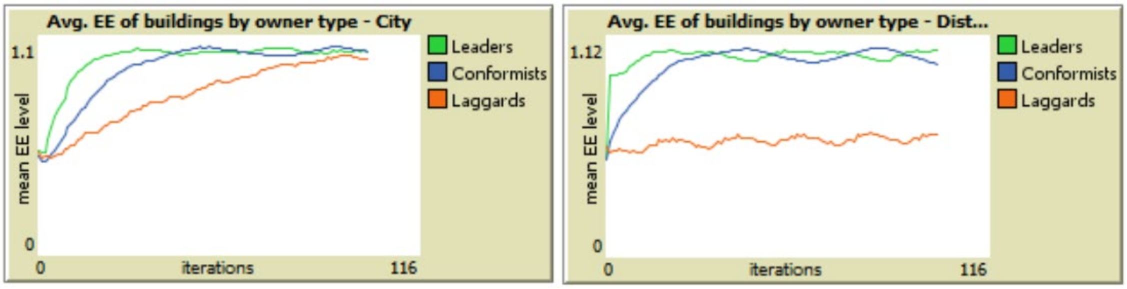


33% non-District tipping point



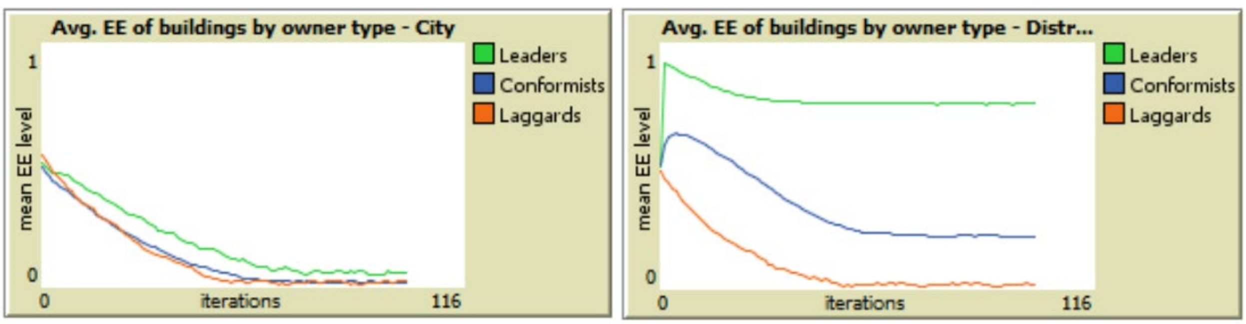


50%

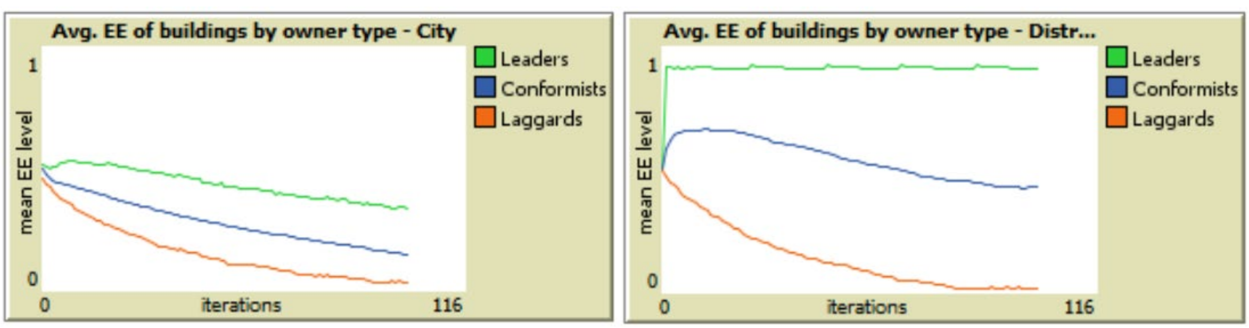


10.6 Diminish return curve

X^1



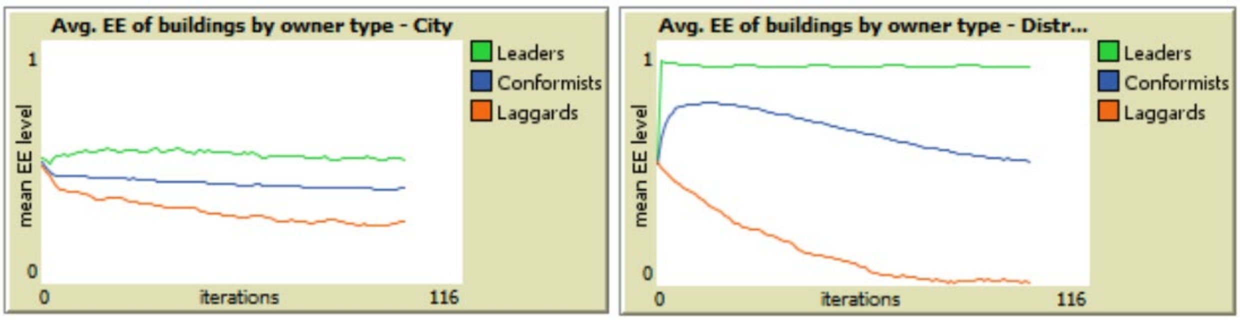
X^10



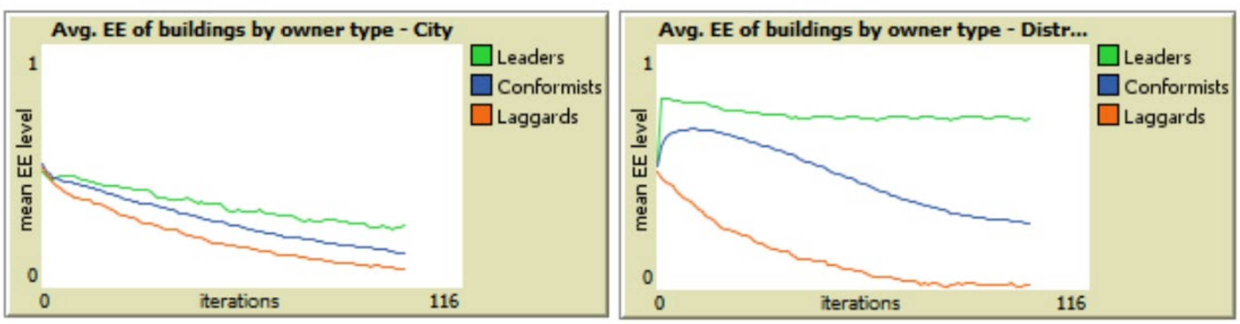
<u>10.7 Perceived Benefit curve</u>

Perceived Benefit curves change the level of upgrade, but the behavior of the system, the relationship between building owner types based on different goals, remains the same.

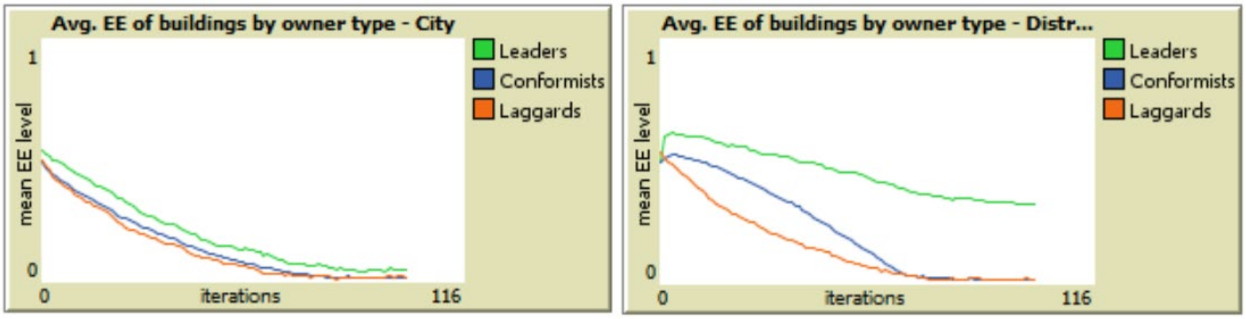
All building owner types with Leader Perceived Benefit ratio



All building owner types with Conformist Perceived Benefit ratio



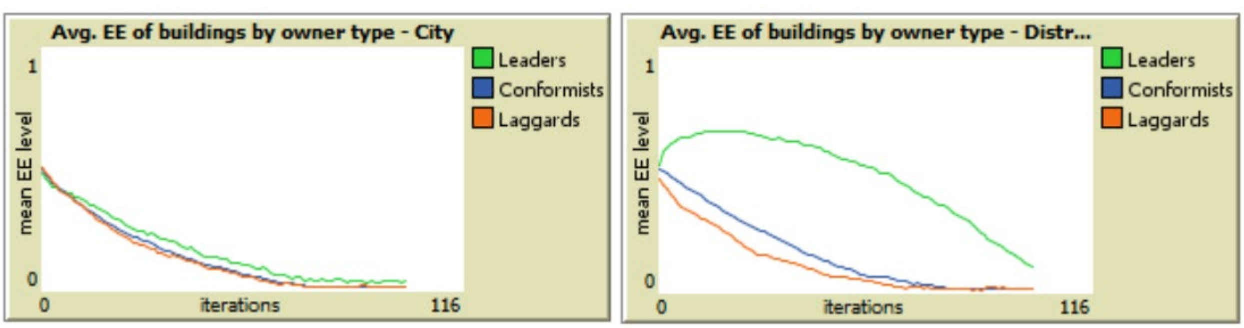
All building owner types with Stigma-avoider Perceived Benefit ratio



