

Article

Incremental Urbanism and the Circular City: Analyzing Spatial Patterns in Permits, Land Use, and Heritage Regulations

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Abstract

The construction industry is a major contributor to global resource consumption and waste. This sector extracts over two billion tons of raw materials each year and contributes over 30% of all solid waste generated annually through construction and demolition debris. The movement toward circularity in the built environment aims to replace linear processes of extraction and disposal by promoting policies favoring building preservation and adaptive reuse, as well as the salvage and reuse of building materials. Few North American cities have implemented explicit policies that incentivize circularity to decouple urban growth from resource consumption, and there remain substantial hurdles to adoption. Nonetheless, existing regulatory and planning tools, such as zoning codes and historic preservation policies, may already influence redevelopment in ways that could align with circularity. This article examines spatial patterns in these indirect pathways through a case study of a college town in New York State, assessing how commonly used local planning tools shape urban redevelopment trajectories. Using a three-stage spatial analysis protocol, including exploratory analysis, Geographically Weighted Regressions (GWRs), and Geographic Random Forest (GRF) modeling, the study evaluates the impact of zoning regulations and historic preservation designations on patterns of demolition, reinvestment, and incremental change in the building stock. National historic districts were strongly associated with more building adaptation permits indicating reinvestment in existing buildings. Mixed-use zoning was positively correlated with new construction, while special overlay districts and low-density zoning were mostly negatively correlated with concentrations of building adaptation permits. A key contribution of this paper is a replicable protocol for urban building stock analysis and insights into how land use policies can support or hinder incremental urban change in moves toward the circular city. Further, we provide recommendations for data management strategies in small cities that could help strengthen analysis-driven policies.

Keywords: building permits; redevelopment; zoning; historic preservation; sustainable cities; circular cities



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1. Introduction

Processes of urban redevelopment have a substantial impact on the sustainability of cities. Each year it is estimated that over two billion tons of raw materials are extracted and consumed for construction [1] (Townsend and Anshassi, 2023). More than 30% of the billions of tons of waste generated annually comprises construction and demolition debris

(CDD) (Soto-Paz et al., 2023) [2]. These linear processes of extraction, use, and disposal exert significant environmental impacts across the lifecycles of buildings and infrastructure. In contrast, the concept of “circular cities” aims to decouple urban growth from resource consumption by promoting strategies such as adaptive reuse, material recovery, and the maintenance of existing building stock [3].

Circular city strategies are of great interest in cities around the world and across disciplines. Paiho et al., 2020 created a framework for defining circular cities, synthesizing a growing literature [4]. More recently, Falah et al., 2025 used advanced machine-learning techniques to map circularity indicators and their relationships to the U.N. Sustainable Development Goals (SDGs) [5]. Focusing more specifically on circularity in the built environment, a recent international conference brought together scholars from around the world to share the state of progress, particularly in the areas of architecture, engineering, and construction [6]. Williams (2023) has analyzed circular cities strategies in Europe, emphasizing the necessity of regulatory action and critiquing a reliance on market-driven approaches [7]. The field is clearly vast and multi-faceted, but our study is most concerned with indirect urban strategies for conserving embodied carbon.

Embodied carbon is a form of environmental accounting used to describe the greenhouse gas emissions generated during the manufacturing, transportation, installation, maintenance, and disposal of building materials [8–10]. Strategies to lower embodied carbon associated with the built environment include extending the life of buildings through repair, preservation, adaptive reuse, or even moving buildings. Other strategies involve managing the end-of-life of buildings through deconstruction and material reuse [11–13] (Boeri et al., 2019; Heisel et al., 2023; Ross, 2023). These methods of lowering or conserving embodied carbon serve additional circular goals of diverting construction waste away from landfills.

A few cities in North America have adopted measures that directly incentivize or require circular practices, such as calculating embodied carbon in new construction, diversion of waste from landfills, or the deconstruction of buildings and reuse of building materials [14,15]. Additionally, some have adopted requirements or offer incentives for LEED certification, which provides points for waste diversion. LEED certification is typically undertaken for large-scale institutional and government buildings but is only a limited proportion of new construction or remodeling of existing buildings. Despite such progress, there is little federal support for sustainable practices and significant local hurdles to adopting such policies in many communities.

Meanwhile, existing regulatory planning tools at the local level, such as zoning codes and historic preservation policies, may already influence urban development in ways that could be harnessed to work toward circularity in the built environment. In the U.S., zoning is a pervasive regulatory tool used to guide the spatial distribution of housing, employment, and other land uses in most cities [16]. On the one hand, form-based codes, New Urbanism, and Smart Growth have been promoted through the adoption of zoning regulations. On the other hand, outdated and ineffective zoning regulations can hinder the development of more walkable, livable, and sustainable cities, as noted by Bronin (2024) [17]. Cities and states such as Minneapolis, Charlotte, and Oregon have implemented zoning reforms to incentivize higher densities and mixed-use developments to meet housing demands through redevelopment [18,19]. Historic preservation regulations in the U.S. are similarly divisive: some scholars view local preservation regulations as obstacles to sustainable urban development [20], while others argue they are essential tools for achieving it [21].

A key distinction between these two local government tools—zoning and preservation designations—is their divergent approaches to the built environment. Zoning reforms, particularly up-zoning, most often assume that building removal, primarily through demo-

lition, is a necessary and desirable step before the construction of new buildings. Zoning reforms, however, largely overlook the environmental consequences of demolition. Demolition not only generates waste that ends up in landfills, but it also poses public health risks in communities where it is concentrated [22]. Demolitions are associated with the release of hazardous leachate, methane from landfills, and significant greenhouse gas emissions from the construction of replacement buildings [23–25]. In contrast to zoning, which often leads to demolition in preparation for new construction, historic preservation programs aim to prevent demolition and preserve existing building stock. However, historic preservation programs limit their scope to buildings and districts that are eligible for designation due to their historical or cultural significance. These policies typically ignore the value of maintaining and refurbishing existing buildings beyond the set eligible through their historic associations.

While both zoning and historic preservation policies impact the nature of building stock in urban areas, their effects on waste streams and embodied carbon are auxiliary to their role in guiding urban character. Thus, there remains an untapped potential to explore these tools of incremental urbanism and their influence on the multitude of modifications to the built environment that have the potential to affect circular city outcomes. Thus, the primary research questions guiding this paper are as follows: How do changes in building stock correspond to underlying zoning and preservation regulations? What are the implications for how local governments build sustainable and circular cities?

While federal and state or provincial policies are important to climate action, it is local governments that enact regulations of construction, preservation, and demolition in cities [26,27]. We thus conduct our study at this level using building permits issued by the City of Ithaca, a college town in upstate New York, as a case study. The study applies spatial and machine learning methods to analyze patterns in demolition and building permits, identify associations between permitting activity and underlying influences in the city, and understand how local government regulation can be best deployed to pre-empt pressures of redevelopment.

The following section presents a literature review on the use of building permits as tools to understand urban change. Next is a discussion of the methods used in this research and an overview of the results. The article concludes with key takeaways for local government officials, researchers, and professionals concerned with sustainability, as well as insights from our research into the unique challenges of pursuing these objectives in smaller communities.

1.1. Shifting Focus from New Construction to Existing Building Stock

The Smart Growth and New Urbanist movements in the U.S. advance sustainability primarily by influencing new construction. Some local governments have adopted higher-density, mixed-use, and form-based zoning codes, which reflect the conventional emphasis on designing and regulating newly constructed urban spaces to address climate action goals. This emphasis has begun to shift. Recent data indicate that “billings for reconstruction projects at architecture firms exceeded billings for new construction projects” [28], underscoring the growing importance of increasing the longevity of existing buildings [29–31]. Such retrofitting of buildings for decarbonization has become a key sustainability strategy, focusing on reducing operational energy consumption, and transitioning building operations away from fossil fuels.

