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Rethinking demolition plans to fight neighborhood blight in shrinking cities: Applying agent-based policy simulations

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ABSTRACT

Demolition plans have been used to promote revitalization in America's Rust Belt shrinking cities. However, demolition can barely keep up with abandonment in shrinking cities like Buffalo, New York. This study uses the agent-based approach to explore alternative demolition and neighborhood revitalization policies, built on previous studies on abandonment in Buffalo and other cities. We developed a spatially explicit agent-based modeling framework to simulate four demolition policy scenarios: 1) random demolition; 2) targeted demolition in the areas with the highest abandonment density and near amenities with public interests; 3) targeted demolition in the areas with the highest abandonment density and near commercial corridors, and 4) targeted demolition in the areas with the highest owner-occupied housing rates. The results of our analysis suggest that Buffalo's approach to demolition and neighborhood revitalization resembles a policy framework that uses the demolition of residential units to stabilize commercial corridors. Under this strategy, public investments in commercial corridors are expected to trickle down to adjacent neighborhoods. However, to date, this has not been the outcome. This suggests the need to consider alternative strategies to achieve neighborhood revitalization goals.

1. Introduction

Many industrial cities in America's Rust Belt have been experiencing deindustrialization and outmigration (Pallagst, 2008; Silverman et al., 2013). This change has contributed to job losses, depopulation, the weakening of public and social institutions, a gap between housing supply and demand, and an increase in abandoned and blighted properties. The abandoned and blighted properties are associated with increased crime rates, higher expenditures for the city, and plunging property values (Accordino & Johnson, 2000; Yin et al., 2020). Silverman et al. (2013) argued that the housing abandonment and blight in these shrinking cities with sustained demographic and economic decline are different and more problematic than in other cities and labeled them *zombie properties*. The proliferation of *zombie properties* begets more property abandonment in their neighborhoods and furthers these neighborhoods' vicious spiral downward (Kraut, 1999; Morckel, 2014; Yin et al., 2022).

To address the abandonment and blight crisis and to spur revitalization, many shrinking cities have launched programs such as massive demolition plans (Fairbanks, 2008) and anti-flipping efforts. However, demolition can barely keep up with abandonment in cities such as Buffalo, Baltimore, and Youngstown (Cohen, 2001; Rhodes & Russo, 2013). In these cities, the number of *zombie properties* did not drop after massive demolition, and the spatial distribution of abandonment remained unchanged. Buffalo's demolition plan was symbolic of one implemented without a clear strategy. A recent analysis concluded that it was a "demolition and slum clearance policy akin to mid-twentieth-century urban renewal programs focusing on removing blighted properties without a concomitant revitalization component" (Yin et al., 2022; p.17).

In light of these findings, shrinking cities must approach the problem of *zombie properties* more holistically when designing demolition plans. Policymaking and proactive interventions must be guided by informed insights to break the persistent abandonment patterns. There has been, however, limited reference to theoretical insights and evidence-based analysis about demolition plans and their influences on abandonment.

The Agent-based models (ABM) have been applied to help inform policymaking by generating potential alternative representations of future or counterfactual system conditions (Carley, 2002; Yin, 2010). Using the agent-based approach, this study built on previous studies on abandonment and Buffalo's local housing market (Accordino & Johnson, 2000; Hillier et al., 2003; Silverman et al., 2013; Yin, 2009; Yin &

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Silverman, 2015) to examine housing abandonment in a declining city in the rust belt and simulate alternative policies to combat the issue of numerous *zombie properties*. We simulated how two types of agents, households and city government, operate in a shrinking city market and decide on the disposition and demolition of a property in response to building attributes, neighborhood conditions, other property owners' decisions, and the city's demolition policies.

We developed a spatially explicit agent-based modeling framework for assessing the cumulative effects of alternative demolition policies by dynamically incorporating the policy effects into the household decision-making process at the micro level. We focus specifically on four demolition policy scenarios during the mayor's aggressive five-year demolition plan implementation period (Yin et al., 2022): 1) random demolition; 2) targeted demolition in the areas with the highest abandonment density and near amenities with public interests; 3) targeted demolition in the areas with the highest abandonment density and near commercial corridors, and 4) targeted demolition in the areas with the highest owner-occupied housing rates.

2. Dealing with zombie properties in a quintessential shrinking city: Buffalo, New York

Shrinking cities have higher housing vacancy rates and higher concentrations of minority populations and poverty compared to the metropolitan areas (Silverman et al., 2015). According to the U.S. Census 2000, 2010, and 2020, the City of Buffalo, New York is among the U.S. cities with the highest vacancy rates and poverty rates. The "other" category within the census classification of vacant units increased from 8788 units in 1990 to 9980 units in 2000, 11,196 units in 2010, and 14,826 in 2020.[1] This category represents housing units that are permanently vacant in Buffalo. The national average for the percentage of vacant housing units in the "other" category in the urbanized area is 1.6 % while it is 3.2 % in the Buffalo urbanized area and 6.9 %, in the City of Buffalo, more than four times higher than the national average. The problem of vacancy is worsened by continued job and population losses resulting from deindustrialization in shrinking cities.

The presence of these permanent vacant properties accelerates the downward trajectory of neighborhoods and poses high costs and difficulties for governments in shrinking cities with limited resources for neighborhood revitalization, management, public safety, and the delivery of vital services (Silverman et al., 2013; Yin et al., 2022). Some strategies that have been adopted to combat the abandonment problem include demolition, rehabilitation, or creative reuse (Accordino & Johnson, 2000; Cohen, 2001; Hackworth, 2014; Han, 2014; Mallach, 2012).

