NIER: Neighbor Influenced Energy Retrofits

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1. OVERVIEW

The Overview, Design concepts and Details (ODD) protocol for the NIER model presented here is based on the ODD+D protocol (Muller et al., 2013), which is an adaptation of the updated ODD protocol by Volker Grimm and his colleagues (Grimm et al., 2010) to make aspects of human decision-making explicit. The model was developed in Netlogo[1], version 5.3.1. For a more detailed explanation of the NIER model and its contribution to understanding energy retrofit decision-making , see *Investing in the Future by Encouraging Energy Retrofits* (Boria, 2020)[2].

ODD+D
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[1] https://ccl.northwestern.edu/netlogo/
[2] Thesis by the author available in *Proquest Dissertations and Theses*.

1.1 Purpose

Energy efficiency retrofits of multi-unit residential buildings can mitigate the negative environmental and social consequences of high energy consumption. Efforts to motivate building owners to invest in energy retrofits can be hampered by limits in municipal budgets, staff capacity, or resources. Recently, more attention is being paid to the potential of leveraging peer group influences to amplify existing financial incentives to motivate building owners.

Agent-based modeling on energy retrofits has provided useful insights to policy makers by exploring infrastructure, policy, and behavioral factors (Ignacio J. Martinez-Moyano, 2011), behavioral, economic and environmental factors (Rai & 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 NIER model contributes to the literature on agent-based models developed through a combined methodology with qualitative research (Agar, 2005; Yang & Gilbert, 2008; Zellner et al., 2014). The qualitative research included interviews with key stakeholders in Cleveland, Ohio and Detroit and Grand Rapids, Michigan. This research contributes to the literature on energy efficiency-related decision-making by including the influence of neighbor and large-scale, District-wide peer groups upon the motivation of multi-unit residential building owners to invest in energy efficiency retrofits. Insights from the model were developed into planning and policy recommendations.

1.2 Entities, State variables, and scales

This section describes the components of the NIER model. Building owner decision-making is operationalized in agents that interact, assess the information of their peer groups, make energy retrofit decisions, and upgrade their building energy efficiency levels. Agents are represented by 3 building owner types, which differ based on how they assess goals from their peer groups and perceive the benefit of a retrofit given their current energy efficiency level. Peer groups are represented by neighborhood scale from immediate neighbors to all agents in a large-scale area, termed a District. The entities of the NIER model are represented in the Unified Modeling Language (UML) class diagram in Figure 1.

