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ORIGINAL ARTICLE

Vacant Building Removals Associated with Relative Reductions in Violent and Property Crimes in Baltimore, MD 2014–2019

D. H. Locke · R. L. Fix · A. N. Gobaud · C. N. Morrison · J. Jay · M. C. Kondo

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Abstract Vacant and abandoned buildings are common features in many post-industrial US cities, and are consistent predictors of violence. Demolition programs are regularly employed as an urban land use policy to stabilize housing markets and mitigate public health problems including violence. The objective of this research was to examine the effect of vacant building removals on violent and property crimes in Baltimore, MD from 2014 to 2019. We conducted a difference-in-differences analysis using spatio-temporal Bayesian mixed models on six crime types on block faces with and without building removals, before compared with after removal. There were significant reductions in total, violent crimes (with and without assaults), thefts, and burglaries on block faces with building removals relative to their controls. Total crimes decreased 1.4% per mi^2 (CrI: 0.5 – 2.3%), which translates to a relative reduction ~ 2.6 total crimes per mi^2 per year. The largest relative decreases in crime were found among assaults (4.9%; CrI: 3.4 – 6.3%) and violent crimes (3.0%; CrI: 1.9 – 4.1%). Building removals were associated with relative reductions in crime in Baltimore City. The relative reductions in crime, at building removals compared to at control vacant lots, were found among assaults and violent crimes, the crimes of greatest public health

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D. H. Locke (✉)
USDA Forest Service, Northern Research Station, Baltimore Field Station, Suite 350 5523 Research Park Drive, Baltimore, MD 21228, USA
e-mail: dexter.locke@gmail.com; dexter.locke@usda.gov

R. L. Fix
Department of Mental Health, Bloomberg School of Public Health, Johns Hopkins University, 415 N. Washington Street, Room 519, Baltimore, MD 21231, USA
e-mail: rebecca.fix@jhu.edu

A. N. Gobaud · C. N. Morrison
Department of Epidemiology, Mailman School of Public Health, Columbia University, 722 West 168Th St, New York, NY R50510032, USA
e-mail: ang2167@cumc.columbia.edu

C. N. Morrison
e-mail: cm3820@cumc.columbia.edu

C. N. Morrison
Department of Epidemiology and Preventive Medicine, School of Public Health and Preventive Medicine, Monash University, 553 St Kilda Road, Melbourne, VIC 3004, Australia

J. Jay
Department of Community Health Sciences, School of Public Health, Boston University, 801 Massachusetts Ave., Crosstown 444, Boston, MA 02118, USA
e-mail: jonjay@bu.edu

M. C. Kondo
USDA Forest Service, Northern Research Station, 100 North 20Th Street, Suite 205, Philadelphia, PA 19103, USA
e-mail: michelle.c.kondo@usda.gov

concern. Building removals provide co-benefits to their communities, and may be considered part of a crime reduction strategy compatible with other approaches. A systematic effort to understand the role of care for remaining vacant lots could further inform our findings, and efforts to further decrease violence and improve community health.

Keywords Vacant building removal · Demolition · Crime · Baltimore

Introduction

Violence constitutes a major public health problem, including consequences extending over the life course including injury, premature death, poor physical and mental health, and lost economic output [1, 2]. Policies responding to violent crime often employ the criminal legal system. Yet violence is tied to place and tends to concentrate in neighborhoods with racial and economic segregation and disinvestment [3, 4]. A prominent symbol of neighborhood disinvestment in US cities is abandonment. Associated concentrated disadvantage, over-crowded housing, low home-ownership rates, and low collective efficacy are predictors of violent crime [5]. In the current study, we examined whether vacant and abandoned building removal reduced crime in Baltimore, MD from 2014 to 2019.

There is growing recognition of the importance of places and neighborhoods in violence prevention [6]. Cities have implemented a number of neighborhood-level place-based interventions to reduce crime and violence [7]. Modern public health approaches addressing crime – particularly violent crime – target the built environment, with promising results [7]. Research has demonstrated that reducing alcohol availability, changing neighborhood zoning, adding street barriers, or improving natural features near housing can reduce violence [7, 8]. Removal of vacant and abandoned buildings (hereafter referred to as vacant) is another crime prevention strategy. Vacant buildings have demonstrable negative impacts on public health, and consistently predict violence [9, 10]. Accordingly, cities characterized by high rates of vacant housing such as Baltimore, MD [11] also have high homicide rates relative to other US cities [12].