In the City of Buffalo, programs were initiated with a focus on demolition. The City had the power to acquire any property considered a hazard to public safety and tear down the property. These properties were placed on the City's demolition list for which Buffalo was allocated $5 million by the 2006 State of New York Budget (Fairbanks, 2008). In August 2007, Mayor Brown launched the "5-in-5" demolition plan aiming to remove 5000 vacant structures in five years to alleviate the problems associated with housing abandonment within the city (Fairbanks, 2008).

Despite the increased magnitude of demolitions during the 5-in-5 plan's implementation period, the findings across multiple studies suggest that the spatial distribution of abandonment remained unchanged on the east side of Buffalo where demolitions were clustered in African American neighborhoods (Weaver & Knight, 2018; Yin et al., 2022; Yin & Silverman, 2015). Demolition alone was not sufficient to curb the spread of *Zombie properties* in Buffalo.

In addition to demolition, a variety of policies are needed to address abandonment problems in declining cities, including substantial investment from state and federal governments (Reese, 2006), the development of new governance structures and public-private partnerships (Bernt, 2009), the adoption of right-sizing policies and green infrastructure (Shilling & Logan, 2008), and the establishment of land banks as an alternative to disposing of tax-delinquent property through public auctions or demolition (Dewar et al., 2015) as part of a broader neighborhood revitalization effort (Gallagher, 2010). Other strategies include ways to use community gardens, stores, and art projects to bring vibrancy to blighted neighborhoods. These approaches can be contrasted with policies like Buffalo's 5-in-5 plan, which solely focused on aggressive demolition and land clearance but without neighborhood revitalization components to help stabilize neighborhoods.

In addition to combining demolition with other policies, researchers argue that the acute levels of decline in Rust Belt cities require demolition to be targeted to create a stable environment for redevelopment (Mallach, 2012). Targeted demolition is considered most beneficial when decisions about the removal of structures consider surrounding land uses and are accompanied by public funds to catalyze redevelopment. Yin and Silverman (2015) found that this type of targeted demolition was absent in Buffalo. In that context, both the persistent neighborhood abandonment and the lack of redevelopment after site assembly had damaging effects. Hence, they concluded that there was a need to strengthen the policy nexus between demolition and neighborhood revitalization efforts in Buffalo.

Cities like Buffalo can benefit from evidence-based, targeted demolition policies focused on revitalizing declining neighborhoods. Possible targeted demolition strategies range from investing in neighborhoods with a high concentration of abandonment to abate its spread to investing in neighborhoods with low levels of abandonment to buffer them from future decline. At a minimum, demolition policies should consider elements that rehabilitate and/or replace abandoned residential properties, for example, clustering demolition in areas that are near public amenities and commercial corridors (Wang & Fukuda, 2019; Weber et al., 2006) or areas with high concentration of owner-occupied housing (Raleigh & Galster, 2015).

3. Modeling the patterns and dynamics of abandonment and demolition: an agent-based approach

Empirical research can inform the development of targeted demolition strategies. Extensive research efforts have been devoted to predicting housing abandonment using statistical methods such as exploratory factor analysis, multilevel regression, and logistic regression (Morckel, 2013, 2014; Yin & Silverman, 2015). However, these statistical models often take an aggregate and static approach to studying housing abandonment other than studying how the abandonment emerged from the micro-level interactions of households' decisions and interactions between households' decisions and the city's demolition plans.

In addition to referencing the results from statistical models, there is a need to use other methodologies to design targeted demolition strategies. This is because land use and abandonment patterns reflect the cumulative influence of decisions made by diverse agents, for example, individual households and organizational actors or municipal governments (Brown et al., 2005; Parker et al., 2003; Yin, 2009). An effective integrated modeling framework for studying the patterns and dynamics of abandonment and demolition must allow the dynamic linkage of decisions made by households and organizational actors, as well as the linkage of micro-level decisions with social, economic, and physical characteristics of the neighborhood or environment where individuals reside.

The Agent-based models (ABM) can uniquely inform the development of targeted demolition strategies. These models have been attracting attention in recent years as data has become more abundant and our understanding of complex urban systems calls for a move of urban models from traditional aggregate forms to more dynamic,

[1] ACS data is used for the year 2020.

disaggregate, and realistic representations of individual behavior (Brown et al., 2005; Caprioli et al., 2023; Parker et al., 2003; Yin, 2009). ABMs portray urban systems as having emerged from dynamic interactions among rule-based agents and between those agents and the environment, with spatial patterns also emerging from these interactions (Batty, 2009; Yin, 2009). Such an approach that captures local interactions during the simulation is particularly useful for studying non-linear complex dynamic systems such as housing abandonment and demolition (Jiang et al., 2021).

ABMs allow for different behaviors of heterogeneous agents across a study area can be characterized and decisions and interactions can be simulated based on decision rules. The rules reflect the goals, information, and resources that characterize each agent in the complex system and are also constrained by features of the environment, market context, and policy. Each agent's decision responds to the changing environment and other agents' behaviors (Parker et al., 2003; Yin, 2010).

The agent-based simulations can help us understand possible contributing factors from the social, built, and physical environments and their interactions with different policy alternatives. This approach allows us to model how decisions made currently have effects on the neighborhood and how aggregate effects emerge at the macro level (Yin, 2010). ABMs are useful for policy scenario generation and have roots in both social and behavioral theory (Brady et al., 2012; Jiang et al., 2021). They also allow us to incorporate interactions between agents and feedback loops that reflect the impacts of any imposed policies (Brady et al., 2012; Yin, 2010).