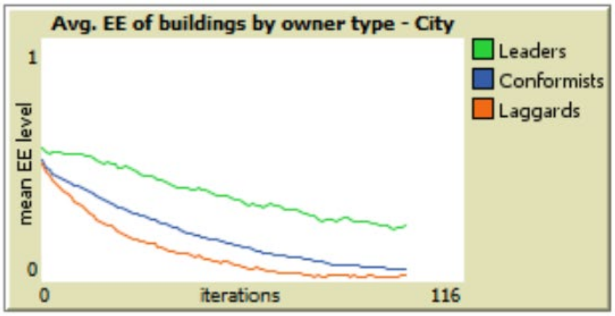
<u>10.8 Cost curve</u>

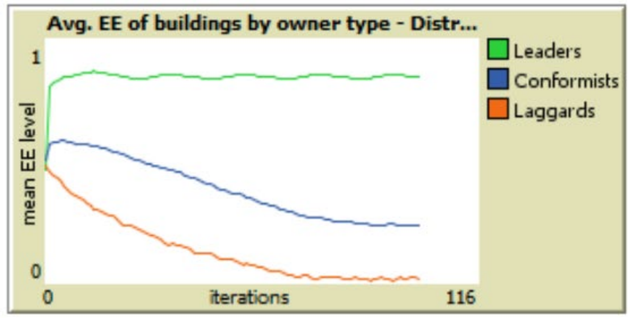
Changing the shape of the cost curve affects the amount that agents upgrade. Given the calculation is to assess motivation to retrofit, then assess the amount of retrofit by Perceived Benefits – Costs, it is expected that pushing that difference to zero will start to look like a system that has no retrofits (as seen in the x^0.1 example below).

X^0.1

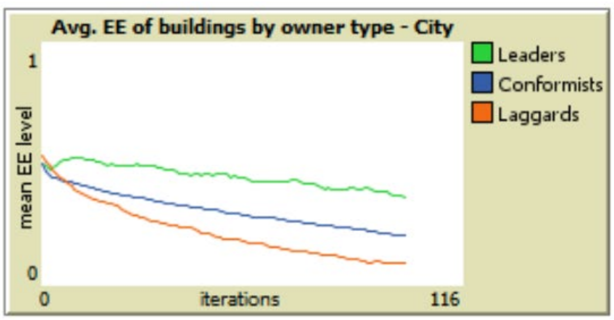


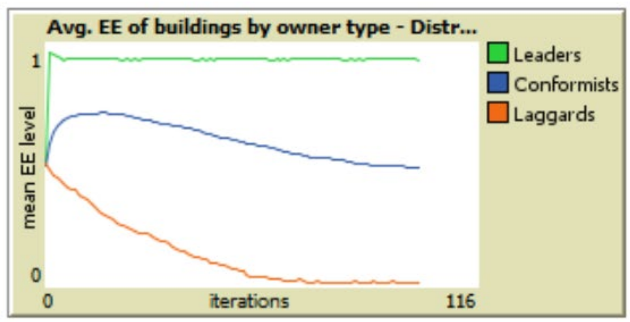
X^1


Avg. EE of buildings by owner type - City
1
0
mean EE level
0
iterations
116
Leaders
Conformists
Laggards


Avg. EE of buildings by owner type - Distr...
1
0
mean EE level
0
iterations
116
Leaders
Conformists
Laggards

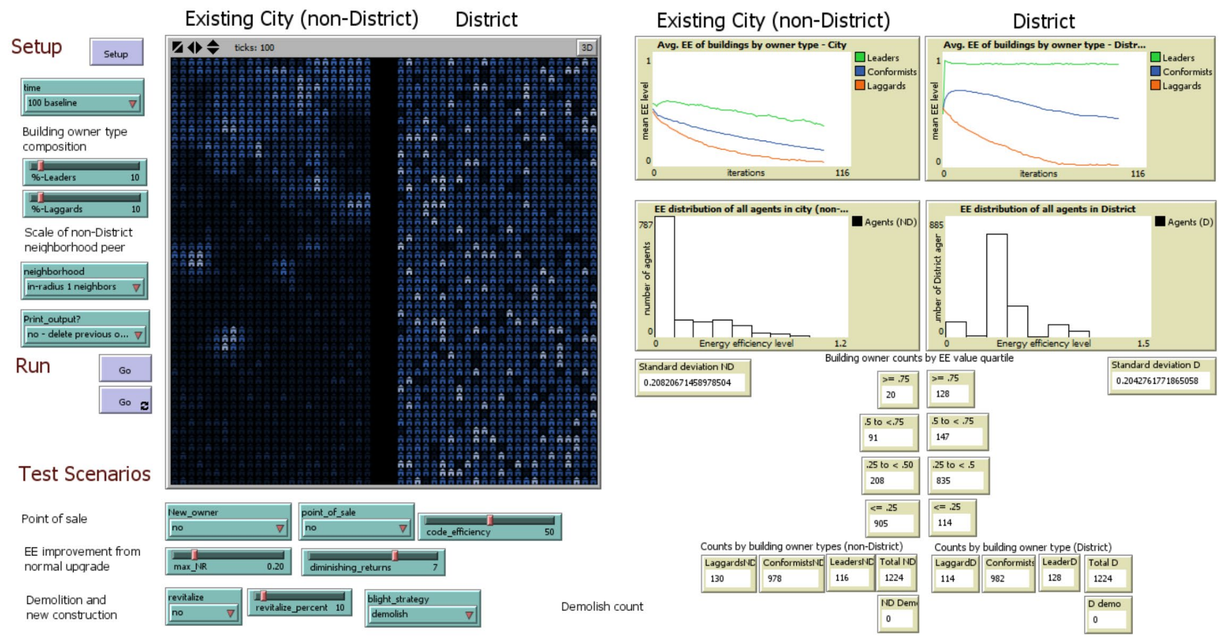
X^10


Avg. EE of buildings by owner type - City
1
0
mean EE level
0
iterations
116
Leaders
Conformists
Laggards

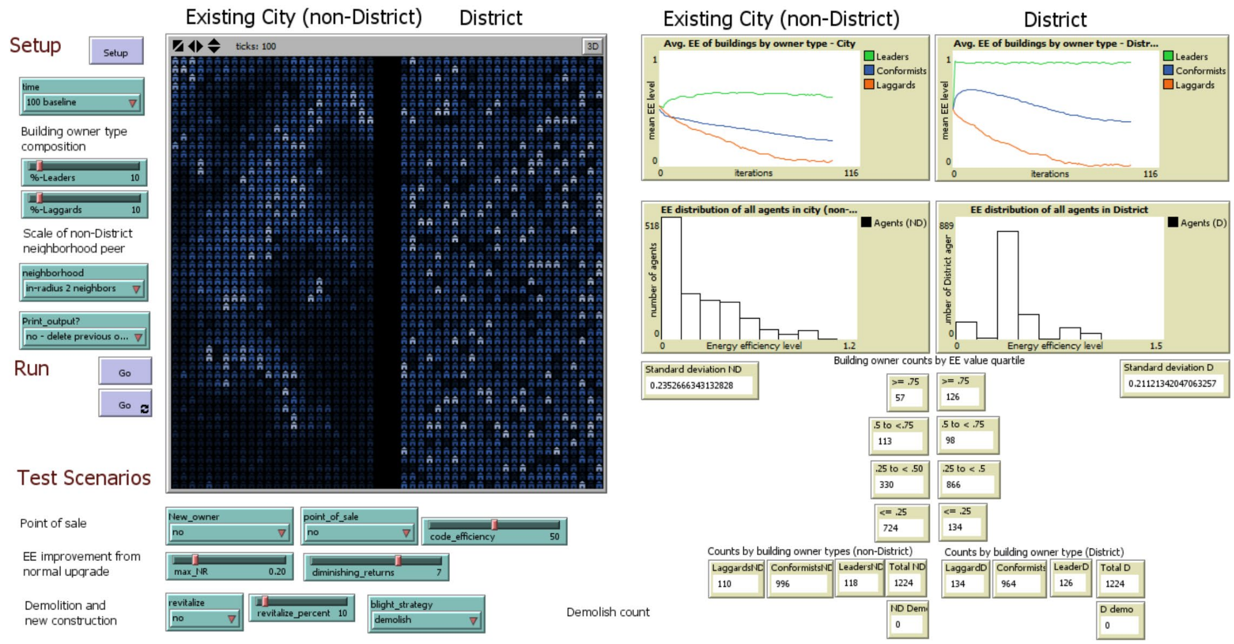

Avg. EE of buildings by owner type - Distr...
1
0
mean EE level
0
iterations
116
Leaders
Conformists
Laggards