In recent years, some local governments in the US have begun to work toward conserving embodied carbon. Although still nascent, local government efforts include building reuse, deconstruction, and material reuse policies [10,32–34]. Preserving and adapting existing building stock is a method of conserving material in place [21,35,36], while decon-

struction and material reuse can reduce carbon emissions associated with new building materials and the end-of-use treatment of used construction materials when disposed of in landfills as waste [12]. Choosing between building adaptation and demolition is influenced by factors such as maximizing land productivity, the condition and safety of the buildings, their heritage value, as well as potential adaptive uses [37]. Capital investment and, importantly, local regulations also influence the decision to preserve and adaptively reuse buildings [38].

The tools at local governments' disposal may prove to be even more important in an era when climate action is ever more urgent but with federal leadership that is at best ambivalent and, at worst, adverse to environmental policy. Sustainability planners might consider paying more attention to available policy tools that enable incremental changes to the built environment.

1.2. Mapping Building and Demolition Permits as Indicators of Urban Change

As events in the urban fabric, building and demolition permits document urban change. Permits can reveal the efficacy of planning initiatives focused on achieving transit-oriented development [39], measure the effectiveness of disaster recovery [40], or signal the loss of valued buildings and landscapes. Demolitions have been used as a tool to remove vacant or abandoned properties in efforts to spur reinvestment [41,42], particularly among legacy cities such as Buffalo [43] and Detroit. Understanding patterns of redevelopment can also constitute the basis for early warning systems that signal significant neighborhood change and potential displacement due to gentrification [44].

Spatial analyses of building and demolition permits hold great potential for understanding buildings and neighborhoods most susceptible to redevelopment. They can proactively inform the creation of policies aimed at increasing building longevity, preserving historic resources, improving the character of infill in neighborhoods, and reducing construction and demolition waste. Spatial and temporal patterns in building permits also indicate the priorities of community actors and their response to local government policies. Examples can include the decisions of stakeholders to demolish or invest in existing buildings, or the collective action of citizens who organize local historic districts to prevent or slow demolition activity.

Previous scholarship has identified several variables that increase the propensity for a property to be demolished: Older properties [45], proximity to abandoned and vacant properties, and lower overall neighborhood value increase the likelihood of a property being abandoned [43], which in turn triggers demolition as a potential tool. In some places, average building age at the time of demolition has decreased significantly over the years [46]. Further, properties with smaller houses, lower floor-area-to-lot-size ratios, of lower value than the surrounding neighborhood [47], and those located in dense and diverse environments [45] are most prone to redevelopment. The majority of the research we found focuses on medium- to large-sized cities such as Quebec, Chicago, and Buffalo, or at a national scale, such as across Finland [43,45,48,49], suggesting a gap with regard to smaller cities.

1.3. The Building Reuse to Waste Hierarchy

Figure 1 illustrates the Building Reuse to Waste Hierarchy, which describes preferred to less preferred treatment of buildings and building materials from the perspective of conserving embodied carbon and reducing waste. It was developed to use in considerations of carbon neutrality and efforts toward circularity in the built environment. The top portion of this figure represents the extension of building life through (in decreasing order of preference) building maintenance, preservation, and refurbishment; adaptive reuse,

overbuilding, and building expansion; and whole building relocation. These are most preferred, as they involve conservation of the greatest amounts of materials and, thus, embodied carbon. At the bottom of the hierarchy are events that involve the end of life for building stock, in which deconstruction, salvage, and material reuse are preferred over demolition as a last resort.

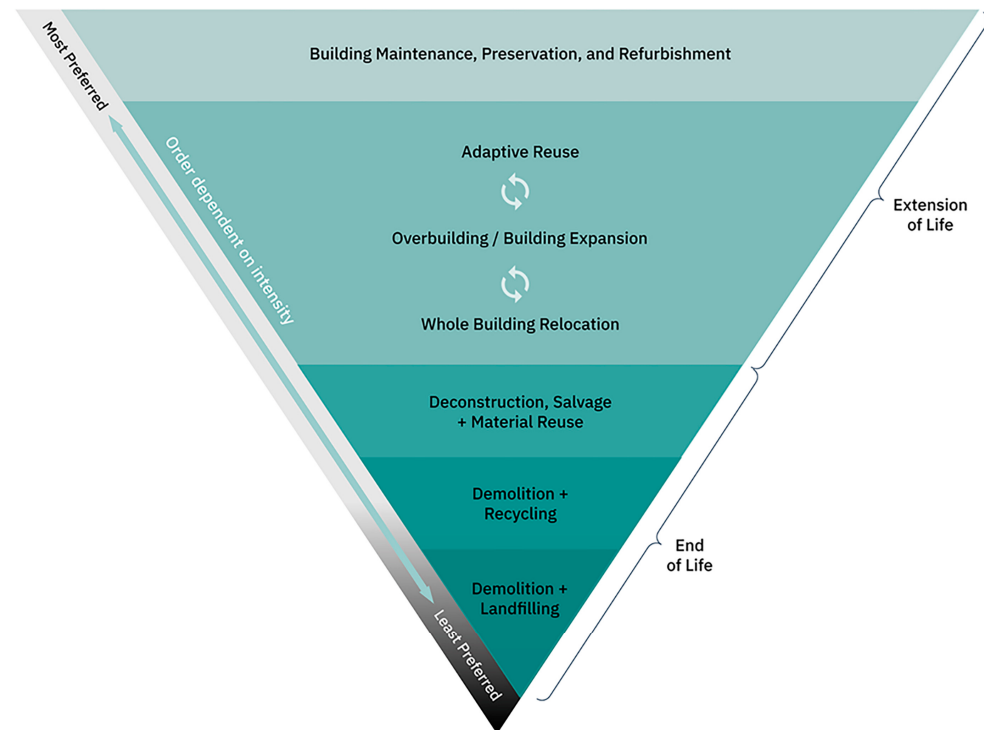


Figure 1. Building reuse-to-waste hierarchy: Wyeth Augustine-Marceil and additional Just Places Lab researchers.

Demolition of building stock for the purposes of redevelopment is thus in tension with tenets of circularity that preferentially promote the conservation of embodied carbon. Reinvestment in existing building stock and reuse of building materials in situ offer alternatives to demolition [50,51] and the large amounts of waste it generates [52]. The deployment of local government tools to mitigate redevelopment is in turn contingent upon proper characterization of the underlying patterns of investment in building stock, which this study aims to contribute to.

Much of the literature has focused on building permits as an indicator of redevelopment; less so on the dynamics of building maintenance, preservation, and refurbishment. Nonetheless, in recording the range of activities authorized on existing building stock, building permits offer rich information on the dynamics of change underway in cities. More specifically, of interest in this study are the ways in which building permits can herald remodeling and retrofitting activities related to both embodied carbon and waste.

A key distinction that we make in this paper is between the different types of building permits and the processes of urban change that they represent. For instance, a demolition permit can indicate redevelopment when issued for an entire building structure, while other types of permits, such as an addition, alteration, or repair (collectively called adaptation permits in this research), are ways of reinvesting in existing building stock. The extent to which these permits are deployed is influenced by city regulations. Local planning tools like zoning and historic preservation can thus be used to encourage less carbon-intensive building activity such as preservation and refurbishment. Hereafter, we characterize demolition permits as indicative of carbon-intensive redevelopment and adaptation permits

as indicative of reinvestment in existing building stock. Building adaptations, while not necessarily low-carbon by themselves, are preferable to demolition in that they are associated with a reduction in the use of virgin materials and the generation of waste.