With the help of GIS which describes the heterogeneous landscape and software programs that allow the simulation of individual behavior following the rules, spatial ABMs can represent the temporal and spatial variability of agents, spatially situate agents in their environment, and dynamically link their decisions to relevant social, economic, and physical information about their environment and other agents such as the municipal government (Batty, 2009; Ligtenberg et al., 2001; Yin, 2010). Spatial ABM simulation results from different policy scenarios can help understand how to manage abandoned properties and revitalize the communities.

4. Method

4.1. Data collection

Table 1 summarizes the data collected and their sources. Vacancy and abandonment are not universally defined. Nationally, there are vacancy data provided by census boundaries, usually at the tract level, by the U.S. Census Bureau and the U.S. Postal Service. Parcel-level information regarding possible vacancy and abandonment is often spread among several local agencies. We collected datasets from multiple sources such as different departments in the City of Buffalo and *The Buffalo News* to build a comprehensive database on abandonment at the parcel level based on the annual auction of tax-delinquent (*inrem*) properties, emergency fire, and board-up database for various years.

Yearly tax-delinquent auction results data were collected from the City of Buffalo's Department of Assessment and Taxation in Microsoft Excel and PDF formats. These files were converted into dbase files to spatially match auctioned parcels with the City of Buffalo parcel shapefile using the geocode method. *The Buffalo News* data was compiled by postal carriers as they go house-to-house. This database is comprised of residential, commercial, and industrial parcels that are owned by the City of Buffalo due to vacancy. The emergency fire data was compiled by the fire department. These datasets were supplemented by the board-up request data and demolition list data collected from the City of Buffalo. We also collected census-level vacancy data from the US Census Bureau and a HUD Aggregated USPS Administrative Data on Address Vacancies for 2006–2010 complied quarterly.

A list of datasets was collected for explanatory variables following what the literature suggested to understand the factors driving

Table 1
Data Source.

Categories	Data	Source	Year
Abandonment	Vacant Structures	City of Buffalo, The Buffalo News	2003, 2008
	Board Up Requests	City of Buffalo	2007–2008
	INREM	City of Buffalo	2006–2013
Demolition	Demolition List for Vacant Structure	City of Buffalo	2003, 2005–2013
Building and Neighborhood Information	Property Lot Front Size	City of Buffalo	2010
	Property Year of Built	City of Buffalo	2010
	Property Sales	City of Buffalo	2004–2013
	311 Service Requests	City of Buffalo	2008–2013
Policy Simulation	Hospitals/Clinics	New York State Department of Health	2010
	Colleges/Schools	New York State Department of Education	2010
	Libraries	New York State Department of Education	2010
	Museums	New York State Department of Education	2010
	Parks	New York State GIS Clearing House	2010
	Streets	New York State GIS Clearing House	2010
	Housing Tenure	U.S. Census Bureau	2013
Spatial Reference	Block Groups	U.S. Census Bureau	2006–2010
	Blocks	U.S. Census Bureau	2006–2010
	Parcels	City of Buffalo	2006–2010

abandonment. Yin and Silverman (2015) found that abandonment itself begets new abandonment. Specifically, the proximity to abandoned properties and neighborhood vacancy density increases the probability of the property being abandoned. Previous studies also found that variables on building attributes and neighborhood conditions were associated with housing abandonment such as lot front size (Morckel, 2013; Yin & Silverman, 2015). We also gathered other spatial data such as streets, census boundaries, and tax parcels as references to map the non-spatial data.

4.2. Study area

This study focuses on the east-side neighborhoods of Buffalo where about two-thirds of the city's abandoned properties are located as shown in Fig. 1. Our selected study area is highlighted in red that suffered from the problem of housing abandonment over a long period as demonstrated by the kernel density plots of abandoned houses from 2003 to 2012 (Fig. 1a). It also has the highest spatial concentration of abandonment in Buffalo over the years. Different land use types were highlighted in Fig. 1b, including residential parcels, parks, hospitals, and colleges.

4.3. Building the agent-based models

We adopted the agent-based approach to simulate housing abandonment and demolition. The dynamic spatial ABMs were used to simulate the interacting processes that shape decisions on housing abandonment by households and demolition by the city in the study area. NetLogo was used to build the models that represent agents' temporal and spatial variability and decisions.