11.0 APPENDIX 1: MODEL RUNS

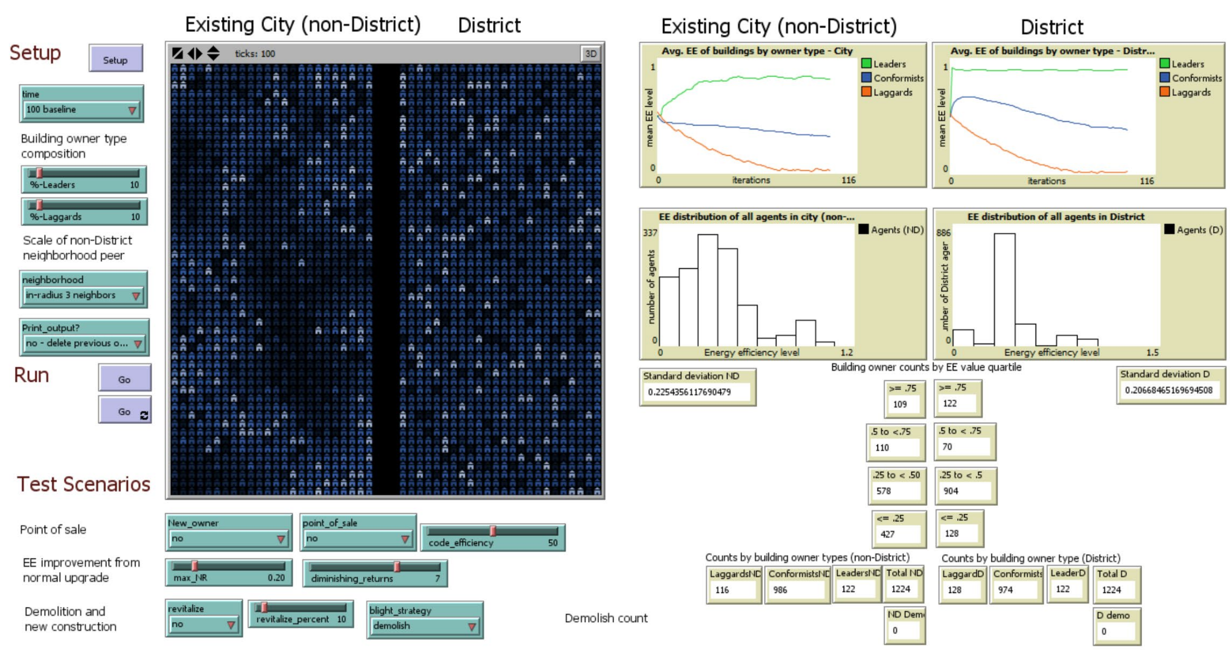
11.1 Baseline



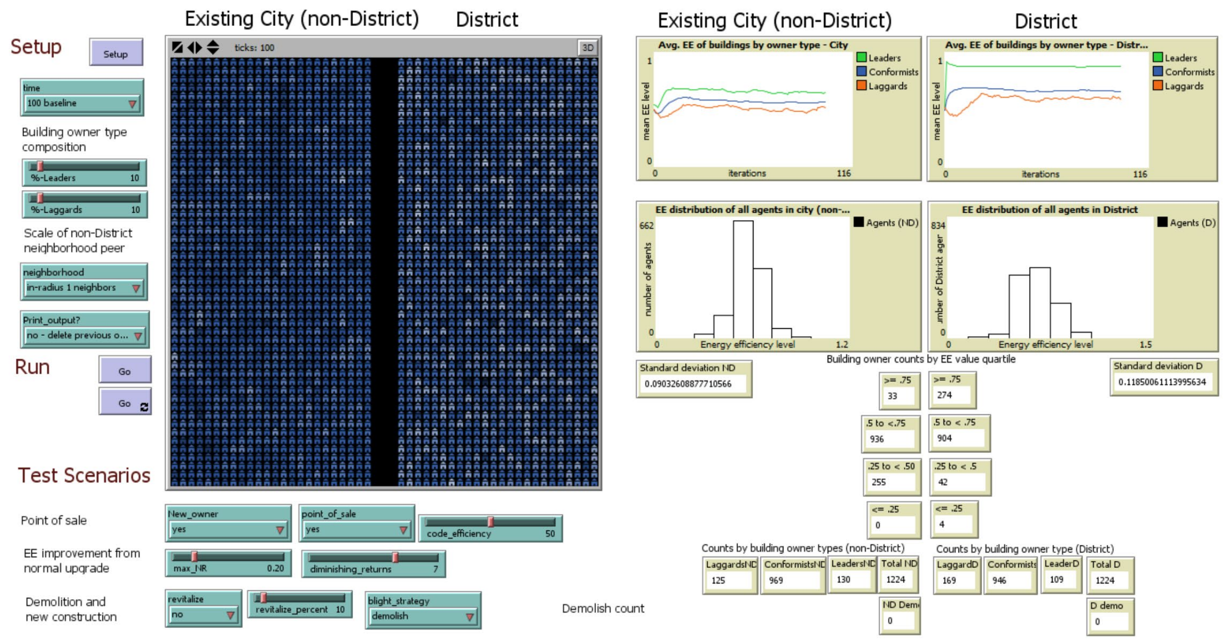
11.2 Scale in-radius 2



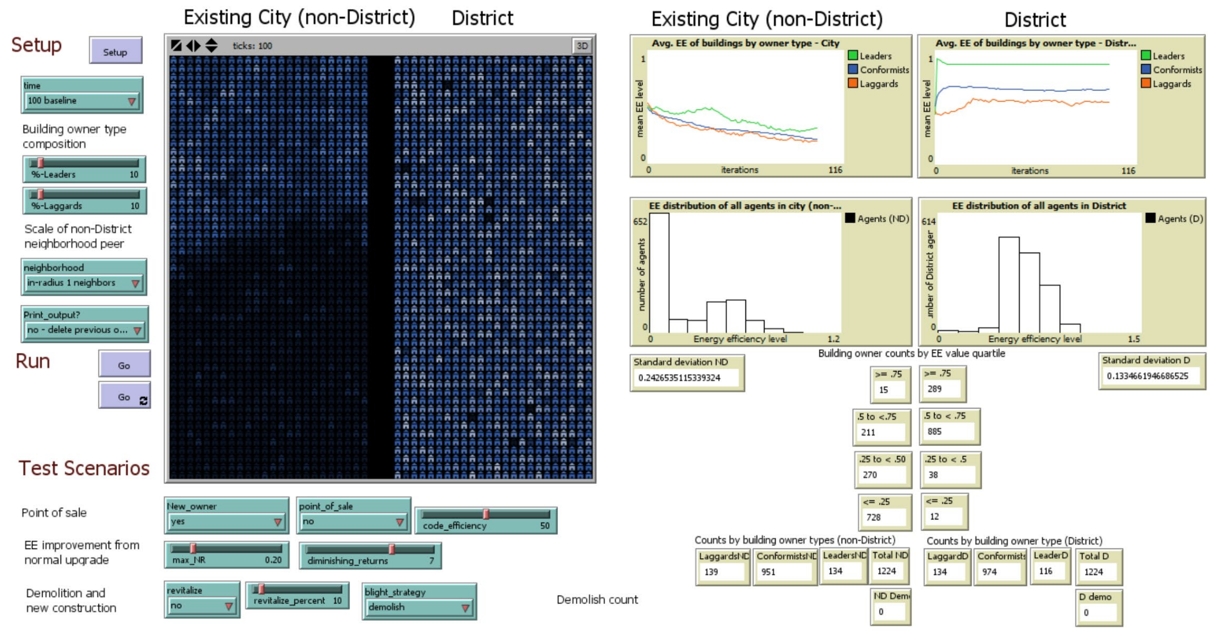
11.3 Scale in-radius 3



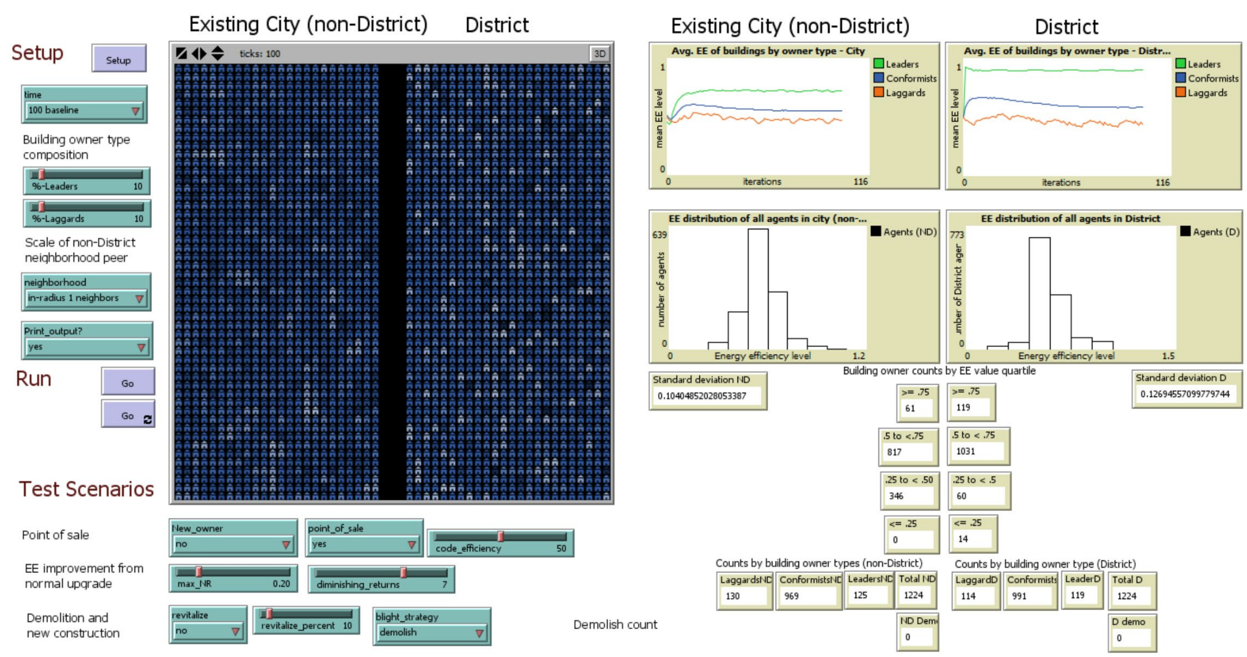
11.4 Point of sale: ownership and code enforcement



11.5 Point of sale: ownership, no code enforcement

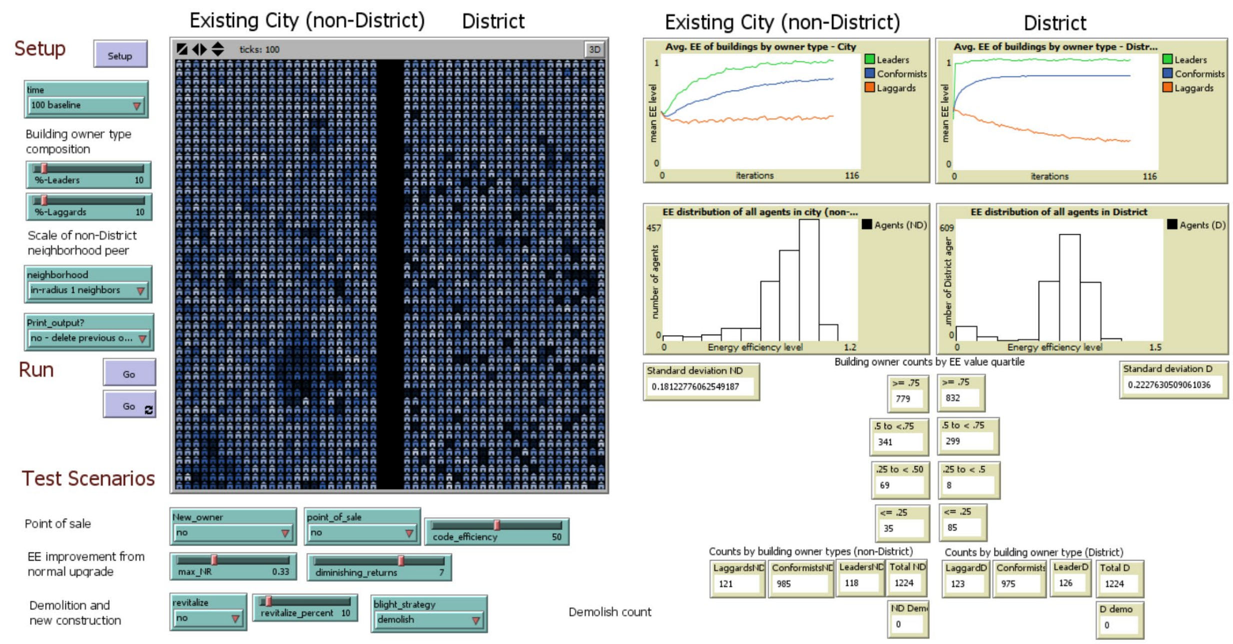


11.6 Point of sale: no ownership change, with code enforcement



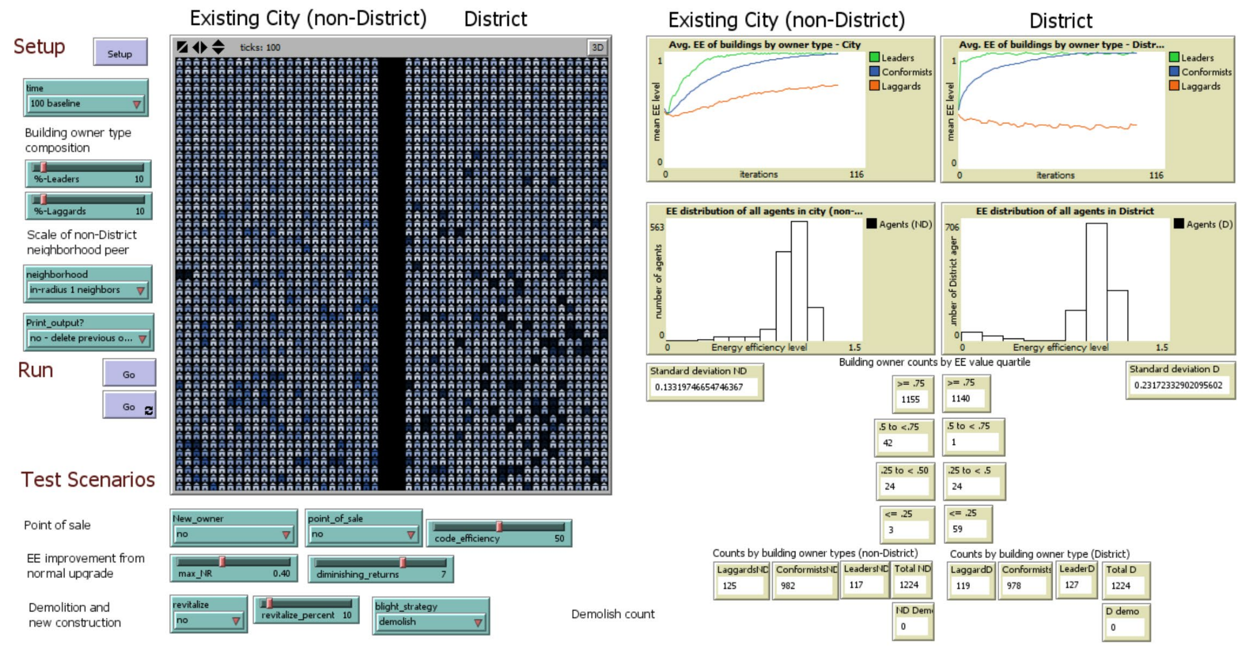
11.7 Increasing EE returns per normal upgrade 33%NR

Tipping point for non-District Stigma-avoiders is around a max_NR of .33



Past that point, the non-District is better at raising the energy efficiency of Stigma-avoiders than Districts.

11.8 Increasing EE returns per normal upgrade 40%NR



12.0 APPENDIX 2: Interview Protocol

12.1 First round questionnaire

Factors influencing choice of energy efficiency measures

1. How does your city/organization decide on which energy efficiency programs to pursue?
    a. What is the role of economic incentives? Does the program need to demonstrate economic viability and if so, what is the accepted ROI to pursue the program?
    b. How important is the economic feasibility (public support) for a program? Do you expect public support to change as the program is implemented? If so, how?
    c. What is the role of sustainability goals or plans in driving your choice of energy efficiency programs?
    d. What other factors influence your choice of energy efficiency measures and how important are they in your final decision?

Factors influencing investment in energy efficiency measures

2. When an energy efficiency measure/program is selected, what factors influence how much investment is allocated towards its implementation?
3. What are the main challenges to allocating investment towards energy efficiency measures and how do you address those challenges?

4. How can budgets be organized to better meet city and regional energy reduction goals?
    a. Can you give us specific examples as to when budgetary limitations caused issues for implementing energy efficiency?
5. What is the role of sustainability plans in allocating investment towards energy reduction measures?

Role of facilitating organizations

6. What kind of collaborations (state or federal departments, regional organizations and/or NPOs) help with the successful selection and implementation of these programs?
    a. What kind of assistance did they provide that was most valuable?
    b. What kind of information did they share that helped your city invest in energy efficiency programs?
    c. Have you worked with nonprofit organizations as facilitators? If so, what support did they provide and how was that different from governmental support?
7. What is the role of Federal or State level government support?
    a. How much influence does that support have upon your energy efficiency decisions?
    b. Are there ways that you can continue to pursue the energy efficiency program without that support? If so, how?

8. Are there programs that are managed across multiple cities?
    c. How are competing priorities addressed?
    d. How do you coordinate program implementation across cities.
    e. If there was a facilitating organization, can you speak about how they supported collaboration?