Cities remove buildings to enforce codes and standards designed to protect public health and safety [13]. Vacant housing removal is hypothesized to remove visual cues of social disorganization, and promote *busy streets* to engage neighbors in positive ways [14]. Interventions following demolition, such as vacant lot gardening or greening [15], may further reduce crime and promote public health.

However, previous research on demolitions and crime is mixed. A study of demolitions in Denver, Cleveland, and Chicago from 2008–2013 found decreases in property crimes immediately surrounding demolitions relative to areas farther away (in Cleveland only), but no significant reductions in violent crimes [16]. Demolitions in Saginaw, MI between 2008–2009 were associated with a relative decrease in violent and property crime in block-groups. While violent crime decreased one month after demolitions, it increased between one and four months post-demolition [17]. In Kansas City, MO a study found no significant impact of vacant housing demolition on property or violent crime [18].

More recent research has demonstrated positive results. A point-level study of 2,000 demolitions between 2010 and 2015 in Buffalo, NY found violent and non-violent crime declines near demolitions compared with spatially-distant control locations (though these effects disappeared in neighborhood/tract-level analyses) [19]. A block group-level analysis of demolitions between 2010–2014 in Detroit, MI found significant declines in violent and property crimes relative to control block groups [20]. Demolitions in Detroit between 2009–2016 were associated with significant relative reductions in firearm violence, specifically, in block groups with 5 + demolitions, but not drug-related offenses [21]. Finally, an analysis of demolitions in Rochester, NY between 2000 and 2020 using 152 m x 152 m grid squares with at least one demolition, and adjusted for spatial dependence, found both short- and long-term reductions in shootings compared to citywide rates [22].

Specific types of property and violent crime may be differentially impacted by demolition, yet there is a paucity of research evaluating whether this is the case. Kim and Wo [23] looked at whether there were differential impacts of demolitions of vacant residential versus commercial buildings on crime in Los Angeles, CA neighborhoods. They found residential – but not commercial – demolitions were associated with reductions in burglary.

Most prior studies were conducted at coarse neighborhood levels of analysis, often defined using Census administrative boundaries [17, 20, 21]. However, site-level interventions such as building demolitions have been shown to have localized impacts [16, 18, 19, 23, 24], which may not be measurable at the neighborhood scale due to aggregation bias [18, 19, 25]. In addition, vacant buildings concentrate spatially and temporally, therefore the traditional regression assumption of independence may not hold. Yet few prior studies adjust for spatial dependency.

Our study had two primary research questions. We first asked whether removing compared to leaving vacant housing units reduced overall crime. Buildings are either removed with traditional demolition, or via labor-intensive deconstruction where materials are salvaged for reuse, providing job opportunities. We analyzed them together simply as building removals. Second, we sought to answer whether specific subtypes of crime (burglary, theft, and two measures of violent crime) were impacted by vacant removal. In the current study, we focused on Baltimore City, Maryland from 2014 to 2019 because of its high crime and vacancy relative to similarly sized US cities. We analyzed crime on block faces with occupied housing, vacant housing units, building removals, compared to block faces with occupied housing units and vacancies, but without building removals. Over the past decade, State of Maryland and Baltimore have engaged multiple organizations in removing the city's large vacant building supply, aimed in part to reduce gun violence [26].

Methods

Study Setting

Baltimore, MD (2020 pop: 585,708) is a post-industrial city with abundant vacant housing, that has suffered population loss since 1950 [11]. Approximately 62% of the city population is Black. There are an estimated 17,000 units as of April 2022 out of approximately 337,000 units. Baltimore has consistently higher rates of crime compared to other similarly sized U.S cities [12], and is experiencing a gun violence epidemic.