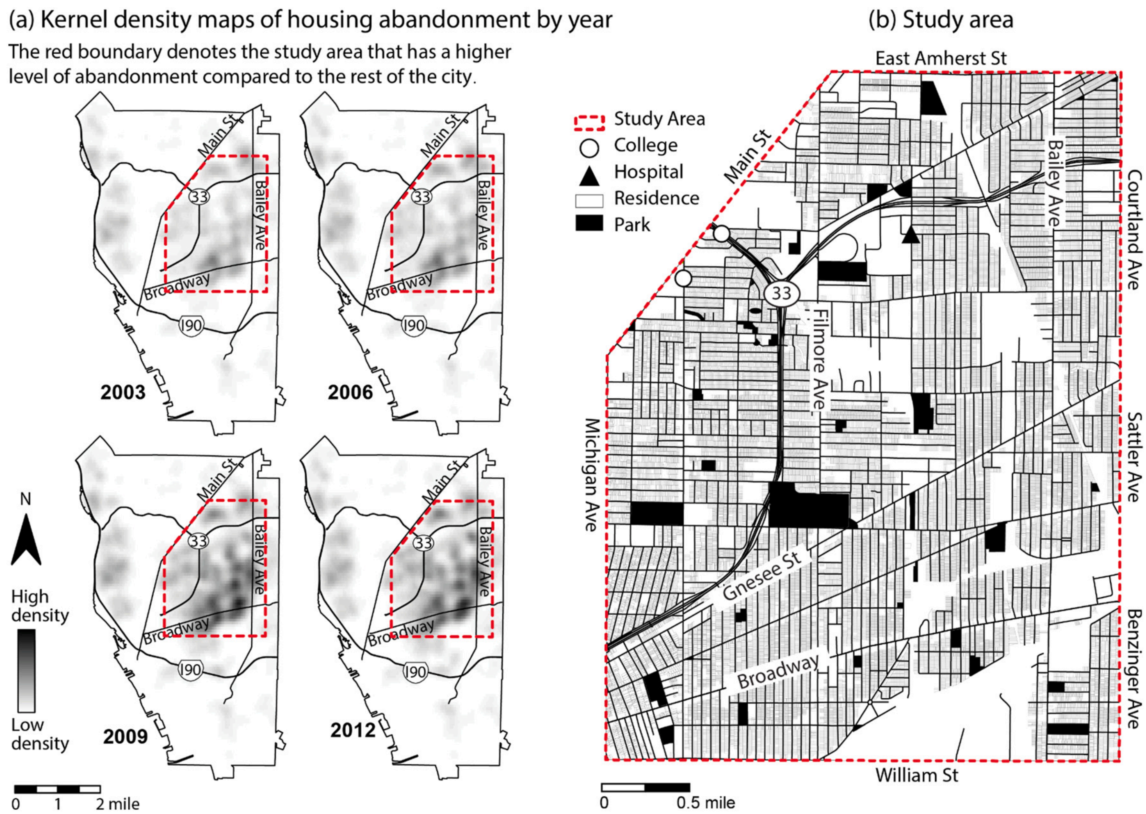

Fig. 1. Study Area.

4.3.1. *Model structure*

Fig. 2 illustrates our spatially explicit modeling framework with all the components and their connections. There are three major components: (1) the environmental system with a spatial context, (2) the human system comprising two types of agents including households and the city along with their decision-making rules, and (3) the policy scenario testing sub-model. Our model simulates housing abandonment and demolition from 2004 to 2013 covering the period when the city's "5-in-5" demolition plan with massive demolition took place.

The environment in which the agents interact is a geographic space represented by a 60 × 60-ft grid to match roughly the average size of residential parcels in the study area. There are two components included in the environmental system including building attributes and neighborhood characteristics. Table 2 summarizes these variables as spatial representations of the environmental system under the explanatory variables category. These are variables used by the agents to determine the statuses of parcels listed as "*parcel_status*" in Table 2 for each time step. There are three possible cell statuses for every residential parcel in the study area with only one status for any time step for each parcel. Five properties were abandoned at each time step. The model stopped until the number of abandoned properties matched the ground truth data. There were 2913 houses abandoned during the years 2004–2010. Thus, our model used 583 steps to abandon a total of 2915 houses to represent the abandonment process between 2004 and 2010.

Since the explanatory variables are measured in different units, we used the min-max standardization method to normalize them to values between 0 and 1 so that they were comparable to each other. The last part of Table 2 describes the auxiliary variables that are used for the demolition policy scenarios, together with their measurements.

4.3.2. *Agents and their decision-making rules*

There are two types of agents in our model: households and the city. We assumed that each residential parcel is one household agent, and each household agent assesses their level of dissatisfaction or satisfaction based on the site attributes and neighborhood characteristics represented by the explanatory variables in Table 2. The level of dissatisfaction for household agent *i* at time step *t* is calculated using Eq. (1):

$$S_i^{(t)} = \sum\nolimits_{j=1}^{n} \beta_j x_{ij}^{(t)} \tag{1}$$

where $x_{ij}^{(t)}$ indicates the condition *j* of the parcel that the *i*-th household resides at time step *t*, β_j is the coefficient of the condition *j*, and *n* represents the six explanatory variables that are listed in Table 2 under the explanatory variables category. Household agents updated their levels of dissatisfaction at each time step *t* to make decisions on abandonment. Our model did not assume that every agent had the perfect information to calculate their dissatisfaction levels to make the best decisions. Thus, among the top 200 households with the highest dissatisfaction levels, five were randomly selected to abandon their properties to represent the stochastic process in their decision-making (Power, 2009; Yin & Muller, 2007). Since this process may introduce randomness to our model, we repeated each run 50 times and recorded the average results as the final modeling outcomes for each run to ensure the modeling results were not accidental but robust (Crooks et al., 2018).

The left side of Fig. 3 shows the user interface (UI) of the model.[2] The right side shows the flowchart of the household agent's decision-making process. '*Setup*' loads the GIS environment of the study area. '*Aban Demo 2003*' restores the ground-truth abandonment and demolition patterns as in 2003 when the simulation started. '*Initialize HH score* initializes households' dissatisfaction level based on Eq. (1). '*Go*' runs the model. '*n_aband_everystep*' specifies how many parcels are abandoned at each time step. '*n_sample_pool*' specifies how many households with the highest dissatisfaction level have potentials to abandon their properties.

[2] Model documentation and source codes available upon request.