Influence of existing measures upon future energy efficiency planning

9. Does your initial selection of energy efficiency programs affect the programs you will select in the future? Can you give an example of how your choice of programs affected subsequent choices or investment?
10. What are the main factors that will help your city better plan for energy efficiency in the future? Why are those factors important?

12.2 Second round questionnaire

1. How do apartment building owners think through whether or not to do an energy retrofit (the steps they take and the factors they weigh) and how is this process different between apartment buildings occupied by home owners and those occupied by renters (assuming that the tenant pays the electrical bill)?
    a. I'm particularly interested in the non-economic incentives/ motivations for investing in retrofits. What factors do they weigh, such as considerations of their neighborhood, comparison with similar buildings, status, aesthetics, comfort?
    b. For buildings where individual tenants pay for their own electricity, are there economic benefits building owners gain from a retrofit?
2. How then do building owners decide on the type of retrofit (the technology or how extensive of a retrofit they seek – ex.: lighting vs. HVAC replacement)? Is it all about the cost of technology and the potential savings? Are there neighborhood considerations for the choice of retrofit?
3. There is much emphasis upon shortening the time for a return on investment. What is more influential: low initial cost, a short ROI time or the potential for large, long term savings?
    a. What is an acceptable window of time for a short ROI to motivate a building owner to proceed with a retrofit and how is this impacted by the

building owner's management strategy? (or is any non-immediate economic return a barrier?)

b. Is there a level of potential energy cost savings from a retrofit that would justify a long ROI, say a particular percentage of savings?

4. What is the role of communication between building owners and associations in encouraging retrofits? Is there information shared that is particularly effective, such as like or dislike of particular technologies or funding mechanisms?
5. For the apartment buildings that are high performers – lead the pack in energy efficiency – what motivates them and who do they compare themselves with (types of buildings they see as peers or inspiration).
6. How do the steps building owners take in making retrofit decisions differ between those that are high performers vs. low performers (assuming both are old buildings that need to be or have been retrofitted)?
7. What do cities do to help apartment building owners implement retrofits and what do they do that creates barriers for building owners (ex. Incentive programs or building code enforcement)?
    a. Besides specific actions/programs, what can cities do to provide an environment/culture where retrofits are encouraged?
    b. How does the city's sustainability efforts impact building owners' retrofit decisions, if at all?
8. What organizations help apartment building owners to choose a retrofit (ie. City departments, nonprofits, business associations, foundations)?

    a. What kind of assistance did they provide that was most valuable?

9. What is the role of Federal or State level government support?

Can you speak about the effect that making energy efficiency data publicly available, or visible to a building owner's network of other building owners, may have on encouraging a decision to retrofit?

13.0 APPENDIX 3: IRB EXEMPTION LETTER

Exemption Granted

October 6, 2017

Eric Boria, Ph.D.
Urban Planning and Policy
412 S. Peoria St. Chicago, Illinois 60607
Chicago, IL 60607
Phone: (773) 541-1567 / Fax: (312) 413-8095

RE: Research Protocol # 2017-1075
"Sustainable Legacy Cities"

Sponsor(s): None

Dear Dr. Boria:

Your Claim of Exemption was reviewed on October 6, 2017 and it was determined that your research protocol meets the criteria for exemption as defined in the U. S. Department of Health and Human Services Regulations for the Protection of Human Subjects [(45 CFR 46.101(b)]. You may now begin your research.

Exemption Period:	**October 6, 2017 – October 6, 2020**
Performance Site:	UIC
Subject Population:	Adult (18+ years) subjects only
Number of Subjects:	100

The specific exemption category under 45 CFR 46.101(b) is:
(2) Research involving the use of educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures or observation of public behavior, unless: (i) information obtained is recorded in such a manner that human subjects can be identified, directly or through identifiers linked to the subjects; and (ii) any disclosure of the human subjects' responses outside the research could reasonably place the subjects at risk of criminal or civil liability or be damaging to the subjects' financial standing, employability, or reputation.

You are reminded that investigators whose research involving human subjects is determined to be exempt from the federal regulations for the protection of human subjects still have responsibilities for the ethical conduct of the research under state law and UIC policy. Please be aware of the following UIC policies and responsibilities for investigators:

1. Amendments You are responsible for reporting any amendments to your research protocol that may affect the determination of the exemption and may result in your research no longer being eligible for the exemption that has been granted.

2. Record Keeping You are responsible for maintaining a copy all research related records in a secure location in the event future verification is necessary, at a minimum these documents include: the research protocol, the claim of exemption application, all questionnaires, survey instruments, interview questions and/or data collection instruments

associated with this research protocol, recruiting or advertising materials, any consent forms or information sheets given to subjects, or any other pertinent documents.

3. Final Report When you have completed work on your research protocol, you should submit a final report to the Office for Protection of Research Subjects (OPRS).

4. Information for Human Subjects UIC Policy requires investigators to provide information about the research to subjects and to obtain their permission prior to their participating in the research. The information about the research should be presented to subjects as detailed in the research protocol, application and supporting document(s).

Please be sure to use your research protocol number (listed above) on any documents or correspondence with the IRB concerning your research protocol.

We wish you the best as you conduct your research. If you have any questions or need further help, please contact me at (312) 355-2908 or the OPRS office at (312) 996-1711.

Sincerely,
Charles W. Hoehne, B.S., C.I.P.
Assistant Director, IRB #7
Office for the Protection of Research Subjects

cc: Nikolas Theodore, Urban Planning and Policy, M/C 348
Moira Zellner, Urban Planning and Policy, M/C 348

UNIVERSITY OF ILLINOIS AT CHICAGO
Office for the Protection of Research Subjects
201 AOB (MC 672)
1737 West Polk Street
Chicago, Illinois 60612
Phone (312) 996-1711