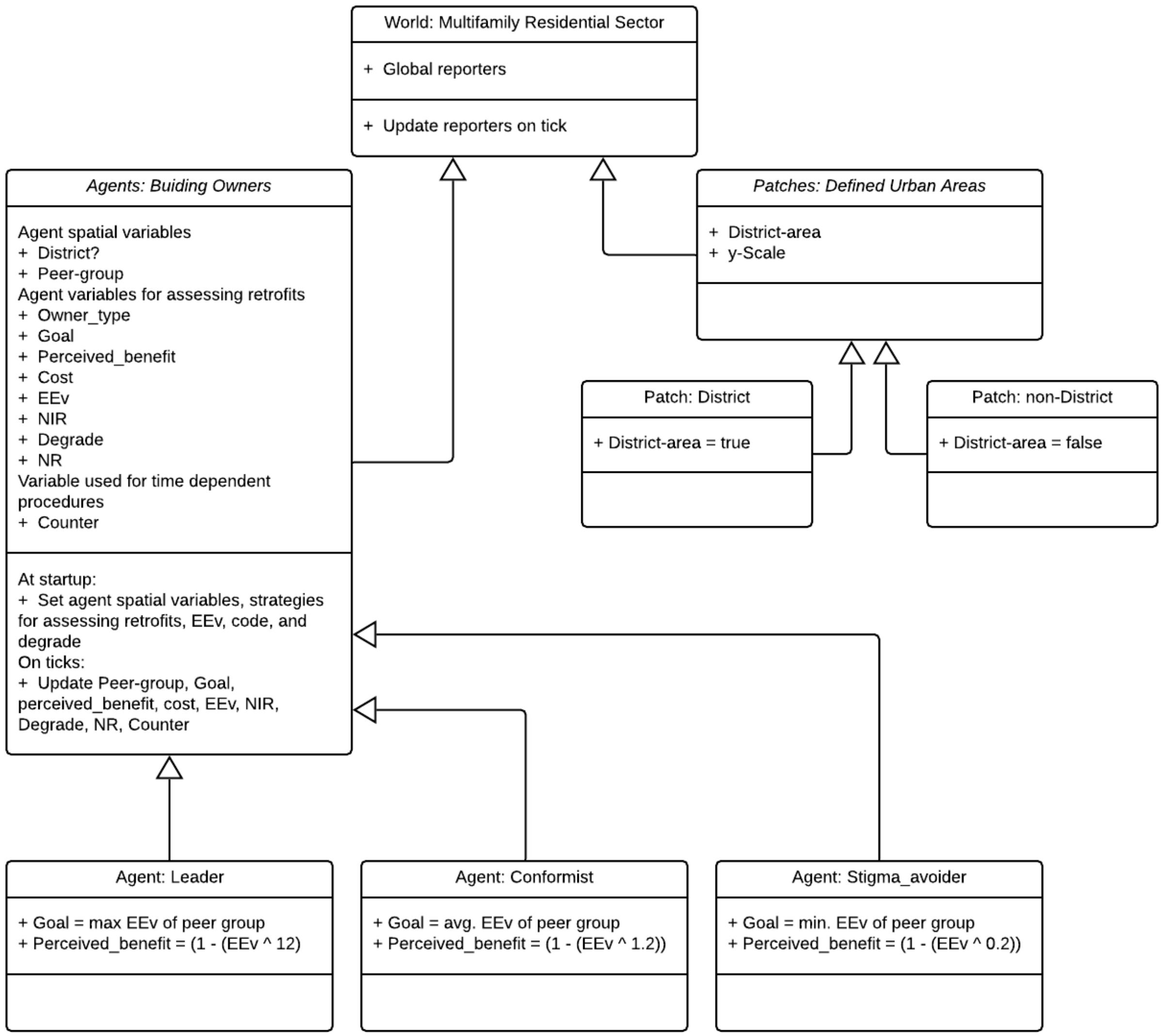

Figure 1: NIER Model UML Class Diagram

The model is spatially and temporally explicit. The world contains 51 rows and columns (including zero). Each patch contains one building agent. Neighborhoods are spatially represented by the number of patches extending from an agent. The model runs for 100 years (ticks). 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 as different agents, but the NIER model does not require them to behave independently. Cost and two values used in the normal retrofit (NR) calculation, the percentage of EEv upgrade at NR and the curve for diminishing returns, are exogenous, being influenced by the cost and quality of technology. All other variables are endogenous. Variables are described in Table 1.

Variable	Values	Description
Global		
maximum-iterations	100 or 1000 (for testing)	Determines the maximum length of the model run
mean_#	Mean of values	To report average EEv on interface and print output; substitute # for each building owner type in and out of District
sd#	Standard deviation of values	To report average EEv on interface and print output; substitute # for each building owner type in and out of District
owner_ change	Counter starting at zero	Records the number of agents who change owner type at a sale
Patches		
district-area	true; false	Identify a patch as a District or non-District
y-scale	0-1	A normalized, scaled value (pycor/max-pycor) to be used to set initial EEv
Agent spatial variables		
District?	true; false	Identify an agent as a District or non-District
Peer-group	Agentset of others in peer group	For agents in District, the peer group = all District agents; for non-District agents, peer group is neighborhood scale (interface slider)
Agent variables for assessing retrofits		
Owner_type	Leaders; Conformists; Stigma-avoiders	Different building owner types; determines agents' goals and perceived benefits
Goal	Goal formula ([goal] EEv of peer-group); Leaders [goal] = [max]; Conformists [goal] = [mean]; Stigma-avoiders [goal] = [min]	Building owner types differ by what peer group value they identify as their goal