1.4. A Case Study of Sustainability and Circularity in Ithaca, New York

Ithaca is a small city with an estimated population of 31,792 as of 2023 [53]. It has a large student population attending two major universities—Cornell University and Ithaca College. Small scale and limited government resources in a city of this size significantly influence data availability and quality, which we describe in the discussion. These issues limit the range and applicability of various analytical methods. Nonetheless, studies in small cities are crucial. Among the 3093 incorporated places in the United States with a population greater than 10,000 people (as of 2019), only 780 have a population greater than 50,000 [54]. In other words, the vast majority of local governments in the United States serve small cities. Developing analytical protocols that assist them in developing evidence-based policy is important to promoting sustainability action at the local level.

Local historic designations and zoning are two primary tools that Ithaca has implemented in its comprehensive plan [55]. Historic resources in the U.S. may be designated at the federal, state, or local level but have different levels of oversight. In many communities, ordinances protect locally designated historic buildings by requiring the review of alterations or preventing demolition. National historic districts, in comparison, are purely honorary and do not prevent demolition unless federal funding is involved [56]. In addition to its zoning codes, which permit varying degrees of development density, the City of Ithaca has adopted a Planned Unit Development Overlay (PUD), which offers developers more flexibility in proposing development otherwise not permitted within base zoning districts. Additionally, the city has approved other overlay zoning districts, such as the South Hill Overlay District near Ithaca College, which was driven by residents' concerns over the neighborhood character being compromised by increased student housing and student-centered establishments [57]. In 2019, the City of Ithaca also adopted a Green New Deal resolution that sought to achieve carbon neutrality in 2030 while redressing historic inequities [58]. City officials primarily focused on decarbonization efforts through electrification, thus emphasizing the reduction in operational carbon, or the greenhouse gases emitted in the operation of buildings. This has resulted in changes to the city's building energy code but has not addressed embodied carbon specifically. Thus, although these tools demonstrate the city's efforts towards guiding the character of place, their effects on building permit activity and consequent carbon implications are not well understood.

2. Methods

This paper should be understood as embedded in a larger research project (Figure 2) consisting of both qualitative (Part 1) and quantitative (Part 2) elements. The larger project is action research involving the Circularity, Reuse, and Zero Waste Development (CR0WD) network, which involves academic labs working with community leaders in planning, preservation, and building material reuse. This paper does not represent the full scope of that research but focuses primarily on the spatial analysis of building permits, i.e., Part 2. These spatial analyses consisted of several steps, which we will recount in order in this methodology. For this analysis, a dataset of building permits was acquired from the city. Permits of interest, i.e., demolition and adaptation permits, were extracted and cleaned.

Analysis of the demolition and adaptation permits was performed in the following three stages: Firstly, the research team conducted an exploratory analysis to investigate the spatial and temporal distribution of permitting activity, which we contextualized to local dynamics (2A). For this, the team developed heat maps in selected intervals of time to

understand areas of the city where demolitions were higher in number. Second, the research team estimated two different specifications of a Geographically Weighted Regression (GWR) model to understand local factors that influence spatial patterns of adaptation (2B), i.e., we used the count of adaptation permits as a measure of reinvestment in building stock and ran regression models to look at potential factors that are correlated to it. Third, the results of the GWR were assessed using a Geographically Weighted Random Forest Model (GRF) to explore the potential of developing predictive models for evaluating reinvestment activity (2C).

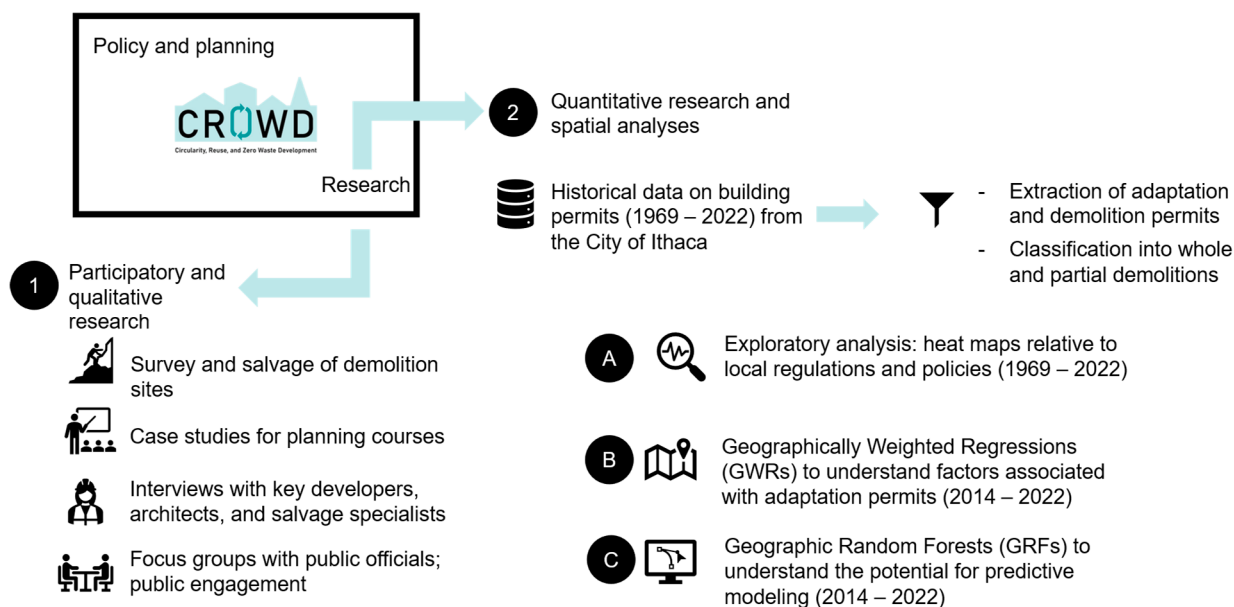


Figure 2. Flowchart outlining the research methods used in the study.

In the next sections, we first introduce our data collection and cleaning strategies and then outline each of these three steps in turn. We also make efforts to specify data limitations at each stage of the process.

2.1. Collection and Classification of Data from Ithaca's Building Permit Database

A building permit certifies local government approval of any proposed change to a building structure, subject to city regulations. The City of Ithaca provided multiple databases of building permits and a geodatabase of digitized city services dating to 1969, from which different types of permit data were extracted for time periods of interest (Table 1).

The following types of permits indicate different extents of reinvestment in building stock: (i) demolition permits to partially or completely remove structures; (ii) relocation permits to move buildings; (iii) building permits associated with adaptation and reinvestment in existing buildings, classified by the research team and hereafter known as 'adaptation' type permits; and (iv) new construction. Of primary interest are demolition and adaptation permits. While demolition permits represent building material outflow into waste or reuse streams, adaptation permits represent preservation or reinvestment into existing building stock, i.e., material flux and the preservation of embodied carbon.

Although Table 1 presents the full set of permits issued, steps 2B and 2C used only a subset of them. The city shifted to a new system for recording their building permits from 2014 onward. Prior to this, the recording of other variables associated with the permit data was often missing, inconsistent, or misrepresentative (for example, the year the building was built), which would influence modeling accuracy. Moreover, other independent

variables of interest, such as zoning policies, have undergone significant shifts in the last few decades, making analysis over a longer time horizon difficult. In the interests of accuracy, we use only data from 2014 onward for the GWR and GRF modeling.

Table 1. Distribution of permits in the City of Ithaca’s database.