14.0 APPENDIX 4: NIER MODEL CODE

```
globals [
maximum-iterations ; used in the run-length procedure to determine the maximum length of the model run.
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
;;; the following globals are only used ;;;
;;; for monitoring and reporting ;;;
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
mean_LeadD ; for reporting average EE values of District leaders agents per tick
mean_ConformD ; for reporting average EE values of District conformists agents per tick
mean_SaD ; for reporting average EE values of District Stigma-avoiders agents per tick
meanD ; for reporting average EE values of District agents per tick
SdD ; for reporting standard deviation of District agents per tick
mean_LeadND ; for reporting average EE values of non-District leaders agents per tick
mean_ConformND ; for reporting average EE values of non-District conformists agents per tick
mean_SaND ; for reporting average EE values of non-District Stigma-avoiders agents per tick
meanND ; for reporting average EE values of non-District agents per tick
SdND ; for reporting standard deviation of non-District agents per tick
owner_change ; for verification, counter recording the number of agents who change owner type at point of sale
]
patches-own [
district-area ; defines the area as within or outside of the district
yscale ; variable used to create a scale of EE values throughout the world at setup
]
turtles-own [
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
;;; agent spatial variables ;;;
```

```
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

District? ; a turtle value reporting the district-area patch value they are on
peer-group ; this is the value that non-District agents use to define the scale of their neighborhood peer group. It identifies other turtles based on the neighborhood shape on the interface slider

;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
;;; agent variables for assessing retrofits ;;;
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

Owner_type ; holds the information for building owner type (leader, conformist, Stigma-avoider)
Goal ; goal determined by type
Perceived_benefit ; the value an agent has for a unit of EEv upgrade with respect to the agent's existing EEv level; Perceived_benefit equation differs by building owner type
Cost ; the cost of a unit of EEv upgrade with respect to the agent's existing EEv level; The cost equation is the same for all building owner types
EEv ; a measure of the energy efficiency value/index of a building (0-100% efficient, so value between 0-1)
NIR ; temporary variable to hold the value of EEv increase due to neighbor influenced retrofits
NR ; temporary variable to hold the additional value of normal upgrades above the NIR upgrade
Degrade ; temporary variable to hold the value of the amount of degradation per iteration

;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
;;; variable used for time dependent procedures ;;;
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

counter ; variable to count years (ticks) used by the normal upgrades, bring up to code at sale, and owner type change allowed at sale procedures

]


to setup

ca ; clear initial conditions. Ticks will be reset at the end
run-length ; determine the length of the model run. Baseline = 100; for testing purposes, the option of 1000 is also included
setup-patches ; create the district and non-district area in patches. Patches also set the value from which the EE value scale is taken
setup-agents ; Agents are created that have characteristics of both building energy efficiency values and building owner characteristics
update_visuals ; to see the initial interface visualization after
```

```
setup
reset-ticks ; starts the tick counter
output-initial-results ; This procedure prints the requested values at
time
step zero
end
to run-length ; this procedure sets
maximum iterations at one of the two durations below
if time = "100 years" [set maximum-iterations 100] ; the baseline model is
set to
run 100 years (1 tick = 1 year)
if time = "1000 test" [set maximum-iterations 1000] ; 1000 is included as
an
option for testing purposes
end
to setup-patches
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
;;; create building agents ;;;
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
ask patches [ ; sprout one bulding on each
patch
sprout 1 ; sprout is used because
turtle breed and orientation are not needed for this model
set yscale (pycor / max-pycor) ; create a scaled value
normalized between 0-1 based on the y value (to be used to set initial EEv)
]
;;;;;;;;;;;;;;;;;;;;;;;;;;;
;;; Create District and ;;;
;;; non-District areas ;;;
;;;;;;;;;;;;;;;;;;;;;;;;;;;
ask patches with [pxcor > 25 ] [ ; create a district on the
right side of the world
set district-area true
; set pcolor 59 ; for verification
]
ask patches with [pxcor <= 25 ] [ ; create a non-district on
the left side of the world. Note: there's one more column of non-District
than
District (odd number of x-coordinates with 0,0)
set district-area false
; set pcolor red ; for verification
```

```
]
if separate-areas = "District_separation"[ ; this procedure is used to
test whether Districts and non-Districts have spillover effects. The default
is set
to district_separation to evaluate the behavior in each area separately
ask turtles-on patches with [pxcor < 27 and pxcor > 23 ] [ ; creates the
separation between District and non-Districts by killing agents (having no
buildings) betwen the two areas (neighborhoods only extend to in-radius 3, as
defined in a later procedure)
die
]
]
end
to setup-agents ; This procedure assigns
building and building owner values (this version of the model represents
building
characteristics and building owner values in the same agent)
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
;;; identify agents in district ;;;
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
ask turtles-on patches with [district-area = true] [
set District? true ; ID buildings within a
District (transfer the District designation from patches to turtles)
; set color red ; verification
]
ask turtles-on patches with [district-area = false] [
set District? false ; ID buildings outside of a
District (transfer the District designation from patches to turtles)
; set color 59 ; verification
]
;;;;;;;;;;;;;;;;;;;;;;;;;;;
;;; assign agent values ;;;
;;;;;;;;;;;;;;;;;;;;;;;;;;;
ask turtles [
set shape "house" ; for interface visualization
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
;;; values for retrofit decision ;;;
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
set Owner_type "conformist" ; to get the proportions
according to the slider, all start at conformist then are reassigned
```

```
ifelse District? = true [ set peer-group other turtles with [District? =
true]] ; for agents in District, the peer group includes all
members of the District
[
; for agents not in District, the peer group is defined by the
neighborhood shape and size by the chooser on the interface
if neighborhood = "neighbors" [ set peer-group (turtles-on
neighbors)] ; neighbors is included, but note for
comparative purposes that it has a different shape than in-radius
if neighborhood = "in-radius 1 neighbors" [ set peer-group other turtles
in-radius-nowrap 1 ] ; Note: nowrap prevents turtles on edges from assessing
neighbors on the other side of the world
if neighborhood = "in-radius 2 neighbors" [ set peer-group other turtles
in-radius-nowrap 2 ]
if neighborhood = "in-radius 3 neighbors" [ set peer-group other turtles
in-radius-nowrap 3 ]
]
set counter random 20 ; start with randomness in
agents' individual counters; the counter is used in the following procedures:
normal upgrade, ownership type change allowed, and bring up to code
set EEv yscale ; start with an EEv scale
between 0-1 (using the agent's y-axis value to create a scale of EEv for
initial
conditions)
;;;;;;;;;;;;;;;;;;;;;;;;
;;; EEv verification ;;;
;;;;;;;;;;;;;;;;;;;;;;;;
; show "EEv " print EEv
; if EEv < 0 [ show "<0" print EEv ]
; if EEv > 1 [ show ">1" print EEv ]
]
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
;;; reassign turtle Owner_type from conformist ;;;
;;; to the other two building owner strategies ;;;
;;; based on the interface sliders ;;;
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
Ask n-of ((%-Leaders / 100) * count turtles) turtles with [ Owner_type =
"conformist"] [set Owner_type "leader"]
Ask n-of ((%-Stigma-avoiders / 100) * count turtles) turtles with [
Owner_type =
"conformist"][set Owner_type "Stigma-avoider"]
;;;;;;;;;;;;;;;;;;;;
;;; verification ;;;
;;;;;;;;;;;;;;;;;;;;
; show "EEv LeadersND, ConformistsND, Stigma-avoidersND, LeadersD,
```

```
ConformistsD, Stigma-avoidersD"
; print mean [EEv] of turtles with [ District? != true and Owner_type = "leader"]
; print mean [EEv] of turtles with [ District? != true and Owner_type = "conformist"]
; print mean [EEv] of turtles with [ District? != true and Owner_type = "Stigma-avoider"]
end


to go

if ticks = maximum-iterations [ ; the model is set to run 100 years (ticks). If this value is reached, the model stops and exports the results
output-results
stop
]
implement_policy ; if enabled on the interface, this procedure checks if the counter reaches 20 and runs the scenarios: new owner type allowed and bring up to code
retrofit_decision ; this procedure calculates Neighbor-influenced retrofits (NIR) and Normal retrofits (NR)
calc_degradation_rate ; calculate the projected decline of EE based on the annual degradation rate (which depends on the EEv). This represents the effect of weather and age
update_values ; update the EE value of the building each time step. = EEv + neighbor_influenced_retrofit + normal_retrofit - Degradation
update_visuals ; update building color on the interface to reflect EEv
output-results ; print the results
reset_temp_values ; reset the temporary variables for the next iteration
tick ; register a time step and it updates monitors and plots

end

to implement_policy

ask turtles [
if counter = 20 [ ; check if the 20 year mark has been reached
if new_owner_at_sale = "yes" [ ; procedure to test the scenario of allowing ownership type to change (proportions of building owner types in the world are maintained according to initial conditions)
new_owner_type_allowed
]

if upgrade_to_code_at_sale = "yes" [ ; procedure to test the scenario of at the point of sale (at 20 years), bringing low EEv buildings up to the energy code
```

```
level set by the interface slider
bring_up_to_code
]
]
]
end
to retrofit_decision ; NIR will hold the calculated value of
projected EE gains from neighbor influenced retrofits ;
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
;;; agents compare their EEv ;;;
;;; with their neighbors ;;;
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
ask turtles [
calc_neighbor_values ; this procedure updates
agents' goal, perceived benefit and cost at every iteration
if goal > EEv and Perceived_benefit > cost [ ; THIS IS THE KEY MECHANISM
OF NIER: Peer groups influence building owner motivation to retrofit when
peers
have a higher EEv than the calling turtle and the perceived benefit is
greater than
the cost (which depends on owner type)
let GapToGoal (goal - EEv) ; the GapToGoal value
measures the difference between an agent's current EEv and their goal value
(determined by building owner type and peer group value)
let Perceived_Net_benefit (Perceived_benefit - Cost) ;
Perceived_net_benefit is
the benefit that the owner will gain above the cost
set NIR (GapToGoal * Perceived_Net_benefit) ; the neighbor-influenced
retrofit is the portion of the EEv gap (goal from peer group) that the owner
perceives as economically feasible to retrofit (perceived_net_benefit)
]
;if counter < 20 [ print counter ] ; verification
if counter = 20 [ ; at time = 20, NR will