Perceived_benefit	Leaders = (1 - (EEv ^ 12)); Conformists = (1 - (EEv ^ 1.2)); Stigma-avoiders = (1 - (EEv ^ 0.2))	The value an agent has for a unit of EEv upgrade above existing EEv level; differs by building owner type
Cost	EEv ^ 3; Note: if EEv >= 1, then cost = 1	The cost of a unit of EEv upgrade above existing EEv level; same for all building owner types
EEv	Initial value set by y-scale; adjusted every iteration by NIR, NR, and degrade	Measure of a building's energy efficiency value (0-100% efficient is represented as 0-1)
NIR	((Goal - EEv) * (Perceived_benefit - Cost))	Temporary variable to hold the value of EEv increase due to neighbor influenced retrofits
NR	((%_EEv_upgrade_at_NR * (1 - EEv ^ diminishing_returns_curve)) - NIR)	Temporary variable to hold the additional value of normal upgrades above the NIR upgrade
Degrade	y = .05 (1/4) ^ EEv	Temporary variable to hold the value of the amount of degradation per iteration
Variable used for time-dependent procedures		
Counter	Initial value set as a random value between 0-20; every iteration adds 1 (counter + 1)	Variable to count years (ticks) used by the normal upgrades, bring up to code at sale, and owner type change allowed at sale procedures

Table 1: Variables

1.3 Process overview and scheduling

The process overview is represented in Figure 2: NIER Model Decision Tree. Each iteration represents a year, and proceeds in discrete time steps to a maximum run of 100 years. All agents' values follow the schedule in the Figure 2 flow chart and are updated synchronously at every iteration. The process overview is divided into six components: *Initialization, Policy Implementation, Neighbor Influenced Retrofits (NIR), Normal Retrofits (NR), Annual Degradation Rate, and Updating Energy Efficiency Value*. Asynchronous updating is allowed when the counter reaches 20 years and enables one of the following procedures: owner change allowed at sale, bring up to code at sale, or NR.