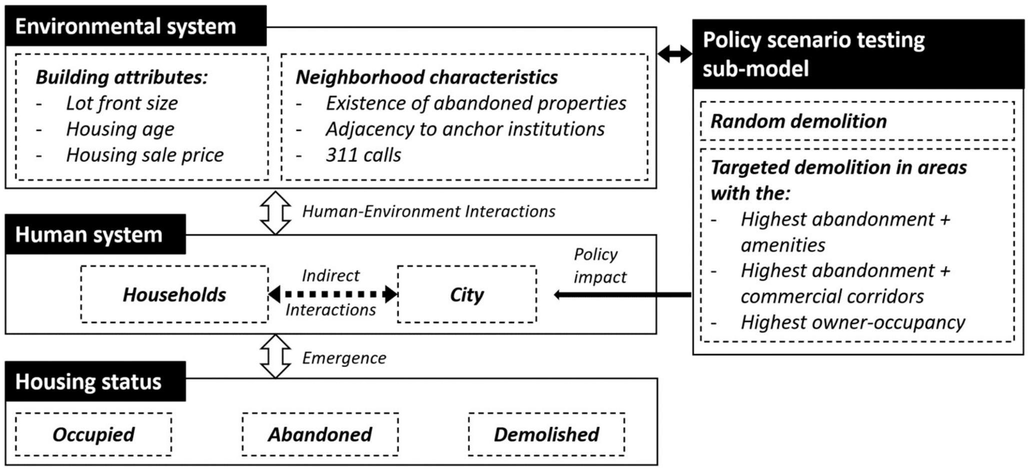

Fig. 2. Spatial ABM Modeling Framework.

Table 2
Variables.

Parameter	Description	Range/unit
parcel_status	Status of a residential parcel	occupied, abandoned, demolished
Explanatory Variables		
if_aban_neighbr	If abandoned properties exist in the neighborhood (0.25-mile radius)	0 – not exist, 1 – exist
lot_front_size	Lot front size of a residential parcel	feet
if_anchor_inst_half_mile	If anchor institutions including hospitals and colleges exist in the neighborhood (0.25-mile radius)	0 – not exist, 1 – exist
n_311_calls	No. of 311 calls in each census block group	times
housing_age	Housing age	years
housing_sale_price	Interpolated housing sale price	price per square foot
Auxiliary Variables for Policy Simulation		
n_aban_neighbr	No. of abandoned properties in the neighborhood (0.25-mile radius)	–
if_near_amenity	If public amenities including college, library, museum, park, and school exist in the neighborhood (0.25-mile radius)	0 – not exist, 1 – exist
if_near_comm_corridor	If a residential parcel is located within commercial corridors including Broadway, Genesee Street, Filmore Avenue, and Jefferson Avenue.	0 – not within corridors, 1 – within corridors
Owner_occupied_rate	Percentage of owner-occupied housing in each block group	%

The city agent made decisions about demolishing abandoned properties. During the model training and testing process period, the city agent made demolition decisions based on real-world data using the city's demolition list data. For policy simulations, the city agent applied different demolition strategies based on the designed policy scenarios.

4.3.3. Model verification, calibration, and validation

While verification involves checking the "internal validity" to ensure the models match their design and the outcomes are "intuitive" (Axelrod, 1997, p16; Manson, 2001), calibration refers to fitting the model to data so that the behaviors of the model can match the system of interest (Crooks et al., 2018). Validation is similar to calibration whereas it focuses on validating the parameters and models using some new data to avoid overfitting (Sun et al., 2016).

We conducted model verification through code walkthroughs, visual debugging, and sensitivity tests (Grimm, 2002; Niida et al., 2019) to ensure the model behaves as expected. It is followed by splitting the ground-truth abandonment data into training (88 %) and testing (12 %) sets for model calibration and validation. We used the year 2003 ground-truth data for model setup, the years 2004–2010 data for training and calibration, and the years 2011–2013 data for validation.

We utilized the training data to calibrate the model by tuning the model parameters through the application of domain knowledge, conducting sensitivity analysis, and performing a grid search across six explanatory variables (Fent et al., 2013). We initiated the process by determining the directions of the explanatory variables based on the existing literature. Next, the one-factor-at-a-time sensitivity analysis was performed to examine the impacts of each of the explanatory variables on the target variable abandonment. Based on the sensitivity analysis results, we then combined all explanatory variables, adjusted their weights using domain knowledge, and compared the modeling outcomes with the ground truth abandonment patterns. Multiple techniques including face validation and accuracy check were used to evaluate modeling outcomes. By doing so, we derived an initial range for each explanatory variable that can reproduce similar ground truth abandonment patterns. Based on these initial ranges of all the six explanatory variables, we then performed a grid search. The grid search looked at every possible combination of explanatory variables within their initial ranges and identified the combination that could produce the best result (Niida et al., 2019).

The "face validation" method was combined with an accuracy check to measure and improve model performance (Crooks et al., 2018). Specifically, for the "face validation", we juxtaposed the modeling and ground-truth abandonment maps side by side, visually compared them, and adjusted the model parameters until the model looked correct (Yin & Muller, 2007). Meanwhile, a quantitative evaluation method called accuracy check was also performed to make sure the model was adjusted in the right direction. Specifically, the accuracy score was calculated as the proportion of correctly predicted abandonment overall ground truth abandonment. This accuracy check allowed us to quantify how much of the ground-truth abandonment was correctly predicted. Since the purpose is to predict the overall patterns of the abandonment rather than focusing solely on site-by-site matching, we used a 0.25-mile radius to calculate the accuracy scores. If an observed abandonment had a predicted abandonment within the radius, the abandonment was considered correctly predicted. Note that one predicted abandonment can only be matched with one observed abandonment. Using "face validation" and calculating accuracy scores, we selected the parameters that could produce the best modeling outcomes and validated these parameters on the testing data.