fill the gap between the NIR retrofit and the shortfall with the normal 20-
year
retrofit upgrade. At this time, agents will upgrade to normal_upgrade_benefit
level.
let tempNR (%_EEv_upgrade_at_NR * (1 - EEv ^ diminishing_returns_curve))
;
%_EEv_upgrade_during_NR is the value the agent will gain from a normal
retrofit;
diminishing_returns equation accounts for diminishing returns of
%_EEv_upgrade_during_NR as EEv approaches 100%
ifelse NIR >= tempNR [ set NR 0 ] ; checking to see if the
20% upgrade was already reached by NIR
```

```
[ set NR ( tempNR - NIR ) ] ; the normal retrofit will fill the shortfall with NIR

;print (word counter ", " EEv ", " tempNR ", " NIR ", " NR) ; verification
set counter 0
]
]
;;;;;;;;;;;;;;;;;;;;
;;; verification ;;;
;;;;;;;;;;;;;;;;;;;;


; file-open "C:/Users/ericb/Desktop/output/mechanism.csv"
; file-print (word "ticks, " "Owner_type, " "District?, " "max peer-group, " "mean peer-group, " "min peer-group, " "goal, " "EEv, " "Perceived_benefit, " "Cost, " "counter, " "NR, " "NIR peer-group, ")
;
; ;;; select one of the following first lines for verification of retrofit decision mechanism for building owner type and District?
;
; ask turtles-on patches with [pcolor = green][ ; selects one-of Leaders in non-District
; ask turtles-on patches with [pcolor = lime][ ; selects one-of Leaders in District
; ask turtles-on patches with [pcolor = blue][ ; selects one-of Conformists in non-District
; ask turtles-on patches with [pcolor = violet][ ; selects one-of Conformists in District
; ask turtles-on patches with [pcolor = orange][ ; selects one-of Stigma-avoiders in non-District
; ask turtles-on patches with [pcolor = red][ ; selects one-of Stigma-avoiders in District
;
; file-print (word ticks ", " Owner_type ", " District? ", " (max [EEv] of peer-group) ", " (mean [EEv] of peer-group) ", " (min [EEv] of peer-group) ", " goal ", " EEv ", " Perceived_benefit ", " Cost ", " counter ", " NR ", " NIR)
; ask peer-group [file-print EEv] ; will print EEv of agents in spatially defined neighborhood or all agents in District
; ]
;
; file-close


end
```

```
to calc_neighbor_values

if any? peer-group [ ; checks to see that there are neighbors to assess as a peer group
ifelse EEv >= 1 [set cost 1][ ; stops the cost curve at a maximum value of 1
set cost ( EEv ^ 3 ) ; the cost curve represents the cost per unit increase of EEv. It applies to all agents equally because it is based on the average cost of technology

;;;;;;;;;;;;;;;;;;;;
;;; verification ;;;
;;;;;;;;;;;;;;;;;;;;

; print ( word EEv ", " cost ) ; verification
; show "EEv, cost"
; file-open "C:/Users/ericb/OneDrive/Documents/2017/Masters Thesis/ABM/cost.csv"
; file-print ( word EEv ", " cost ) ; to print EEv and perceived benefit values to an external file

]

if Owner_type = "leader" [
set goal (max [EEv] of peer-group) ; the goal is calculated based on the neighbor EEv for each time step
ifelse EEv >= 1 [set Perceived_benefit 0 ][ ; if EEv is already 1, there is no benefit for investing in a retrofit
set Perceived_benefit (1 - (EEv ^ 12)) ; this value represents the benefit that this type of building owner expects to gain at each EEv
]
;;;;;;;;;;;;;;;;;;;;
;;; verification ;;;
;;;;;;;;;;;;;;;;;;;;

; print ( word EEv ", " Perceived_benefit ) ; verification
; show "EEv, Perceived Benefit Leader"
; file-open "C:/Users/ericb/OneDrive/Documents/2017/Masters Thesis/ABM/leader_PB.csv"
; file-print ( word EEv ", " Perceived_benefit ) ; to print EEv and perceived benefit values to an external file
]

if Owner_type = "conformist" [
set goal (mean [EEv] of peer-group ) ; the goal is calculated based on the neighbor EEv for each time step
ifelse EEv >= 1 [set Perceived_benefit 0 ][ ; if EEv is already 1, there is no benefit for investing in a retrofit
set Perceived_benefit (1 - (EEv ^ 1.2)) ; this value represents the benefit that this type of building owner expects to gain at each EEv
]
```

```
;;;;;;;;;;;;;;;;;;;;
;;; verification ;;;
;;;;;;;;;;;;;;;;;;;;
; print ( word EEv ", " Perceived_benefit ) ; verification
; show "EEv, Perceived Benefit Conformist"
; file-open "C:/Users/ericb/OneDrive/Documents/2017/Masters
Thesis/ABM/conformist_PB.csv"
; file-print ( word EEv ", " Perceived_benefit ) ; to print EEv and
perceived
benefit values to an external file
]
if Owner_type = "Stigma-avoider" [
set goal (min [EEv] of peer-group ) ; the goal is calculated based on the
neighbor EEv for each time step
ifelse EEv >= 1 [set Perceived_benefit 0 ][ ; if EEv is already 1, there
is no benefit for investing in a retrofit
set Perceived_benefit (1 - (EEv ^ 0.2)) ; this value represents the
benefit that this type of building owner expects to gain at each EEv
]
;;;;;;;;;;;;;;;;;;;;
;;; verification ;;;
;;;;;;;;;;;;;;;;;;;;
; print ( word EEv ", " Perceived_benefit ) ; verification
; show "EEv, Perceived Benefit Stigma-avoider"
; file-open "C:/Users/ericb/OneDrive/Documents/2017/Masters
Thesis/ABM/Stigma-avoider_PB.csv"
; file-print ( word EEv ", " Perceived_benefit ) ; to print EEv and
perceived
benefit values to an external file
]
]
end
to calc_degradation_rate ; Degrade will hold the
calculated value of projected EEv loses from degradation
ask turtles [
set degrade (.05 * (.25 ^ EEv)) ; degrade formula y = .05
(1/4)^x ; inefficient buildings degrade at a faster rate, range .05 - .01 per
time
step
; show "EEv degrade" print EEv print degrade ; verification
;;;;;;;;;;;;;;;;;;;;;;;
;;;verifying degrade;;;
;;;;;;;;;;;;;;;;;;;;;;;
;show "EEv, degrade"
;print ( word self "," EEv "," degrade "," )
;file-open "C:/Users/ericb/OneDrive/Documents/2017/Masters
Thesis/ABM/degrade.csv"
```

```
;file-print (word self ", " Owner_type ", EEv," EEv ", degrade, " degrade
) ; to print EEv and degrade values to an external file
]
end
to update_values ; update the EE value of the building
per time step.
Ask turtles [ ; all turtles will update their EEv.
This summarizes all of the building EEv changes that happen in this year.
; let EEv0 EEv ; for verification printout used
below. This is the EEv before updating
set EEv (EEv + NIR + NR - Degrade) ; THIS IS THE MAIN EEv UPDATE FORMULA
truncate EEv ; EEv values cannot be below zero,
but they can be above the existing 100% EEv standard
set counter (counter + 1) ; every time step is one year. the
counter takes note of how many years since the last normal upgrade
;;;;;;;;;;;;;;;;;;;;;;;
;;;verifying updates;;;
;;;;;;;;;;;;;;;;;;;;;;;
; let EEv1 EEv ; for verification printout used
below. this is the EEv after updating
; file-open "C:/Users/ericb/Desktop/output/updatemechanism.csv"
; file-print (word "ticks, " "Owner_type, " "District?, " "EEv0, " "NIR,
" "NR, "
"Degrade, " "EEv1, ")
; file-print (word ticks ", " Owner_type ", " District? ", " EEv0 ", "
NIR ", " NR
", " Degrade ", " EEv1)
; file-close
]
end
to update_output_values
;;;;;;;;;;;;;;;;;;;;;
;;; For Reporting ;;;
;;;;;;;;;;;;;;;;;;;;;
if count turtles with [ District? != true and Owner_type = "leader" ] >=
2 [ set
mean_LeadND mean [ EEv ] of turtles with [ District? != true and Owner_type =
"leader"]]
```

```
if count turtles with [ District? != true and Owner_type = "conformist" ]
>= 2 [ set
mean_ConformND mean [ EEv ] of turtles with [ District? != true and
Owner_type =
"conformist"]]
if count turtles with [ District? != true and Owner_type = "Stigma-
avoider" ] >= 2 [
set mean_SaND mean [ EEv ] of turtles with [ District? != true and Owner_type
=
"Stigma-avoider"]]
if not any? turtles with [ District? != true and Owner_type = "Stigma-
avoider" ][ set
mean_SaND "n/a"]
if not any? turtles with [ District? != true and Owner_type = "leader" ][
set
mean_SaD "n/a"]
if not any? turtles with [ District? != true and Owner_type =
"conformist" ][ set
mean_SaD "n/a"]
if not any? turtles with [ District? != true and Owner_type = "Stigma-
avoider" ][ set
mean_SaD "n/a"]
if any? turtles with [ District? != true ] [
set meanND mean [ EEv ] of turtles with [ District? != true ]
set SdND standard-deviation [EEv] of turtles with [ District? != true ]
]

if count turtles with [ District? = true and Owner_type = "leader" ] >= 2
[ set
mean_LeadD mean [ EEv ] of turtles with [ District? = true and Owner_type =
"leader"
] ]
if count turtles with [ District? = true and Owner_type = "conformist" ]
>= 2 [ set
mean_ConformD mean [ EEv ] of turtles with [ District? = true and Owner_type
=
"conformist"]]
if count turtles with [ District? = true and Owner_type = "Stigma-
avoider" ] >= 2 [
set mean_SaD mean [ EEv ] of turtles with [ District? = true and Owner_type =
"Stigma-avoider"]]
if not any? turtles with [ District? = true and Owner_type = "leader" ][
set mean_SaD
"n/a"]
if not any? turtles with [ District? = true and Owner_type = "conformist"
][ set
mean_SaD "n/a"]
if not any? turtles with [ District? = true and Owner_type = "Stigma-
avoider" ][ set
mean_SaD "n/a"]
if any? turtles with [ District? = true ] [
set meanD mean [ EEv ] of turtles with [ District? = true ]
set SdD standard-deviation [EEv] of turtles with [ District? = true ]
]
```

```
End


to truncate [t] ; this procedures ensures that the value stays between 0 and 1.
if EEv < 0 [ set EEv 0 ] ; it does not make sense for EEv to go below zero

end


to new_owner_type_allowed

let previous_type Owner_type ; FOR VERIFICATION: record the previous building owner type for comparison after the draw

let draw random 100 ; select a random number between 0 and 100
let leader% ( 100 - %-Leaders ) ; create a temporary variable to choose between building strategies

if draw >= leader% [ ; leaders can just be assigned because there are no converts.
set Owner_type "leader"
]
if draw < leader% and draw > %-Stigma-avoiders [ ; compares randomly drawn
number to 100 - %-leaders (sets Owner_type leader if greater than than the remainder
of 100 - leader slider value)
set Owner_type "conformist" ; maintain the percentage of conformists
]
if draw <= %-Stigma-avoiders [
set Owner_type "Stigma-avoider" ; maintain the percentage of Stigma-avoiders
]


;;;;;;;;;;;;;;;;;;;;
;;; Verification ;;;
;;;;;;;;;;;;;;;;;;;;

; show "draw" print draw
; show "( 100 - %-Leaders )" print leader%
; print (word count turtles with [ Owner_type = "leader" ] ", " count turtles with [
Owner_type = "conformist" ] ", " count turtles with [ Owner_type = "Stigma-avoider" ])

let after_sale_type Owner_type ; Record the building owner type after the draw

if previous_type != after_sale_type [ ; Compare the owner types
set owner_change owner_change + 1 ; Record the number of owner
```

```
type changes on the interface monitor
; set pcolor yellow ; To identify the agent that changed owner type
]

end


to bring_up_to_code

if EEv < ( code_min_EEv_level / 100 ) [ ; To identify whether agent's EEv is below code code
; print ((code_min_EEv_level / 100 ) - EEv) ; verification
set EEv ( code_min_EEv_level / 100 ) ; If the agent's EEv is not up to code, bring the building up to the value for code (determined by interface slider)
; set pcolor yellow ; verification: To identify the agent that upgraded to code
; print Owner_type
]

if EEv < ( code_min_EEv_level / 100 ) and ((( code_min_EEv_level / 100 ) - EEv ) >= %_EEv_upgrade_at_NR ) [
set counter 0 ; If an agent retrofits at or above the same level that they would have normally done, they will not also do a normal retrofit (NR) during this time step

; print ((code_min_EEv_level / 100 ) - EEv) ; verification
; set pcolor red
; print Owner_type
]

end



to update_visuals

ask turtles [set color 101 + ( EEv * 7 ) ] ; This sets the color for the agents that reflects their EE value. It gets updated every time step to reflect the updated EE value.

;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
;;; the commented codes below are ;;;
;;; just to easily show how the ;;;
;;; interface plots are calculated ;;;
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

;;; the coding for the interface plot on upgrades per iteration ;;;