Permit Type	Count (n)	Reclassification
Demolition: removal of any building or structure.	718	Divided into whole-building demolitions and partial demolitions. Whole-building demolitions are typically indicative of redevelopment. Partial demolitions are often a precursor to reinvestment.
Relocation: relocated or moved buildings.	7	Relocation
Alteration: Any construction or renovation to an existing structure other than repair or addition.	20,555	Adaptation-type permits reflect a reinvestment in existing building stock.
Change of use or change of occupancy		
Repairs: The restoration to good or sound condition of any part of an existing building for its maintenance.		
Heating and electrical		
Addition: An extension or increase in floor area, number of stories, or height of a building or structure.	871	New construction indicates redevelopment or expansion.
New construction: All new structures, including accessory structures, residential, commercial, and industrial properties.		
Other permits: Includes signs, parking, unissued permits, etc.	1332	Not considered in the analysis.

Each demolition permit from the new dataset (2014 onwards) was classified as either a whole or partial demolition using a text analysis of the permit description. Even in recent years, there is limited recorded information for many permits. As the best alternative, we enriched the subset of demolition permits by imputing missing data by corroborating information recorded on the permit entry with other data sources: Tax Assessor’s Data, Google Maps, and Google Streetview. For instance, historical Streetview of an address might show a garage that is not present in the current Streetview, or Google Maps might show a parking lot where a building was formerly located. Whole-building demolitions were defined as those involving the demolition of the entire building structure, while partial demolitions were defined as those that involved accessory structures like garages, sheds, porches, or interior remodeling. The distinction between whole- and partial-building demolition permits is important. Where whole-building demolitions point to redevelopment pressures stemming from zoning changes, partial demolitions are typically associated with improvements, additions, or preparation for new accessory structures to existing properties, thereby indicating reinvestment in existing building stock. Thus, they depict fundamentally different economic rationales and, consequently, are theorized in this research project to have different impacts on embodied carbon and waste.

2.2. Exploratory Analysis and Demolition Pattern Mapping Offer Insight into Local Dynamics

A series of heat maps was created using ArcGIS Pro to understand the concentration of demolitions and their shifts over time. Since historic preservation policies limit the extent of permissible demolition and potentially create shifts towards reuse and preservation, we also delineate local and national historic districts in these maps. In the results discussed

below, we compare these demolition hotspots relative to the location of historic districts as well as over time.

2.3. Geographically Weighted Regression (GWR) of Reinvestment in Existing Building Stock

Next, we used R software (Version 4.3.3.) to estimate regression models to analyze factors influencing reinvestment in building stock. Specifically, we evaluated the association between the count of adaptation permits and potential explanatory variables. These included the following: (i) zoning; (ii) building stock characteristics (e.g., property age); and (iii) neighborhood characteristics. Variables of interest and our rationale behind using them are detailed along with results in Table 1. We chose not to include additional variables characterizing population demographics or income since Ithaca, as a college town, has a large floating population of students who primarily rent as opposed to own property. These variables would thus not provide an accurate measure of influence on property reinvestment.

The number of whole-building demolitions, partial demolitions, building adaptation permits, and other variables were aggregated into the cells of a uniform fishnet of 600 ft × 600 ft spanning the city limits. This size was chosen to strike a balance between a sufficient sample size for modeling and being a reasonable spatial distance of approximately 1–2 city blocks over which permitting data could be aggregated. The average age of buildings was calculated in 2022 for those buildings within the cell that had a reported year built. A total of 117 cells did not have any permits with suitable ‘Year Built’ data, especially in the sparser periphery of the city; this was imputed using K-Nearest Neighbors (KNN) ($k = 8$). We validated its better performance by introducing artificial missingness in the dataset—imputation using KNN demonstrated a lower Root Mean Squared Error (RMSE) as compared to imputation using the average year built (28.1 versus 36.3). Average distances were calculated from the cell centroid to popular places of interest such as major universities, downtown, and popular recreational areas. Subcategories of the zoning code were combined by use case to develop a taxonomy of ten key zoning types—business, university zone, Collegetown area form district, high-density residential, low-density residential, parks and public use, Southwest zone district, special districts, and others, which comprised only small parts of the city. Each cell unit was categorized by the code that represented the majority of the cell area. Furthermore, cells that had over 50% of their area fall into any of the three types of historic districts were designated as such.

Using adaptation permits as the dependent variable, we estimated OLS and GWR models for two different specifications. Both a visual analysis of the heatmaps and spatial distribution of residuals from the OLS indicated spatial autocorrelation (Moran’s $I = 0.28$, p -value < 0.001), suggesting the use of a Geographically Weighted Regression (GWR). GWRs allow for spatial non-stationarity of the modeled relationships with coefficients varying across space. Our understanding of local dynamics in Ithaca provided qualitative evidence for this. For example, the neighborhood immediately adjacent to Cornell University is facing significantly higher redevelopment pressures to accommodate the growing student population’s need for housing as compared to the rest of the city.

The GWR was estimated for the same specification as the OLS using a Gaussian neighborhood with a bandwidth of 1800 feet, which minimized the AIC. This spatial kernel corresponds to approximately 4 to 6 city blocks and, from our subjective experience of Ithaca, is a reasonable distance over which neighborhood character extends. ChatGPT (Version o3-mini) was used to help troubleshoot some initial errors in the code. Researchers then produced maps demonstrating the influence of different variables and local R^2 values indicating model fit, which are presented later in this article.

2.4. Machine Learning Using a Geographically Weighted Random Forest Model (GRF)

As a final step in our analysis, we shifted from descriptive to predictive. Recent years have seen widespread application of Machine Learning (ML) models in urban planning for their capacity to monitor and predict changes in the urban environment [59–61]. In our scenario, ML models have the potential to anticipate areas facing high demolition or reinvestment pressures based on prior patterns. This allows for targeted, pre-emptive policies at the neighborhood level through local government tools, not limited to historic district designation and zoning.

The ML algorithm, Random Forests (RFs), is typically an aspatial technique. Georganos and Kalogirou (2022) have proposed the Geographical Random Forest Model (GRF) through the inclusion of spatial criteria by combining the local spatial heterogeneity of GWRs with the algorithmic performance of RF [62,63]. We use the models in their R package ‘SpatialML’ (2022), built atop the Ranger package, to test the potential for using GRFs as a predictive tool [64,65]. The model generates two simultaneous outputs: a global model fitted to all the data, similar to a linear regression, and a locally variant model, similar to a GWR. Modeling scenarios can be adjusted by changing the relative weights of the global and local outputs.

Using RF conventions, we split the building permit dataset into 80 percent training and 20 percent testing data and the same model specification as the GWR to train the algorithm at different bandwidths. We used a bandwidth of 1800 feet and the fully local model based on error minimization criteria, that is, the model that generated the least Mean Absolute Error (MAE) (Table 2).

Table 2. Prediction error of the GRF model for different local and global output weights.

Local vs. Global Weighting of GRF Outputs	Mean Absolute Error (MAE) of Predictions	Root Mean Squared Error (RMSE) of Predictions
Model 1 Local = 1.0; Global = 0.0	5.57	7.71
Model 2 Local = 0.75; Global = 0.25	5.57	7.76
Model 3 Local = 0.5; Global = 0.5	5.59	7.83
Model 4 Local = 0.25; Global = 0.75	5.62	7.91
Model 5 Local = 0.0; Global = 1.0	5.66	7.99

3. Results

3.1. Exploratory Heatmaps of Demolition Activity and Historic Districting

Figures 3 and 4 provide heat maps showing the density of partial- and whole-building demolitions over time. Where the decade between 2005 and 2015 saw a larger number of partial demolitions across the city, the period post-2015 has seen a shift towards whole-building demolitions, increasingly concentrated in the central city and areas surrounding Cornell University. These are aligned with the period of more rapid redevelopment the city has been witnessing. Importantly, a comparison of demolition activity with reference to the location of historic districts reveals a clear difference—where whole-building demolitions are expressly situated outside historic districts, these districts have been the sites of many partial demolitions, even coinciding with hotspots of activity. According to our sources in the historic preservation community, historic districts were established as a policy response to redevelopment pressures in areas where residents were attached to older urban fabric, either for its architectural character, sense of place, or historic associations. This is also

consistent with observations made by other scholars [56]. Such regulations could thus enable the conservation of embodied carbon through reinvestment in building stock as opposed to redevelopment.