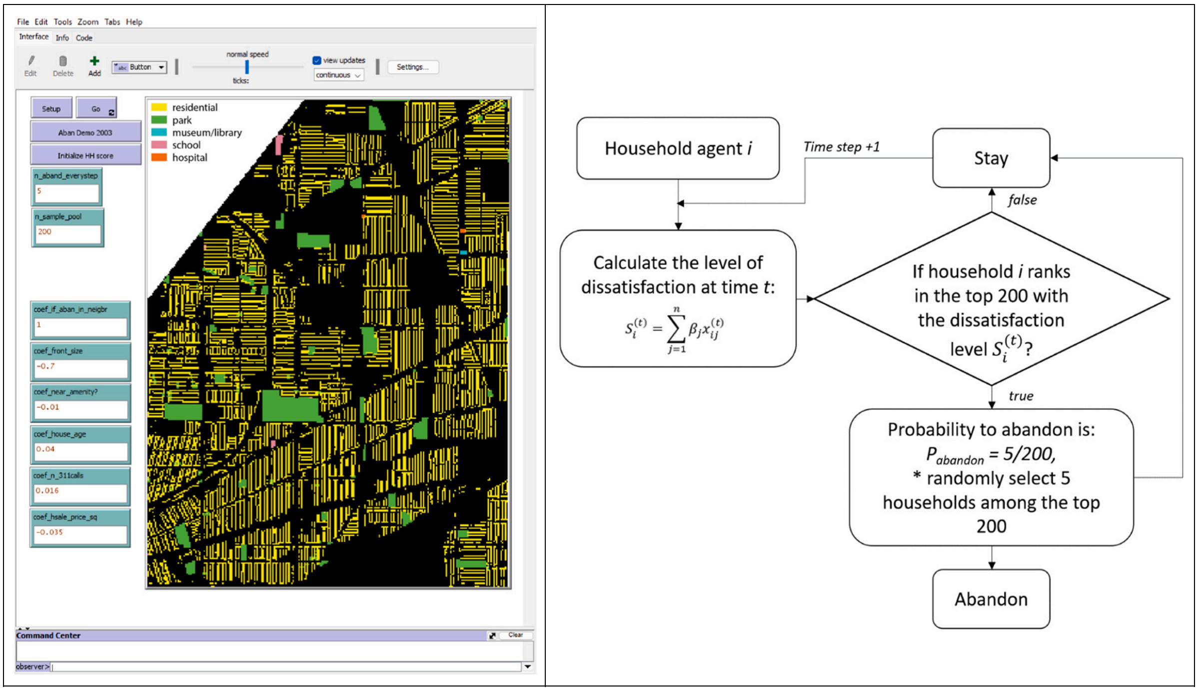

Fig. 3. Agent-based Model User Interface and the Decision-making Flowchart.

4.4. *Demolition policy simulation*

The verified, calibrated, and validated variables and parameters that produced the best accuracy score and face validation results were recorded to be used for the policy simulations. We conducted a series of "what if" experiments that allow decision-makers to examine the impact of alternative policy design to fight against housing blight and abandonment. Based on current discussions about fighting against housing abandonment, we designed four counterfactual policy scenarios including: 1) random demolition, 2) targeted demolition of abandonment clusters near amenities; 3) targeted demolition of abandonment clusters near commercial corridors, and 4) targeted demolition in areas with the highest owner-occupied housing rates (Fig. 2).

The policy simulation period was from 2007 to 2013 covering the period when the city's "5-in-5" demolition plan took place. We evaluated the four policy scenarios by comparing the emergent abandonment patterns against the ground truth. Kernel density maps were used to help analyze abandonment patterns (Morckel, 2014; Yin et al., 2022) after the alternative demolition plans.

5. Findings

5.1. *Agent-based models of property abandonment*

After the model calibration and validation, we obtained the final sets of parameters for the six explanatory variables listed in Table 2. The most significant variable on housing abandonment is "*if_aban_neighbr*" (if abandonment exists in the neighborhood) which has a coefficient of 1, followed by "*lot_front_size*" (the front size of a residential parcel) with a coefficient of 0.7. Other variables have a relatively small impact on housing abandonment including "*n_311_calls*" (number of 311 calls) and "*housing_sale_price*" (housing price per square foot) with coefficients below 0.04, and "*housing_age*" (housing age) and "*if_anchor_inst_half_mile*" (if anchor institutions exist within a half-mile radius) with coefficients about 0.01. Using these parameters, the average accuracy score was calculated to be 76.8 % suggesting that our model can correctly predict 76.8 % of the ground truth housing abandonment. These parameters indicate that the presence of abandoned housing in the neighborhood strongly influences households' dissatisfaction levels which can lead to abandonment. In addition, the site design of a residential parcel plays a significant role in the decision to abandon. These findings align with the results reported in prior studies.

Fig. 4 shows the modeling results for both the training and testing period where darker colors indicate a higher density of housing abandonment in the neighborhood and vice versa. The training period included 589 time steps in our model to abandon a total of 2913 houses. Fig. 4 (a) - (d) shows the abandonment patterns at time steps 100, 200, 300, and 400. These sub-figures depict the progression of housing abandonment in the study area. At time step 100, Fig. 4 (a) demonstrated a relatively dispersed distribution of housing abandonment. However, as time progresses to step 300 and beyond, Fig. 4 (c) and (d) illustrated a noticeable shift towards more clustered patterns of housing abandonment.

Figs. 4 (e) and (f) provide a comparison between the predicted abandonment patterns generated by the model and the actual ground truth abandonment patterns at the end of the training period (the year 2010). This allows for an assessment of the model's accuracy in capturing and reproducing the real-world observed housing abandonment patterns. These figures suggest that while our model underestimates the abandonment densities in the northern part of the study area, the densities in the area around Genesee St. and Broadway were approximately in line with the ground truth data. Fig. 4 (g) and (h) present a comparison between the predicted modeling outcomes and the observed housing abandonment patterns during the testing period, which spans from 2010 to 2013. These figures allow for an evaluation of how well the model performed during calibration and validation. The comparison indicates that the simulation's predicted patterns were reasonably consistent or matched with the observed housing abandonment patterns, especially in the area under scrutiny by many studies in the southern part of the study area.