```

```
; if count turtles with [ District? != true and Owner_type = "leader" ] >
2 [plot
(mean [ NIR ] of turtles with [ District? != true and Owner_type = "leader" ]
+ mean [
NR ] of turtles with [ District? != true and Owner_type = "leader"] )]
; if count turtles with [ District? != true and Owner_type = "conformist"
] > 2 [plot
(mean [ NIR ] of turtles with [ District? != true and Owner_type =
"conformist" ] +
mean [ NR ] of turtles with [ District? != true and Owner_type =
"conformist"] )]
; if count turtles with [ District? != true and Owner_type = "Stigma-
avoider" ] > 2
[plot (mean [ NIR ] of turtles with [ District? != true and Owner_type =
"Stigma-avoider" ] + mean [ NR ] of turtles with [ District? != true and
Owner_type =
"Stigma-avoider"] )]
; if count turtles with [ District? != true ] > 2 [plot (mean [ NIR ] of
turtles with
[ District? != ] + mean [ NR ] of turtles with [ District? != true ] )]
;
; if count turtles with [ District? = true and Owner_type = "leader" ] >
2 [plot
(mean [ NIR ] of turtles with [ District? = true and Owner_type = "leader" ]
+ mean [
NR ] of turtles with [ District? = true and Owner_type = "leader"] )]
; if count turtles with [ District? = true and Owner_type = "conformist"
] > 2 [plot
(mean [ NIR ] of turtles with [ District? = true and Owner_type =
"conformist" ] + mean
[ NR ] of turtles with [ District? = true and Owner_type = "conformist"] )]
; if count turtles with [ District? = true and Owner_type = "Stigma-
avoider" ] > 2
[plot (mean [ NIR ] of turtles with [ District? = true and Owner_type =
"Stigma-avoider" ] + mean [ NR ] of turtles with [ District? = true and
Owner_type =
"Stigma-avoider"] )]
; if count turtles with [ District? = true ] > 2 [plot (mean [ NIR ] of
turtles with
[ District? = ] + mean [ NR ] of turtles with [ District? = true ] )]
;

;;; the coding for the interface plot on mean EE value per building owner
type ;;;

; if count turtles with [ District? != true and Owner_type = "leader" ]
>= 2 [ plot
mean [ EEv ] of turtles with [ District? != true and Owner_type = "leader" ]]
; if count turtles with [ District? != true and Owner_type = "conformist"
] >= 2 [
plot mean [ EEv ] of turtles with [ District? != true and Owner_type =
"conformist"]]
; if count turtles with [ District? != true and Owner_type = "Stigma-
avoider" ] >= 2 [
```

```
plot mean [ EEv ] of turtles with [ District? != true and Owner_type =
"Stigma-avoider"]]
; plot mean [ EEv ] of turtles with [ District? != true ]
;
; if count turtles with [ District? = true and Owner_type = "leader" ] >=
2 [ plot
mean [ EEv ] of turtles with [ District? = true and Owner_type = "leader" ] ]
; if count turtles with [ District? = true and Owner_type = "conformist"
] >= 2 [
plot mean [ EEv ] of turtles with [ District? = true and Owner_type =
"conformist"]]
; if count turtles with [ District? = true and Owner_type = "Stigma-
avoider" ] >= 2
[ plot mean [ EEv ] of turtles with [ District? = true and Owner_type =
"Stigma-avoider"]]
; plot mean [ EEv ] of turtles with [ District? = true ]
end
to output-initial-results ; This procedure
outputs the values after setup to a .csv file
update_output_values ; populates the values
for reporting
if Print_output? = "no - delete previous output" [ ; Deletes the .csv
file
when needed (between scenarios)
if file-exists? "C:/Users/ericb/Desktop/output/output-results.csv" [
file-delete
"C:/Users/ericb/Desktop/output/output-results.csv" ]
;; Note: When "no" is selected, the file is deleted between scenario runs
]
if Print_output? = "yes" [ ; prints the output at
each iteration
ifelse user-yes-or-no? "Do you want to put the headers on the output?" [
;
produces a pop up asking to put headers on the .csv file. Needs to be
activated for
the first model run of each scenario
file-open "C:/Users/ericb/Desktop/output/output-results.csv"
file-print (word "ticks, " "Leader ND avg, " "Conformist ND avg, "
"Stigma-avoider ND avg, " "mean all ND, " "SdND, " "Leader D avg, "
"Conformist D
avg, " "Stigma-avoider D avg, " "mean all D, " "SdD, ")
file-print ( word ticks ", " mean_LeadND ", " mean_ConformND ", "
mean_SaND ", "
meanND ", " SdND ", " mean_LeadD ", " mean_ConformD ", " mean_SaD ", " meanD
",
" SdND)
file-close
][
file-open "C:/Users/ericb/Desktop/output/output-results.csv"
```

```
file-print ( word ticks ", " mean_LeadND ", " mean_ConformND ", " mean_SaND ", " meanND ", " SdND ", " mean_LeadD ", " mean_ConformD ", " mean_SaD ", " meanD ", " SdND)
]
]
end
to output-results ; This procedure outputs the values at every iteration to a .csv file
update_output_values ; populates the values for reporting
if Print_output? = "no - delete previous output" [
if file-exists? "C:/Users/ericb/Desktop/output/output-results.csv" [ file-delete "C:/Users/ericb/Desktop/output/output-results.csv" ]
if file-exists? "C:/Users/ericb/Desktop/output/mechanism.csv" [ file-delete "C:/Users/ericb/Desktop/output/mechanism.csv" ]
;; Note: When "no" is selected, the file is deleted between scenario runs
]
if Print_output? = "yes" [
let ticklist [ 0 10 20 30 40 50 60 70 80 90 100 150 200 250 300 350 400 450 500 750 1000 ]
if member? ticks ticklist [
;;; use this instead if you want multiples of 10 all the way through maximum-iterations: ticks mod 10 = 0 [
file-open "C:/Users/ericb/Desktop/output/output-results.csv"
file-print ( word ticks ", " mean_LeadND ", " mean_ConformND ", " mean_SaND ", " meanND ", " SdND ", " mean_LeadD ", " mean_ConformD ", " mean_SaD ", " meanD ", " SdND)
file-close
]
]
end
to reset_temp_values ; this procedure resets the temporary values for the next iteration
ask turtles [
set Goal 0 ; goal influenced by peer group in this time step
set Perceived_benefit 0 ; Perceived benefit of additional EEv unit
set cost 0 ; cost of additional EEv unit
```

```
set NIR 0 ; temporary variable to hold the value of the projected amount of EEv increase due to neighbor influenced upgrades
set NR 0 ; temporary variable to hold the value of the normal upgrades above and beyond neighbor influenced upgrades
set Degrade 0 ; temporary variable to hold the value of the amount of degradation per time step

]

file-close-all ; closes the external file for the current iteration

end
```

15.0 VITA

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PUBLICATIONS

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