Heat map (for partial building demolitions)

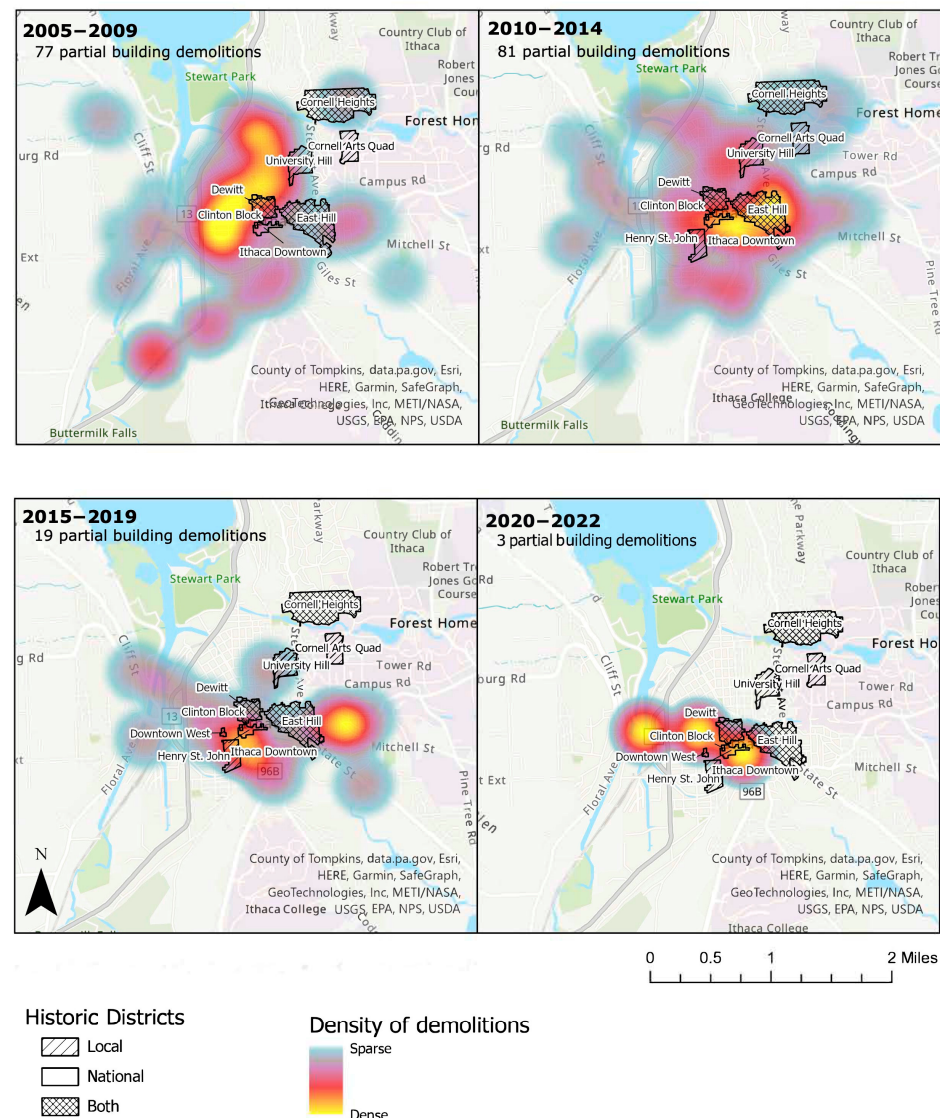


Figure 3. Heat maps in increments showing the density of partial-building demolitions relative to the location of historic districts. These are typically accessory structures such as garages and sheds. Note the final increment in the series ends in the year 2022, the last year for which permits were analyzed.

A local expert in preservation responded to the maps and helped situate them in the local dynamics of the city:

“The maps seem to track with what happened in terms of new policies and upzoning. The 1987 to 2004 hot spots appear to correspond with a lot of the development that Mack Travis discusses in his book [66]... Because the Collegetown construction moratorium ended in April 2009, it’s not surprising to see Collegetown from the creek to E. State to Dryden turned into a true demo hot spot. During the 2010s, so many new projects up there came online after the real estate crash of 2008 and the projects that were on standby waiting for the moratorium to be lifted were finally able to start. This was when a lot of that real estate became highly valued... Developers certainly saw the growth opportunity

with student rentals. After 2015, you also see activity along the downtown corridor because that corresponds to the upzoning that went into effect in that zone.”

(Christine O'Malley, 2022).

This quote alludes to the complex interplay between city policies and developer and property owners' decisions about reinvestment in existing building stock and new construction. The city policies mentioned in the quote describe a pause in development while the City of Ithaca adopted New Urbanist zoning reforms in the Collegetown neighborhood. These reforms aimed to improve the character of new construction while allowing for higher levels of density. In 2015, the City of Ithaca adopted a new Comprehensive Plan [55]. This plan includes broad policies that call for achieving sustainability through the balancing of new development and preservation. Since that time, there have been additional policy innovations, such as the adoption of the Planned Unit Development Overlay (PUD) zone, to offer more flexibility to developers in proposing large-scale development.

Heat map (for whole building demolitions)