5.2. *Agent-based policy simulations*

The policy simulations were run using the calibrated and validated model to compare the performance of alternative demolition policies. Fig. 5 shows the kernel density maps generated to visualize the patterns

Fig. 4. Model Tuning and Validation.

of housing abandonment under various simulation scenarios of demolition policies. Darker colors indicate higher abandonment densities and vice versa. Fig. 5 (a) shows the ground truth densities. Fig. 5 (b) - (e) show the predicted densities under different demolition scenarios.

The simulation results demonstrated that patterns of housing abandonment respond to policy changes concerning the level of abandonment and revitalization efforts in the neighborhood (Fig. 5). The results from the simulations provide insights into the policy considerations guiding demolition in the City of Buffalo. Inferences about the policies guiding demolition can be made by comparing the Ground truth Fig. 5 (a) model with the other simulations. First, the simulations suggest that demolition in Buffalo was not random. There is a clear contrast between the Ground truth 5 (a) model and the Random demolition 5 (b) model.

Further inspection of the policy simulation results suggests that policy considerations guiding demolition in the City of Buffalo were not focused on characteristics often associated with residential and neighborhood quality of life issues. There is a clear contrast between the Ground Truth 5 (a) model and the models that emphasize targeted

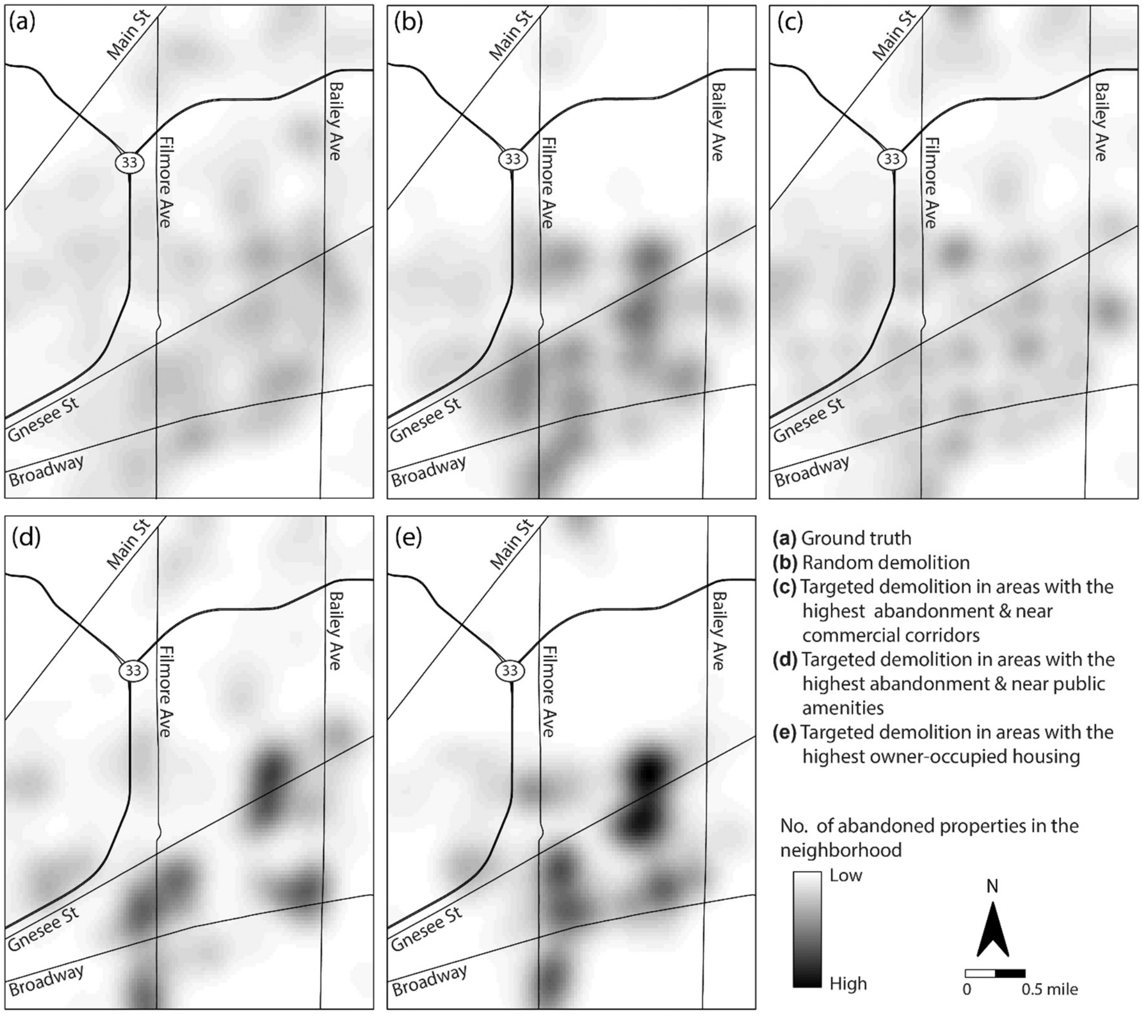

Fig. 5. Kernel Density Maps of Housing Abandonment under Various Demolition Policy Simulations.

demolition in high abandonment areas near public amenities 5 (d) and targeted demolition in areas with the highest owner-occupied housing 5 (e). These models suggest that targeting demolition near neighborhood amenities such as parks and schools or near owner-occupied housing units would lead to more clustered abandonment patterns, which might be more cost-effective to invest in greenspace and other neighborhood amenities and attract investment.