Building Removals

In 2016, the Governor of Maryland and Mayor of Baltimore launched a partnership called Project Creating Opportunities for Renewal and Enterprises (aka Project C.O.R.E) to remove vacant buildings to spur redevelopment [27]. Project C.O.R.E includes a workforce development component via partnerships with more than a dozen state and local agencies, non-governmental groups, trade groups and contractor organizations. Project C.O.R.E oversees both deconstructions and demolitions, which are carried out by city contractors or by the Maryland Stadium Authority contractor. Demolitions and deconstructions differ in that when a building is deconstructed the materials are salvaged for reuse. The deconstruction program trains and employs people from the pre-release prison population, and aims to reduce recidivism [26]. Building removals were also carried out outside the C.O.R.E. program by city contractors in emergencies to prevent collapse.

The Baltimore City Department of Housing and Community Development provided a geocoded database of 2,567 demolitions and 436 deconstructions (3,003 removals total) between January 1, 2014 and December 31, 2019. We assigned the treatment date as the date the removal was recorded as "finished." The Department also provided a geocoded database of 28,291 vacant buildings during the study timeframe, which we used as our pool of control locations. We excluded 11,801 vacant buildings that did not remain vacant throughout the study period (e.g., if they were redeveloped or became occupied).

Our unit of analysis was the block face per year, which is the area between two street intersections, including the space around the street between buildings facing each other [28]. Block faces are well-suited to studying urban crime, as they represent the lived experience. Block faces assign what would have been attributed to a single block to its four surrounding street segments instead, thereby increasing resolution, precision, and realism [28]. There were 775 block faces with building removals ("treated" or "treatment") and 524 block faces with vacant buildings ("controls", Fig. 1).

We matched treated block faces with controls that were over 100 feet away to prevent spatial spillover contamination (Fig. 1). Candidate control block faces needed to have vacant buildings and were randomly assigned to treated units. We therefore selected sites without respect to crime trends. Matching on additional criteria in the pre-period may create selection bias, as controls are artificially more similar to treated sites than from the source population, biasing effects towards the null [29]. After removing spatially