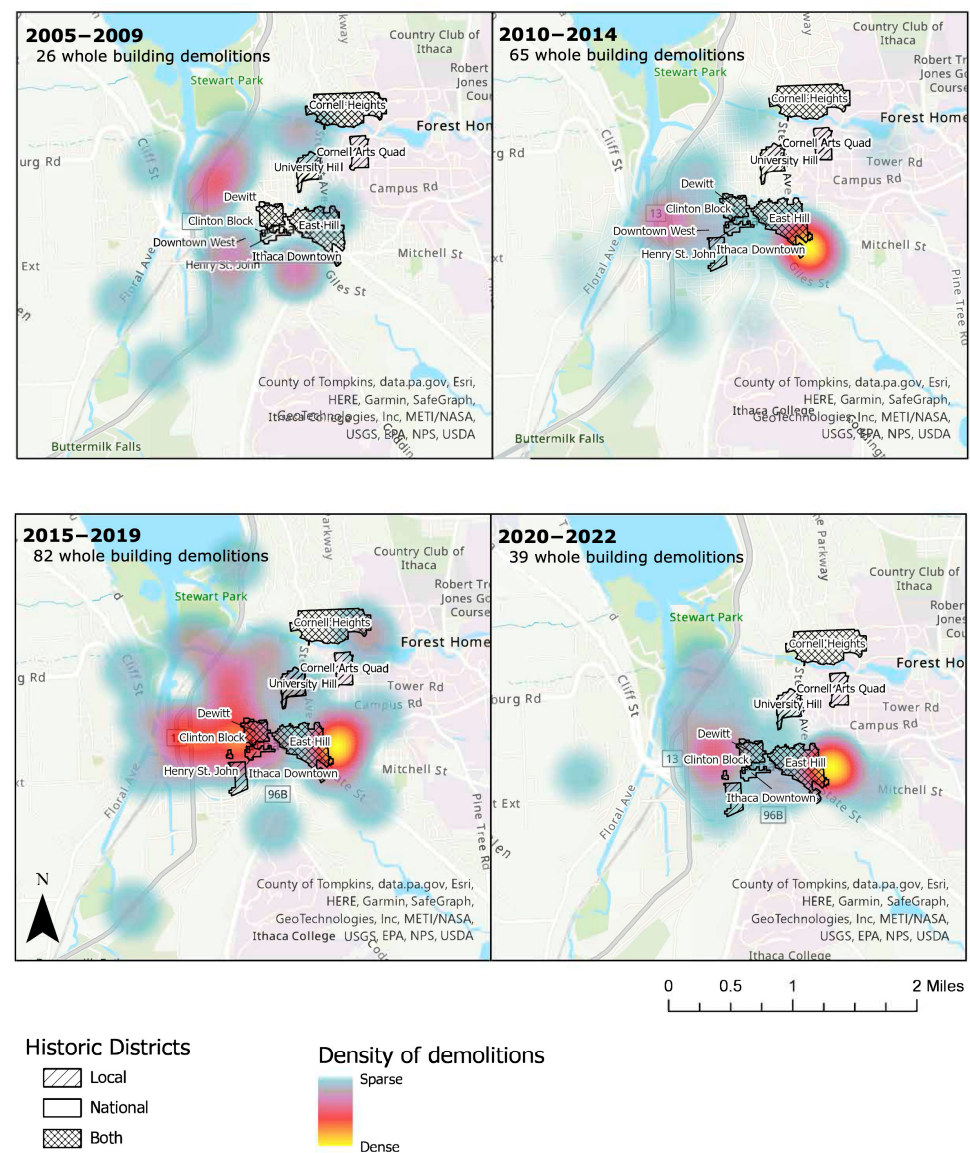


Figure 4. Heat maps in increments showing the density of whole-building demolitions relative to the location of historic districts. Note the final increment in the series ends in the year 2022, the last year for which permits were analyzed.

3.2. Outcomes from the OLS and GWR Modeling

Results from the baseline OLS models are given in Table 3, GWR coefficients for variables of significance are shown in Figure 5, and corresponding local R^2 values are given in Figure 6. Although neither whole nor partial demolitions are significant predictors of adaptation permits, the coefficients on each are in the direction we expect; that is, whole-building demolitions, often precursors to new construction, are negatively associated with adaptation permits, while partial demolitions, indicative of reinvestment in existing stock, are positively associated with adaptation permitting.

Maps of the coefficients on two variables—mean (approximate) year built and improvement-to-land-value ratio—show clear pockets of redevelopment activity (Figure 5). Mean year built is a weak predictor, but its distribution offers clues to underlying pressures in the city. Typically, we would expect that older properties see higher rates of both demolition and adaptation; however, the Collegetown area adjacent to Cornell University (located towards the northeast) saw a positive association between the year built and adaptation permits issued, i.e., a higher reinvestment in younger properties, pointing to the redevelopment pressures in this neighborhood. This is further corroborated by the positive coefficient for the Collegetown zoning district indicated in the OLS results. The improvement-to-land-area ratio is strongly associated with reinvestment. However, where other parts of the city witness a positive association between reinvestment and improvement-to-land-value ratio, areas with the greatest economic potential from redevelopment, Collegetown and Ithaca's downtown area, do not see the same extent of positive association. The urban fabric reflects these trends: Rapidly increasing demand for student housing from a growing university has led to several low-story properties being replaced by multi-story or high-rise housing in the neighborhoods adjacent to the university, irrespective of building age. It possibly represents concentrations of building permits associated with tenant build-out of commercial spaces or finishing of residential units within relatively recently built mixed-use development. Simultaneous with this shift towards Collegetown is a reduction in building activity elsewhere in the city, as reflected by the coefficients on the residential zones.

As expected, many zoning types are significantly associated with adaptation permits. Residential zoning was associated with lower levels of adaptation permits as compared to the university-zoned areas, which probably reflect differences in the availability of capital. Overlay districts, some of which were specifically introduced to restrict high-density, student-oriented redevelopment [57], also saw lower levels of adaptation permits. Parks, public use spaces, and some of the special districts are not as densely built up, which contributes to their lower permit activity. We also see small, positive associations between reinvestment and properties along the waterfront. The following two forces contribute to this: Firstly, Ithaca has designated special zones for areas along the waterfront to permit more flexible land uses. This shift in zoning is likely to have triggered reinvestment in properties here. Secondly, updates to the Federal Emergency Management Agency (FEMA) Flood Map show a dramatic increase in the number of properties at risk of inundation [67] due to flooding of the river. Repairing water damage caused by flooding potentially requires greater reinvestment in properties along the waterfront.

Lastly, historic districting is also a significant predictor of reinvestment. Areas that fall within National Historic Districts see dramatically higher numbers of adaptation permits as compared to areas that are outside of these districts. This provides evidence of the importance of federal historic preservation policies and incentives for reinvestment in existing buildings, and the role of local governments and community organizations in applying for the creation of national historic districts in their community. Further, these findings highlight the role that designations play in influencing the spatial patterns of reinvestment in the built environment.

Table 3. List of variables used in the GWR and results of the OLS regression.

Independent Variables	Detail	OLS Model 1 DV = Adaptation Permits (<i>n</i>)	OLS Model 2 DV = Adaptation Permits (<i>n</i>)
Whole-building demolitions (<i>n</i>)	Whole-building demolitions are often precursors to redevelopment.	−0.339 (0.517)	−0.363 (0.510)
Partial demolitions (<i>n</i>)	Partial demolitions are associated with reinvestment in existing building stock and hypothesized to be correlated with ‘adaptation’ type permits.	1.327 (1.343)	0.987 (1.326)
Mean approximate year built	Older buildings are more likely to require reinvestment for repair or be redeveloped.	−0.016 (0.013)	−0.024 * (0.013)
Zoning	Regulations indicate permissible changes to the built environment.		
	Business	−0.425 (2.709)	−1.357 (2.687)
	Collegetown	16.979 *** (3.810)	17.321 *** (3.753)
	High-density residential	−6.083 *** (1.972)	−5.926 *** (1.944)
	Low-density residential	−4.400 *** (1.612)	−4.267 *** (1.602)
	Overlay district	−3.121 (2.461)	−4.055 * (2.450)
	Parks and public use	−7.885 *** (1.639)	−7.810 *** (1.615)
	Southwest Zone	−3.865 * (2.249)	−3.487 (2.241)
Historic district	Special districts	−9.759 *** (2.100)	−9.340 *** (2.099)
	Other	−10.444 *** (3.252)	−10.156 *** (3.221)
	Binary indicator. Historic properties are less likely to be demolished but may receive reinvestment to preserve them.	6.101 *** (1.131)	
	Local historic district #		1.059 (2.186)
	National historic district #		24.311 *** (5.978)
	Neither local nor national historic district #		−4.796 *** (1.851)
Distance to Cayuga Lake	The waterfront along Cayuga Lake is a major public amenity. There have been efforts to rezone the waterfront for urban mixed-use development.	−0.0003 *** (0.0001)	−0.0003 ** (0.0001)
Distance to Downtown Commons	Ithaca Commons is considered the center of downtown.	−0.002 *** (0.0002)	−0.002 *** (0.0003)
Distance to Cornell University	Reinvestment is likely to happen near the largest employer in the county, plus redevelopment associated with student housing demand.	−0.0002 (0.0002)	−0.0002 (0.0002)
Average ratio of Improvement-to-Land-Value	Higher improvements to land value ratios signify higher reinvestments in existing building stock, possibly indicative of gentrification.	0.737 *** (0.131)	0.727 *** (0.129)
Constant		54.960 ** (24.595)	73.832 *** (24.275)
Observations <i>n</i>		510	510
R ²		0.569	0.583
Adj. R ²		0.554	0.567
Residual std. error		7.747 (df = 492)	7.630 (df = 490)
F Statistic		38.155 *** (df = 17; 492)	36.106 *** (df = 19; 490)

Note: * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$. # The reference category is for cells that fall in districts that have been deemed both national and local historic districts.