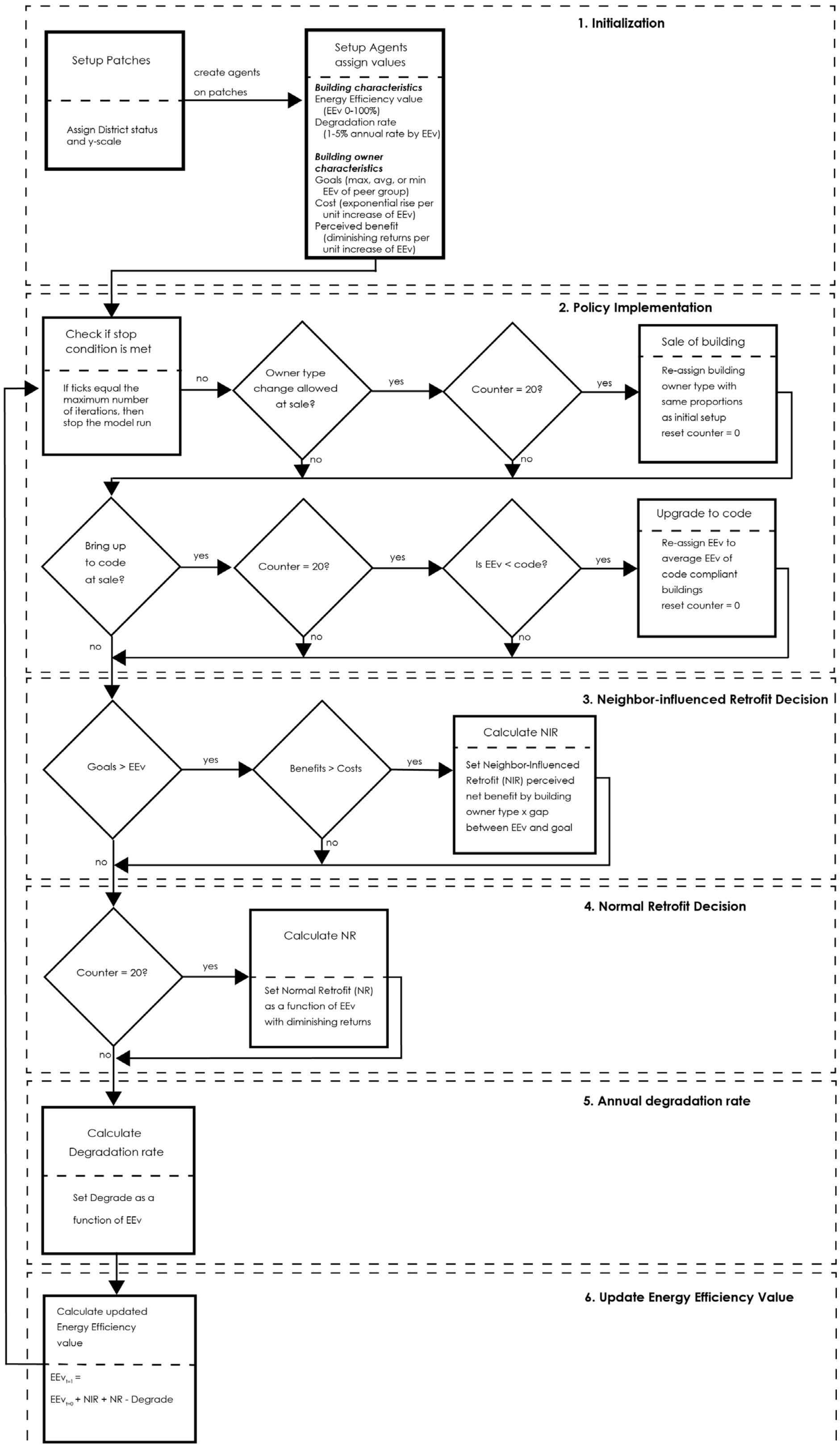

Figure 2: NIER Model Decision Tree

1.3.1. Initialization

Box 1 in Figure 2 describes the model initialization, where agents are created, one on each patch in the world, and assigned all agent attribute values described in Table 1. 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 the normal timing for the 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.

1.3.2. Policy Implementation

Following initialization, the next sequence in Box 2, Figure 2, checks two scenarios of planning and policy interventions. Each scenario can be enabled by choosers on the interface. The agent executes the enabled procedures when the counter reaches 20, indicating that the building is sold every 20 years.

If the scenario allowing ownership change is enabled, then the building type of the new owner is determined by a random number draw, while ensuring equal proportions to the initial settings. Randomness is also introduced into the model with this procedure. 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.

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. 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. This procedure first checks that the minimum level of energy efficiency required by code is greater than the existing energy efficiency value (EEv) of the building. If the building is already at a higher level of energy efficiency, then code is already met. If the building's EEv is lower than code, then the building is upgraded to the EEv level as set on the interface, which is a slider representing minimum energy-related code standards.

1.3.3. *Neighbor Influenced Retrofits (NIR)*

The neighbor-influenced retrofit decision (NIR) is the key component of the NIER model (Box 3 of Figure 2) because it includes peer group influence upon a building owner's retrofit decision-making process. Neighborhood and District-wide peer groups shape an agent's energy efficiency goal. The value a building owner derives from its peer group is determined by the building owner's type: Leaders pick the maximum EEv of the peer group; Conformists calculate the average EEv; and Stigma-avoiders pick the minimum EEv. Building owners calculate the peer group-derived goal every iteration.

Perceived benefit and costs are also calculated every iteration. These three variables are used to calculate NIR. Peer groups only have an influence if the peer group goals are greater than the building owner's EEv (the neighbor-influenced motivation component of the NIER model), and if the perceived benefits are greater than the costs (the economic feasibility argument). If both are true, then NIR is calculated with the following equation: **NIR** = $(G_{pg} - EEv_i) * (PB_i – C_i)$.