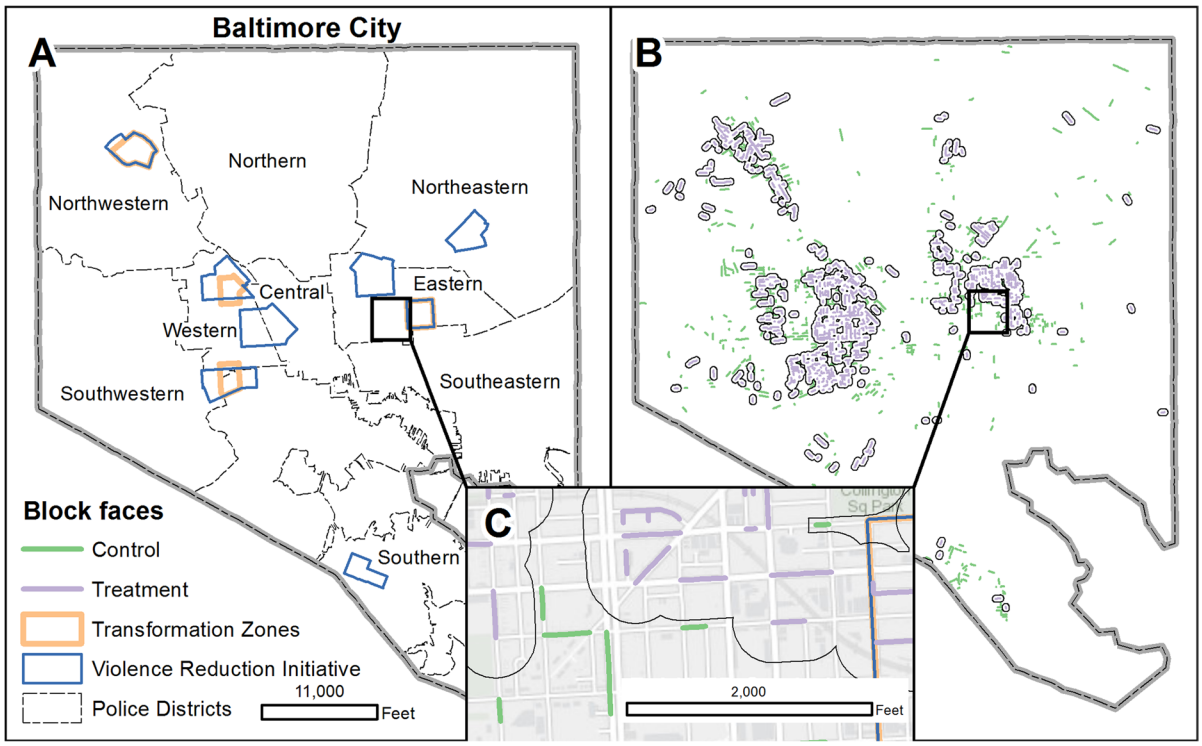

Fig. 1 **A** Baltimore City's Police Districts and areas of increased police presence and enforcement called Transformation Zones (2016 – 2017) and the Violence Reduction Initiative (2017 – 2019). **B**: units of analysis called "block faces" assigned to treated (where building removals occurred) and controls (otherwise similar block faces without building removals), greater than 100 feet away depicted with black buffer. **C**: Treated and control block faces in greater detail. Both treated and control block faces could have vacant lots without buildings.

near candidates, there were more treated units than controls, and we randomly assigned 251 controls a second time to treated block faces; all treated units had a matched pair control and associated treated-control identifier. Matching with replacement in this way diminishes bias [30].

Dependent Measure

We obtained geocoded reported crimes and their type from January 1, 2014 to December 31, 2019 [31]. We removed 990 crimes with addresses matching hospitals (which may not have represented incident location), yielding a georeferenced dataset of 283,601 crimes. We created six crime categories, including 1) burglaries, 2) thefts, 3) violent crimes (comprised of aggravated assaults, murder, rape, and robberies). Violent crime was further subdivided into 4) "Part 1" crimes which excludes simple assaults based on the Federal Bureau of Investigation definition, and 5) assaults, and 6) a total crime category was created by combining 1–3. Aggravated assault is a felony with a firearm or with the intent to cause bodily injury, while simple assault is a misdemeanor. Subdividing violent crime allows for more nuanced analyses. Block faces vary in size, so we assigned crimes per mi^2 to the treated and control block faces by creating 50-m resolution Kernel Density Estimation (KDE) surfaces for each crime type and for each year. A 907-m bandwidth created crimes per square mile surfaces. We assigned the mean intersecting KDE crime rate (by type and year) to each block face.

Confounders

Increased police presence and enforcement began in 2016 in areas of high-crime and longstanding poverty. These

areas, designated as "Transformation Zones," were targeted for increased police presence, housing inspectors to enforce code violations, needle exchange programs, job training, and other city services [32]. After 18 months, the program expanded to other areas and renamed "Violence Reduction Initiative." We coded each block face located inside these zones to account for these efforts.

For each study year, we obtained demographic data from the 5-year sample of the American Community Survey at the census tract level. Demographics included median household income (adjusted for inflation in year 2022 dollars), education (population percentage of those 25 years or older with a high school diploma, equivalent, or higher), race (percentage Black) as a proxy for exposure to dimensions of structural racism not captured by other covariates, and housing density (unit per acre).

In order to minimize the modifiable areal unit problem, we generated an Inverse Distance Weighted interpolated surface for each demographic variable, using demographic values assigned to tract centroids, and assigned interpolated values to block faces. To avoid edge effects, we included tracts within 5,000 feet.

Statistical Analyses

We tested for differences in crime rates and demographic variables between treated and control block faces using the Wilcoxon rank-sum (Mann–Whitney) test. We assessed the parallel trends assumption of difference-in-differences (DID) analysis by visually examining graphs to see if changes in crime rates in the pre-intervention period at treated block faces were the same as changes at control block faces.

Using multivariate generalized linear mixed models and the fixed effects described below, we estimated the effect of building removal pre- versus post-intervention at treated block faces compared to control block faces for all six crime categories. We examined the dependent variables' distribution which appeared to approximate the gamma distribution, so we chose the gamma distribution and specified a log likelihood. We included a DID estimator to compare crime rates at treated block faces post-intervention with crime rates at treated block faces pre-intervention and control block faces pre- and post-intervention. The variance inflation factors showed no presence of multicollinearity, so the predictors were not redundant.