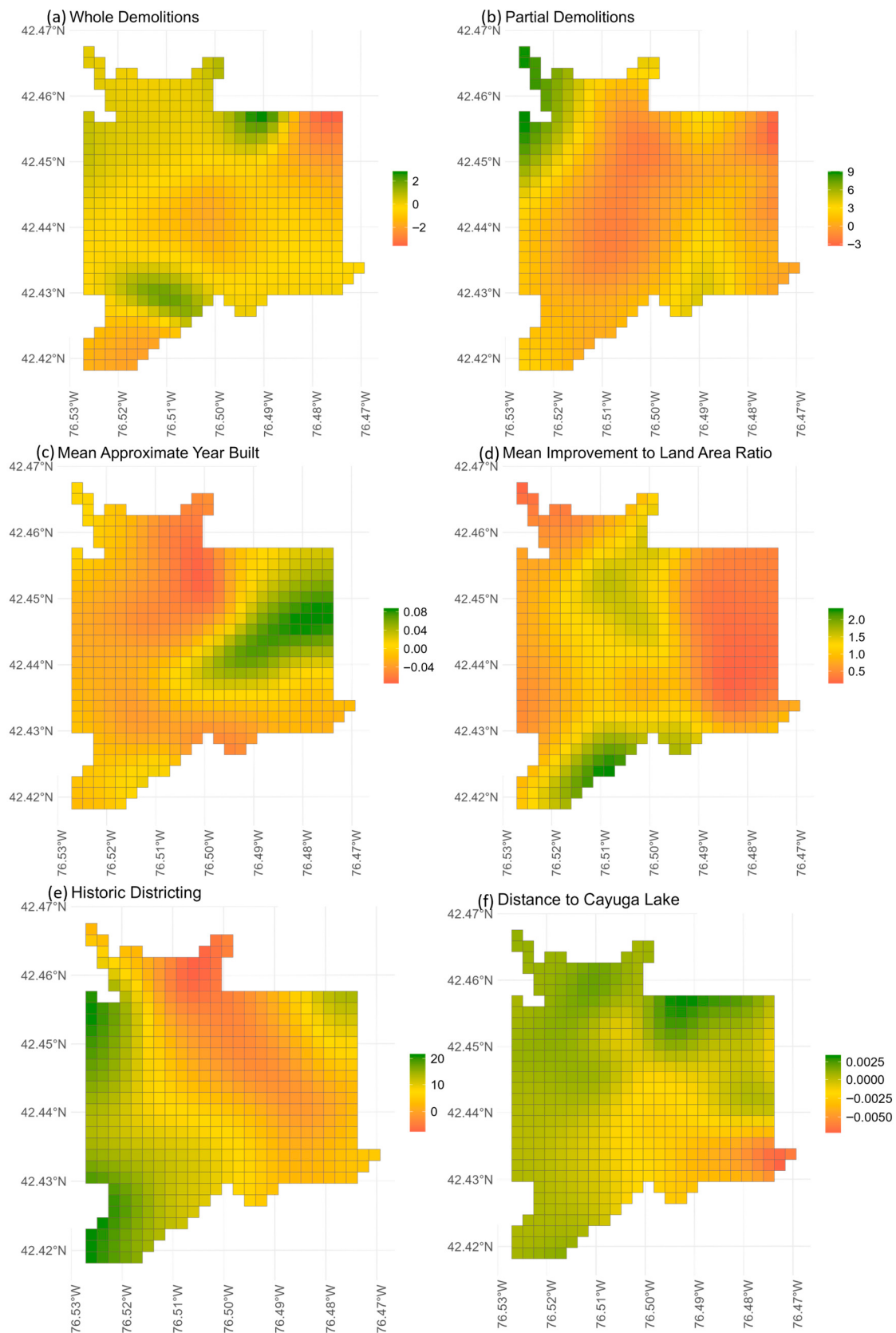


Figure 5. Maps of the GWR coefficients of different variables: (a) whole-building demolition permits; (b) partial-building demolition permits; (c) mean approximate year built; (d) mean improvement-to-land-area ratio; (e) historic districting; and (f) distance to Cayuga Lake.

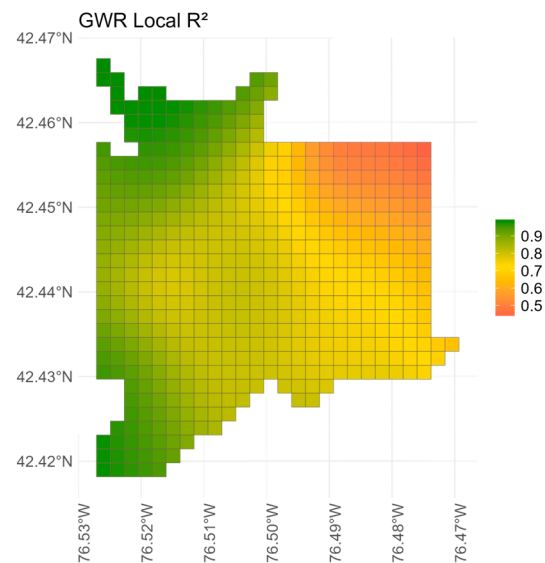


Figure 6. Local R^2 values from the GWR.

3.3. Outcomes from the GRF Modeling

The goal of using a GRF was to demonstrate its potential for use as a predictive model to guide local government responses to the spatial variation in redevelopment pressures. Output from the GRF aligns directionally with output from the GWR. Comparative maps of actual and predicted values by the GRF algorithm show that the model manages to predict the intensity of adaptation permits to a reasonably high degree of specificity using only the limited data of a small city (Figure 7). As can be visually assessed, the model correctly predicts higher levels of adaptation permit activity in the eastern portion of Ithaca, the Downtown, and the Collegetown district for cells that were part of the testing dataset.

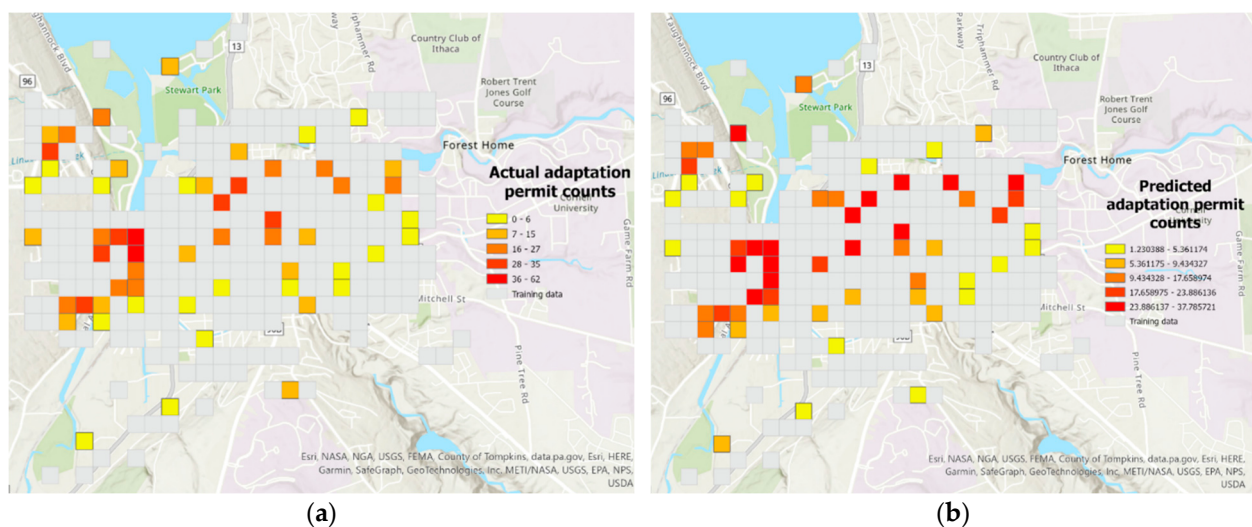


Figure 7. Comparison between (a) actual counts of adaptation permits and (b) predicted adaptation permit activity by the GRF model.