1.3.4. *Normal Retrofits (NR)*

The normal retrofit (NR) decision (Box 4 in Figure 2) only calculates when the counter indicates 20 years. This is to represent the normal replacement of materials due to reaching the end of its useful life. NR is not influenced by peer groups. If the counter condition is met (counter = 20), NR is calculated with the equation: **NR** = ((%_EEv_upgrade_at_NR * (1 - EEv ^ diminishing_returns_curve)) – NIR). With the baseline values added, the equation is: **NR** = ((0.2 * (1 - EEv ^ 7) – NIR).

The normal replacement of equipment and materials is set to a 20% improvement in energy efficiency every 20 years (%_EEv_upgrade_at_NR = 0.2). 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 amount of EEv increase by NR is set as a slider on the interface, which can be adjusted for cases where a new technology much greater (or lower) energy efficiency gains than its current setting.

The curve portion of the equation ensures that the marginal returns diminish as energy efficiency approaches 100% (diminishing_returns_curve = 7). If technology creates additional energy efficiency gains as the building's energy efficiency approaches 100%, this value can be adjusted accordingly.

NIR is also a component of the NR equation because NIR is calculated first in the sequence and a building owner can already be motivated 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 only if NIR has not already covered the upgrade.

1.3.5. *Annual Degradation Rate*

The annual degradation rate, represented by Box 5 in Figure 2, is a building-level attribute and is a function of a building's EEv level. The deterioration of the building envelope and the degraded performance of the heating, ventilation, and air conditioning system (HVAC) has been associated with lowered energy efficiency of buildings (Eleftheriadis & Hamdy, 2017). The NIER model assumes that there is a correlation between energy efficiency level and the basic upkeep of the building, and by extension its rate of degradation. Highly efficient buildings are more likely to be sound, with a sealed building envelope and more resistant to potential damage from weather events. Conversely, low efficient buildings are more likely to be associated with leaky windows, faulty equipment, or other signs of deterioration 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. In their review of building performance, Eleftheriadis and Hamdy (2017) estimate that buildings can degrade by 10%-30% every 20 years. There are a multitude of factors that can change that percentage, as each building component has a different functional lifespan. Given the existing state of the aging building stocks in the cities included in the qualitative study (Cleveland, Ohio, and Detroit and Grand Rapids, Michigan), a wider range for the rate of degradation was used in the equation **Degrade** = (.05 * (.25 ^ EEv_i)).

1.3.6. *Updating Energy Efficiency Value*

The second building level attribute is the updated energy efficiency value (Box 6 in Figure 2), which is the sum of all of the previous retrofit decisions. Every iteration, buildings update their EEv, with 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.

2. DESIGN CONCEPTS

2.1 Theoretical and empirical background

The NIER model was developed to test concepts that emerged from the interview findings in the qualitative research portion of this study. The concepts that the NIER model adds to traditional economic feasibility studies of energy retrofit decision-making are differences in building owner types (reflecting strategies for managing buildings) and peer group scale (neighborhoods of various sizes and large-scale Districts). The idea of exploring the effect of peer group influences upon a building owner's decision to invest in energy efficiency retrofits emerged from the interview findings with building owners. Many incentives assume that building owners make retrofit decisions based on an economic feasibility calculus, as represented in Figure 3. This assumes that building owners weigh benefits and costs as rational actors, and thus incentives are primarily targeted at demonstrating benefits or lowering costs.

Figure 3: Motivation to retrofit: economic feasibility

However, there is extensive research showing how investment decisions are based on factors other than those proposed by a rational actor framework, including biases such as putting more weight on potential costs than benefits (Kahneman, 2011), or how context can shape decisions as Choice Architecture (Thaler et al., 2012). The interview findings also found these non-rational factors affecting building owner decision-making. First, the interview findings revealed that motivation from peer groups preceded the economic feasibility calculus; If a building owner is not even thinking about a retrofit as desirable in the near-term, it is irrelevant if it makes financial sense. Second, the neighborhood and District-wide in which a building owner is embedded shapes the building owner's motivation for considering a retrofit. Both findings are represented in Figure 4.