We examined regression model residuals to assess the independence assumption and included data only from the year 2014 (the first study year), so that block faces in subsequent years would not be spatial neighbors with themselves and induce spatial autocorrelation in the residuals. Moran's I for all six crime type models' residuals indicated strong ($0.65 < I < 0.68$) and significant ($p < 0.001$) spatial autocorrelation when using a contiguity matrix based on the average length of all block faces (73.3 m) to define spatial neighbors.

Therefore, we estimated the effects of building removals on six crime types at the block face-level using a spatio-temporal Bayesian conditional autoregressive model with annual timesteps and the following formula:

$$Y_{it} = \alpha + \beta_1 P_{it} + \beta_2 R_{it} + \beta_3 \left(P_{it} \times R_{it}\right) + \beta_4 TZ_{it} + \beta_5 VRI_{it} + \beta_6 PoliceDistrict_{it} + \beta_7 Income_{it} + \beta_8 Edu_{it} + \beta_9 Black_{it} + \beta_{10} Density_{it} + Match_{0k} + u_{i0} + v_{0t}$$

where Y_{it} is crimes per square mile on block face i in year t and α represents the intercept or the average crime per square mile. P_{it} indicates pre-removal (0) or post-removal (1), R_{it} indicates control (0) or removal (1), and β_3 is the difference-in-differences estimate, and the interaction of pre/post and removal/no-removal. β_4 and β_5 are the coefficients for the time-varying indicator variables for the Transformation Zones and Violence Reduction Initiative areas, respectively. The police districts are included, β_6, to control for variations in policing practices and policies. β_7 through β_{10} are sociodemographic controls, $Match_{0k}$ is a random intercept variable for treated-control pairs k. u_i is a spatially autocorrelated random effect modeled with a conditional autoregressive distribution, established using the mean block face length as the distance to assign spatial neighbors from each block face center. This approach can be interpreted similar to the conventional Besag-York-Mollié model [33] but it omits the unstructured random effect, which we found to be unstable. v_{0t} is a random effect to account for unobserved changes year over year.

We conducted two robustness checks. First, we assessed whether the spatial weights matrix structure biased the estimates, namely whether our definition of neighbor was too local. We ran our analyses where neighbors fell within a distance of four times the average block face length (instead of the average block face length). Second, we ran regression analyses after

applying a second random matching procedure to re-match treatment and control block faces.

We used R version 4.1.2 to conduct analyses using Integrated Nested Laplace Approximation (INLA) via R-INLA version 22.03.16 [34]. INLA provides an alternative to Markov Chain Monte Carlo estimation of posterior probability distributions in Bayesian models. Rather than sampling model parameters, INLA estimates the integral to approximate posterior marginals quickly and precisely [34]. We applied vague priors to prevent unduly influencing the estimates, and report the odds ratios as percent change with 95% credible intervals (95% CrI), the Bayesian confidence interval analogue, calculated from the posterior distributions.

Results

We assigned 436 deconstructions and 2,567 demolitions (3,003 building removals total) to their 775 containing block faces. The range of cumulative building removals per treated block face over the study period was 1–48 (mean = 3.875, median = 2). Control block faces had on average 2.53 vacant buildings (sd = 2.67), and treated block faces had an average of 2.75 (sd = 5.42). Treated block faces were located in areas with low income (median household income $32,000/year compared with $39,000/year among controls), with a high proportion of Black residents (94% compared with 89%), and most residents aged 25 years or older had a high school diploma or higher educational attainment (75% compared with 78%; Table 1). Treated block faces were located primarily in the Western (30%) and Eastern (26%), and Southwestern (11%), police districts, while most control block faces were in the Southwestern (19%) or Southern (17%) districts.

Median crimes per square mile were greater at treated than at control block faces (Table 1). Time series plots of crime rates in the pre-intervention period showed parallel trends in the pre-period between treated and control block faces for all crime types except theft (Figure S1). We therefore dropped theft from subsequent analyses. Unadjusted mean crimes increased from pre- to post-intervention across all study locations, except for theft and total crimes among treated and burglary among controls (Table S1).

Regression analyses adjusted for sociodemographic variables, policing initiatives, and for spatial autocorrelation showed statistically significant reductions in all crime types and subtypes (Table 2) between treated and control sites, from before to after the building removals. There was a relative reduction in total crimes per square mile of 1.4% (95% CrI: -2.28 to -0.5). This translates to a relative reduction ~ 2.6 total crimes per mi^2 per year. The largest relative declines in crime were found in assault (-4.86, 95% CrI -6.3 to -3.41) and violent crime (-3.02, 95% CrI -4.08 to -1.94).