In contrast, the Ground Truth 5 (a) density mirrors the targeted demolition in high abandonment areas near commercial corridors 5 (c) simulation results in many respects. This suggests that policy consideration guiding demolition in the City of Buffalo prioritized characteristics often associated with commercial corridor development, with a tendency to demolish houses near commercial corridors. The net effect of this approach is that the benefits of residential housing demolition are more likely to be realized for businesses and property owners adjacent to commercial corridors. This policy approach reduces the chances that demolition will be concentrated in residential settings where urban revitalization dollars can be invested in neighborhood amenities. Instead, this approach to demolition created incentives for the City of Buffalo to invest its resources in commercial corridor revitalization, under the assumption that those investments would spill over or trickle down to neighborhoods later. This market-based, or neoliberal approach, is reflective of what Kotler (2005) described as an imperial city approach that focused on downtown and commercial corridor revitalization at the expense of neighborhoods and residents.

6. Discussion

Our results from simulating households' interactions corroborate conclusions drawn by other studies that use statistical methods: suggesting that abandonment in a neighborhood is a crucial predictor of further abandonment (Morckel, 2014; Weaver & Knight, 2018; Yin & Silverman, 2015). Yet, the implementation of mass demolition plans with varying focuses can yield substantial differences in the abandonment patterns, as demonstrated by our ABMs. Households' decisions were cumulatively affected by the inclusion of the demolition policy alternatives in our simulations, leading to changes in the dynamic patterns of abandonment throughout the modeling period, compared with both the ground truth data and findings from other studies (Weaver & Knight, 2018; Yin et al., 2022).

To tackle housing abandonment, policy recommendations include targeting demolition and implementing interventions such as creating new green space and neighborhood amenities, building replacement housing, and other initiatives aimed at revitalizing neighborhood (Dewar et al., 2015; Gallagher, 2010; Hackworth, 2014; Mallach, 2012; Shilling & Logan, 2008). Our ABMs helped to identify a distinct pattern of demolition clustered near commercial corridors in Buffalo, which was motivated by policies that differed from those made by advocates for neighborhood-based revitalization.

Our ABMs incorporated dynamic linkages between demolition policies and decisions made by households, as well as the linkage of micro-level decisions with social, economic, and physical characteristics of the neighborhood or environment where individuals reside (Batty, 2009; Jiang et al., 2021). Such models generated abandonment patterns that are challenging to be adequately modeled using traditional statistical approaches (Brady et al., 2012; Yin, 2007; Yin, 2010). This study goes beyond identifying linear relationships between abandonment patterns, demolition, and the neighborhood trajectories (Silverman et al., 2013). For practitioners, such ABMs provide insights to understand how the actors' motivations and decisions shape policy outcomes, shed light on the connection between policies and outcomes, and open up opportunities to reevaluate existing policies and weigh alternative approaches.

7. Conclusion

In this study, prospective ABMs were built to help develop an understanding of the possible impacts of potential alternative policies to fight vacancy and abandonment by way of successive simulations that allow for the comparison of variations in the types of alternative policies. The investigation of abandonment patterns generated under different demolition scenarios can help develop hypotheses to specify more realistic and testable policy alternatives and shed light on factors that have an impact on locations of abandonment to tailor demolition and redevelopment strategies.

The parameters generated after the agent-based model verification and validation suggested that the presence of abandoned housing in the neighborhood strongly influences households' dissatisfaction levels that can lead to abandonment. The site design also contributes to the decision to abandon. These findings align with the results reported in the existing literature.

Our results also suggest that Buffalo's demolition strategy prioritizes commercial corridor revitalization over neighborhood revitalization. Under this scenario, demolition does not target residential areas for revitalization, Instead, it is used as a tool to remove blighted properties adjacent to commercial corridors without reinvesting in residential neighborhoods. This approach focuses on stabilizing commercial corridors and assumes that commercial revitalization would eventually spill over into adjacent neighborhoods. The approach is distinct. It uses residential demolition as a tool to revitalize commercial corridors, and it does not pair targeted demolition with investments in neighborhood amenities. In contrast to the demolition strategy identified in this analysis, an alternative approach would involve greater clustering of residential demolition, accompanied by new housing development and investments in greenspace and other neighborhood amenities.

This analysis, which explores the dynamics and patterns of abandonment under different demolition policies, can help policymakers better understand the abandonment problem, identify potential demolition interventions and policies that produce more equitable outcomes, and provide insights into where to spend resources in shrinking cities like Buffalo. ABMs like the ones used in this study provide opportunities to investigate and discuss a broader range of potential cumulative or emergent effects of demolition policy options. Simulations can also be built in multiple time slots to compare how different scenarios could affect abandonment processes. These models can help reveal the dynamics of neighborhood decline and assist cities and policymakers in designing planning tools to address property abandonment. In addition, they can be used to create more equitable revitalization strategies that change the equilibrium between investments in commercial corridors and neighborhood amenities. For instance, this analysis provides evidence that the City of Buffalo's demolition policy is not random. Instead, it is guided by neoliberal strategies that prioritize investments in private enterprises over neighborhood quality of life. These findings raise questions about the efficacy of this approach and the need to expand the scope of demolition policy to promote revitalization that invests in neighborhood amenities and targets residential neighborhoods.

CRediT authorship contribution statement

Li Yin: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Fuzhen Yin:** Writing – review & editing, Visualization, Software, Methodology, Formal analysis. **Robert M. Silverman:** Writing – review & editing, Writing – original draft, Supervision, Investigation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The authors do not have permission to share data.

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