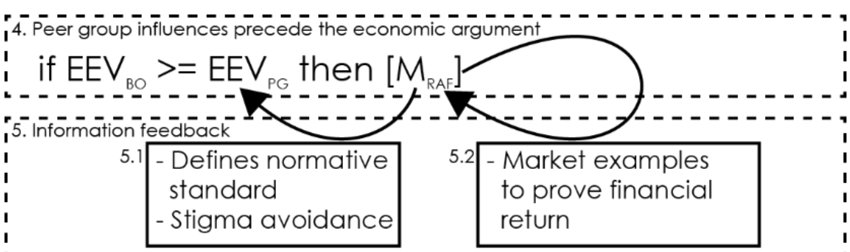

Figure 4: Motivation to retrofit: peer group influences

2.2 Individual decision-making

The individual decision-making process that is being tested in the NIER model is the influence of neighbor and District-wide peer group influences above the economic feasibility calculus. The findings from building owners and management groups 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. These strategies greatly affected their receptiveness to information about energy efficiency. Different building owner types may explain why some building owners seem reluctant to respond to conventional approaches, while others are easily motivated with very little incentive. For the purposes of this model, building owner strategies can be categorized into the following ideal types:

> *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. They put a greater value than the norm on the potential benefits of energy savings.
>
> *Conformists*, instead, compare themselves to the average of their peer group, meaning they conform to normative standards. The value they place on the potential benefits of energy savings is the normative value of their peer group.
>
> *Stigma-avoiders* compare themselves to the lowest energy efficient building in their peer group, applying the motive of stigma avoidance. They place a low value on the potential benefits of energy savings. This represents building owners who have different priorities for the investment decisions

The role of building owner type, defined as individual versus corporate ownership, was found to significantly influence retrofit decisions (Kontokosta, 2016).

The information that building owners used to compare their building's energy efficiency level to their peers included more than Energy Use Intensity (EUI), a measure of energy efficiency per square foot. It included status markers from certifications, aesthetic value, and other factors not normally included in building-level energy efficiency assessments. The qualitative research that informed the NIER model took an inductive approach and thus allowed the interviewees to define the energy efficiency factors that were valuable to them. There are few studies that explored what information building owners share with each other regarding building energy efficiency. Therefore, to represent this diversity of data in a packet of information that building owners can share with their peers, the NIER model created the variable Energy Efficiency Value (EEv).

2.3 Learning

In the NIER model, agents do not change their decision-making rules.

2.4 Individual Sensing

In every iteration, agents derive their Goal value from their peer group. For agents in Districts, their peer group includes all agents in the District. For agents not in the District, their peer group is defined by the scale of neighborhood set at initialization.

2.5 Individual Prediction

Agents do not make predictions in the NIER model. They calculate values every iteration and make decisions based on those values. Updated values are used in the next iteration.

2.6 Interaction

Interaction is represented in the NIER model as the sharing of EEv between building owners. Agents share the information with their peer group.

Assumptions include perfect, complete, and immediate information sharing and building owners interact with all other building owners in their peer group at every iteration.

2.7 Collectives

Collectives are defined at initialization. Macal and North (2010) identify two ways that agents define their neighborhood: one is by locating agents that are near in geographical space; the other are agents identified through a social network. This model employs both concepts through the spatial forms of neighbor and District-wide peer groups.

2.8 Heterogeneity

Agents have building owner and building characteristics; heterogeneity is set in both. The interview findings revealed that building owners have different strategies for managing buildings. These are represented in the model as building owner types: Leaders, Conformists, and Stigma avoiders. Each type differs on two variables, Perceived Benefit and Goals. Heterogeneity is also set in the building characteristic of energy efficiency value (EEv) with a scale from high to low energy efficiency.

2.9 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.

2.10 Observation and emergence

Interface visuals, plots, and reporters are updated every iteration. When enabled, selected data is exported to a .csv file, which is printed at the end of the model run.