Results from robustness checks confirmed our main results. First, applying a more encompassing definition of spatial neighborhoods, 4 × average block group face, up from the average block face length used in the main analyses, did not alter effects for any crime type. After applying a different random match, we found equivalent effects, except the Burglary effect lost statistical significance (Tables S2 and S3).

Discussion

Baltimore City's unprecedented vacant building removal efforts are intended to provide workforce development, and to improve public safety in areas that have experienced decades of population decline [27]. Our study contributes to growing quasi-experimental research on the effects of vacant building removals on crime. We found that vacant building removals in Baltimore were significantly associated with reduced crime overall, and particularly with violent crimes, relative to control vacant properties.

Building removals may provide other co-benefits to their communities outside of crime reduction, such as preventing immediate collapse, absorbing stormwater, and reducing visual cues of disinvestment. Though the condition of each vacant lot post-building removal is not known. Building removal programs also provide job skills training and employment opportunities. Based on our findings, building removals may be considered a viable crime prevention strategy. Preventing any crimes meaningfully impacts individuals, their families, and communities.

Our findings corroborate others demonstrating negative associations between vacant building demolitions and violent crime, in Detroit [21], Buffalo [19], Rochester [22]. Given the epidemic of gun violence in these cities, including Baltimore, this evidence suggests that programs to "right-size" shrinking cities by removing unoccupied, deteriorating, and unsafe buildings, can produce public health benefits in the form of reduced violence. While

Table 1 Descriptive statistics of dependent and independent variables on treated and control block faces. Crimes are per square mile. Baltimore, MD, 2014 – 2019

Characteristic	Overall N = 9,300[1]	Treated N = 4,650[1]	Controls N = 4,650[1]	p-value[2]
Violent	188 (132, 243)	214 (169, 259)	158 (102, 216)	< 0.001
Part 1[3]	111 (76, 146)	125 (96, 155)	93 (60, 129)	< 0.001
Assault	77 (52, 101)	89 (67, 107)	63 (41, 89)	< 0.001
Theft	144 (104, 192)	154 (123, 195)	129 (89, 186)	< 0.001
Burglary	54 (41, 73)	59 (46, 78)	49 (36, 66)	< 0.001
Total	394 (286, 502)	425 (346, 532)	341 (236, 459)	< 0.001
TZ [4](2016 – 2017)	344 (3.7%)	282 (6.1%)	62 (1.3%)	< 0.001
VRI [5](2017 – 2019)	1,299 (14%)	927 (20%)	372 (8.0%)	< 0.001
Geographical region (Police District)				< 0.001
Central	624 (6.7%)	270 (5.8%)	354 (7.6%)	
Eastern	1,782 (19%)	1,218 (26%)	564 (12%)	
Northeastern	474 (5.1%)	132 (2.8%)	342 (7.4%)	
Northern	480 (5.2%)	132 (2.8%)	348 (7.5%)	
Northwestern	1,008 (11%)	564 (12%)	444 (9.5%)	
Southeastern	312 (3.4%)	78 (1.7%)	234 (5.0%)	
Southern	1,170 (13%)	378 (8.1%)	792 (17%)	
Southwestern	1,392 (15%)	504 (11%)	888 (19%)	
Western	2,058 (22%)	1,374 (30%)	684 (15%)	
Median Household Income [6]	35 (29, 42)	32 (27, 37)	39 (33, 46)	< 0.001
Education (%) [7]	76 (72, 81)	75 (71, 78)	78 (73, 84)	< 0.001
Black (%)	93 (78, 96)	94 (88, 96)	89 (57, 96)	< 0.001
Housing Units per Acre	7.16 (5.74, 9.08)	7.73 (6.15, 9.16)	6.80 (5.39, 8.90)	< 0.001

[1]Median (IQR); n (%)

[2]Wilcoxon rank sum test; Pearson's Chi-squared test

[3]Violent excluding assault

[4]Transformation Zones

[5]Violence Reduction Initiative

[6]$1,000 s, year 2022 $ values

[7]Percent of population 25 years old or older with Highschool diploma, equivalent, or greater educational attainment