Clustering is an emergent property that can be seen on the interface visualization. At initialization, agent EEv are set on a y-axis scale from high to low energy efficiency. As the model runs, both high and low energy efficiency clusters emerge as a result of interaction.

Emergent properties are seen in the influence of peer groups upon NIR in the scenarios where higher average EEv emerge among Stigma-avoiders as a result of small neighborhood peer groups raising the minimum EEv. By contrast, Districts do not have small neighborhood peer groups holding different EEv levels, and Stigma-avoiders compare themselves to the minimum value of the larger peer group. These can be seen in both interface plots and the data printed on the .csv file.

3. DETAILS

3.1 Implementation

The NIER model was developed in Netlogo (version 5.3.1). The updated code is included with the .nlogo file on OpenABM. The original version of the code is printed in the thesis Appendix 4, which is available on ProQuest.

The base settings representing the cities included in the qualitative study include:

- Building owner type proportions: 10% Leaders; 80% Conformists; 10% Stigma-avoiders
- Small neighbor peer groups: in-radius 1
- EEv upgrades at normal retrofits: 20% EEv improvement every 20 years with a curve factor of 7
- Scenarios are not enabled; District and non-District are separated

3.2 Input

Qualitative research informed the model development. There are no additional data inputs to the NIER model.

3.3 Submodels

3.3.1 Equations used in the NIER model

EEv = $\mathbf{EEv_i}$ + **NIR** + **NR** – **Degrade**

$\mathbf{EEv_i}$ 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 2

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

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

Laggards 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 ^ 12)

Conformists PB_i = (1 - (EEv ^ 1.2))

Laggards PB_i = (1 - (EEv ^ 0.2))

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

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

%_EEv_upgrade_at_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))

3.3.2 Determining economic feasibility

The aim of the NIER model is to explore how peer groups can influence energy retrofit decisions. Many studies have already calculated energy savings and the economic feasibility of energy retrofits (Guzowski et al., 2014; Heo et al., 2015; Ignacio J. Martinez-Moyano, 2011). The approach taken here is to introduce new qualitative variables, derived from interview findings, into building owner's retrofit decision-making process (Yang & Gilbert, 2008). Given that the NIER model focuses on how the qualitative variables of building owner types and peer groups influence decision-making, the process of determining economic feasibility has been simplified into a benefit-cost assessment. The interview findings that informed the model revealed that building owners vary by how they perceive the benefits of an energy retrofit. This is a qualitative variable; thus, the equations were selected to reflect the differences observed in the interview data. The curves graphed in Figure 5 were informed by diminishing benefits and increasing costs curves from environmental economics (benefits diminish and costs rise as a resource approaches 100% use) (Field & Field, 2006), and the point at which costs cancel benefits for the building owner types represent the differences observed between Leaders (0.9), Conformists (0.7), and Stigma-avoiders (0.5).

Building owners determine motivation to retrofit from their peer groups, but even if they are motivated, they will only do so if their internal calculation of benefits outweighs the costs. Agents calculate the perceived benefits and costs of upgrading at every level of energy efficiency. While cost is an objective value, it is subjectively interpreted by building owners. Differences in the cost curve are not included in this model but could be explored in future versions. For the purposes of this model, all building owners interpret costs equally, but differ on how they perceive benefits. This reflects that the variable EEv has a broader definition than Energy Use Intensity (EUI). Leaders can value many more indirect benefits of an energy retrofit than a Stigma-avoider, for example.

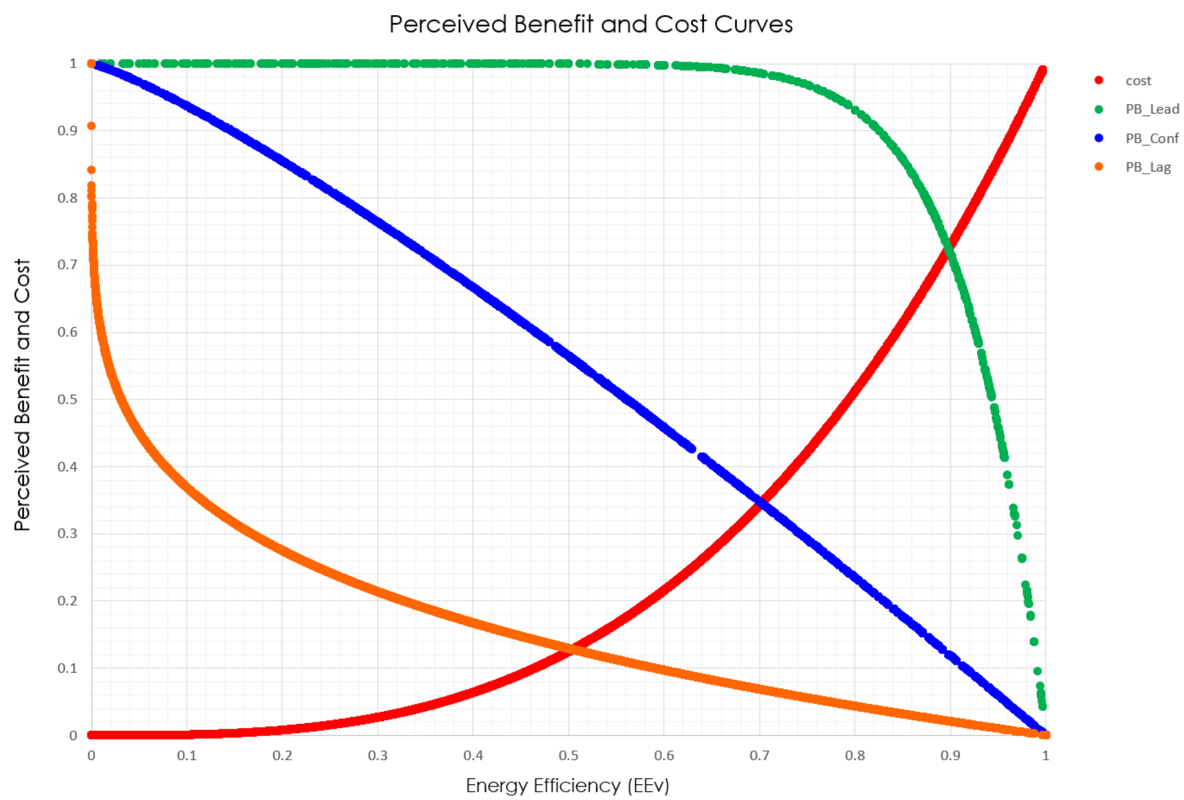

Figure 5: Perceived Benefit and Cost values by building owner type

Source: graph created by author from ABM data output for the purpose of verification.

3.3.3 Neighborhood scale

Spatial relationships in this model represent social influences from peer groups, either in the form of local neighborhoods or large-scale Districts. 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 District-wide (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. Figure 6 (a,b,c) show the spatial relationship of in-radius 1, 2 and 3, which is how many agents away (in cardinal directions) a building owner considers as their peer group. Figure 6(d) represents the District, in that it identifies all agents in the District as its peer group. In deriving insights from the model, Figure 6(d) can also symbolize policies that affect large populations of building owners.

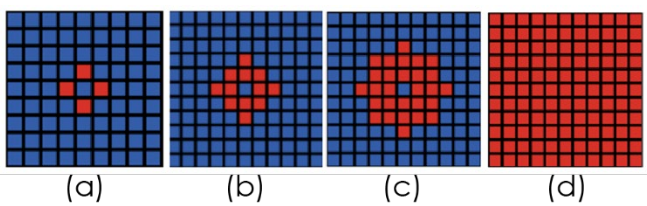

Figure 6: Neighborhood scale modeled

Figure 7 demonstrates the "no-wrap" property of neighbor peer groups (in-radius 3 in this example) 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.

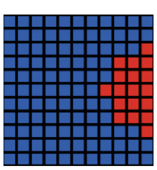

Figure 7: In-radius 3 no-wrap

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