Table 2 Adjusted difference-in-differences estimates of the effect of building removal on crimes per mi^2: Baltimore, MD, 2014 – 2019. Odds ratios were converted to percentage change

Crime Type	Relative Adjusted Difference in Crime Rate	95% Credible Interval	sig
Total	-1.4	-2.28 to -0.5	*
Burglary	-1.94	-3.83 to -0.02	*
Violent	-3.02	-4.08 to -1.94	*
Part 1	-1.56	-2.78 to -0.32	*
Assault	-4.86	-6.3 to -3.41	*

demolitions have historically been used to disadvantage communities of color, particularly Black communities (*e.g.,* urban renewal programs that razed Black neighborhoods for highway construction) [35], our results indicate that safety-focused removal programs may help close racial disparities in exposure to community violence.

Although we did not test for mechanisms of association, there are a number of plausible causal pathways. First, deconstructions take longer than demolitions, and become sites of employment and treat housing stock as valuable resources for reuse [26]. The positive attention that deconstruction sites receive may affect social behaviors surrounding the properties,

and the workforce development program is intended to reduce recidivism. Secondly, according to Busy Streets Theory [36], community interventions that promote social cohesion and social capital create positive social contexts which deter crime. Depending on whether or not maintenance of the resulting vacant lot occurs, the building removal may create more inviting streets for positive activities (such as walking or commuting), thereby supporting improvements in neighbor relations, which can lead to decreases in crime. Abandoned buildings often host illegal activities, and removing them removes the safe havens for crime.

Our study contributes to research using site- or block-level analyses to detect spatially-explicit changes in crime rates surrounding building removals [16, 18, 19, 23, 24]. In addition, our quasi-experimental study is one of few modeling change in outcomes relative to randomly matched control sites, after the deconstruction occurred [16, 18, 19, 24], as opposed to taking a longitudinal cross-sectional approach. We could not randomly assign treatment/control status, but our study approach points towards potential causality.

Our study incorporated spatio-temporal Bayesian conditional autoregressive models to address spatiotemporal dependence on our statistical analyses. Disinvestment from some urban neighborhoods means that vacant buildings usually cluster, potentially biasing assessments of interventions. The statistical assumption of independence of observations does not hold. Only one known previous study of vacant building removals [22] addressed spatial dependence. The sensitivity analyses using a more encompassing definition of spatial neighbors corroborated the main findings. In the sensitivity analyses using a different randomly matched set of controls, the burglary effect did not hold. But, all types of violent crime were shown to decline significantly with building removals.

However, there are study limitations. First, building removals create vacant lots, while maintenance is a goal of some removal programs, it is not guaranteed. Vacant lots can quickly become overgrown with unkempt vegetation. However, the city invests in vacant lot maintenance, and through the CARE-A-Lot program pays residents to maintain lots [25]. There are numerous efforts among community organizations transforming vacant lots into positive spaces such as gardens or parks. While the state of maintenance at each building removal site is unknown, our analyses suggest that these sites have a positive impact via crime reduction. Efforts to streamline administrative records and data collection on vacant lot stewardship activities and site characteristics would help researchers investigate factors related to crime.

Demolitions and deconstructions are done by different groups and entail different processes. Additionally, due to the spatial proximity of vacant buildings, vacant lots, and varied interventions, we were not able to test separately for effects of each type of intervention. Future research may consider the potential differential effects of one versus multiple building removals on the same block face. Control block faces were chosen that were at least 100 feet from building removal block faces. If that distance was too small and there were spatial spillovers, then the results would be biased towards the null. The results reported here may therefore be viewed as conservative. It could be that building removals displaced violent crime to other areas, as shown in Buffalo, NY [37]. This study did not test for displacement.

Building removals were associated with relative reductions in crime in Baltimore City, MD from 2014 to 2019. The largest relative declines in crime were found among assaults and violent crimes. A plethora of organizations and programs care for vacant lots. A systematic effort to understand the efficacy and co-benefits of these predominantly community-driven activities could better inform vacant lot maintenance strategies.

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Data Availability Data and reproducible code are available via Locke et al 2023 [38].

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