Clearly, when used effectively, these models have the potential to inform the use of regulatory tools such as zoning, historic districting, or demolition policies to forestall unwanted redevelopment or redirect reinvestment through more dynamic use of these tools. From the perspective of local government, less important is granular accuracy of such models, and more important is directional accuracy to identify the relative magnitude

of contributing variables and the neighborhoods that they influence. Identified variables or neighborhoods can thus become the focus of responsive local government policy.

Table 4 provides a qualitative summary of the effect sizes of significant predictors and their policy implications from across all the analyses.

Table 4. Summary of the effect sizes of key variables and open-ended policy implications.

Variable Name	Effect Size and Direction	Findings and Planning Implications
Historic districting	Large, positive	- National historic districts were strongly associated with more adaptation permits, possibly due to the inability to demolish and redevelop and tax incentives for eligible properties. - How can historic districting be proactively applied to promote shifts away from high-carbon redevelopment towards lower-carbon adaptive strategies? How can cities extend preservation policies to include variables other than age or historic value?
Zoning	Large, variable	- Mixed-use zoning was positively correlated with increased reinvestment, while residential zones, overlay districts, and low-density zoning districts were mostly negatively correlated with adaptation permits. - How can overlay zoning districts (with time horizons if needed) be used to guide urban development in transitional areas or redirect investment to declining neighborhoods?
Mean year built	Moderate, variable	- Although older buildings were more likely to be adapted overall, younger buildings in neighborhoods with higher levels of economic activity saw more adaptation permits, potentially increasing carbon impacts. - What policy instruments can cities use to reduce carbon-intensive changes to newer construction? For instance, might the city adopt new requirements or incentives for deconstruction as an alternative to demolition, and the use of reclaimed materials in remodeling activity, in addition to policies for new construction?
Mean ILV ratio	Moderate, positive	Improvement to land value measures the extent of reinvestment over time. Which areas have low ILV ratios, which indicate a potential for greater reinvestment in existing stock?
Distance to Cayuga Lake	Negligible, negative	What natural amenities are likely to attract redevelopment pressures, and what are the associated benefits and risks?
Distance to downtown Commons	Small, negative	What are centers of economic activity in the city? How can cities encourage reinvestment or adaptation of existing buildings in central business districts and offset the impacts of demolition and redevelopment?

4. Discussion

In this study, we examine how local government regulations such as zoning and historic districting can contribute to the conservation of embodied carbon in the built environment and, consequently, to a more sustainable and circular city. We imagine conservation of embodied carbon and reduction or prevention of waste as an outcome of prolonged building lifespans and encouraging preservation and adaptation of existing buildings over demolition and redevelopment. Sequential spatial analyses of building permit data offer insights into pressures shaping the urban fabric and how these tools could be most effectively applied to achieving sustainability goals.

4.1. Implications of Circularity in the Built Environment and Local Government Policy

Circular economy and circular city initiatives reimagine regional economies as transitioning from linear and extractive to circular, in which products and materials are

(re)circulated “at their highest utility and value” [68]. Shifting from demolition to reinvestment in existing building stock or deconstruction where redevelopment is necessary represents important steps toward circularity in the built environment.

The multi-stage analysis—exploratory mapping, explanatory regression models, and predictive GRF algorithms—is ground-truthed with local dynamics to offer insights into the role of these policies. In our study, historic preservation and zoning policies in Ithaca appear successful in limiting redevelopment in certain neighborhoods while channeling reinvestment into other districts in the city. For instance, incentives associated with national historic districts may be contributing to reinvestment in building stock instead of demolition. Previous scholarship on the nexus between historic preservation and CE has found that preservation and adaptive reuse of historic buildings and landscapes can improve community economic resilience if harnessed into sectors such as tourism [69] but needs a better set of indicators to evaluate the potential for and performance of these buildings [70,71].

Model outcomes can also inform indirect pathways to conservation. As an example, pressures on the housing market could be eased through concerted management efforts such as tenancy and occupancy laws, coordinated across government, community, industry, and (in Ithaca’s case) university partnerships, which might indirectly help conserve buildings. Predictive models can help pre-empt demolition and redevelopment by guiding local governments to enact targeted conservation policies at granular, neighborhood levels. These could take the form of historic districting or more creative regulatory tools designed to prolong building lifespans.

Lack of sufficient awareness and tools for decision makers on the benefits of these policies and inadequate assessment of their multiple downstream benefits often limit the adoption of these policies [72]. Thus, cities could consider developing comprehensive impact assessments and supporting toolkits targeted at a range of relevant stakeholders—planning officials, real estate developers, and citizens—to enable greater consensus.

Despite significant data limitations that are probably common across many small cities, the protocol we follow can be a useful method for other small cities to enable sustainability policies. Richer datasets offered by larger cities can only enhance the effectiveness of these models.

4.2. Implications for Spatial Analyses in Small Cities and Data-Poor Contexts

Our analysis emphasizes the high degree of spatial heterogeneity even in smaller cities and the need for applying techniques that reflect these local dynamics well. Insights from our participatory research were essential to contextualizing the spatial patterns we observed. However, a significant challenge was that small cities bring with them several data limitations, not just in terms of data management, but also in terms of the models that can be successfully applied.

The authors found many issues in analyzing building and demolition permits with the city’s database: Older, historical data are only partly digitized, a problem common across many cities. More significantly, very little information is collected about the attributions of buildings seeking permits, whether for demolition or adaptation. There is little consistency in information requirements, resulting in a lot of manual cross-referencing and best-guess classifications. Additionally, there is no repository for previous tax assessment data. Temporal dependencies over the course of building lifecycles make the study of property values difficult.

Our data management experience suggests that minor modifications to data management strategies could enable local governments and researchers alike to benefit from the richness of building permit databases. More specifically, we would like to see permits indexed by the specific property, data fields specifying property age, the extent of

demolition or reinvestment, standardized descriptors for proposed changes, and, perhaps more ambitiously, material waste generated and recovered. Consolidated property data at the state or federal level could help with data standardization across geographies and comparative studies on decarbonization in the built environment. Centralized, regional or statewide management of such databases could also address the funding challenges associated with smaller municipalities maintaining their own individual systems. Although our research team was initially motivated by the goal of decarbonization in the construction industry, these data can find applicability in several planning challenges, from affordable housing to disaster management.

From a modeling perspective, Ithaca's college town character introduces additional complexities—demographic variables such as age and race, as well as income variables, might have added greater nuance to the models, providing indications of their influence on property reinvestment. In Ithaca's case, a significant portion of the population are student renters who are a floating population and tend not to own property or directly decide on building preservation or new construction. Although we chose to disregard these demographic variables in our models, we recommend their inclusion in other modeling efforts.

For researchers and sustainability advocates studying construction and demolition debris, we also found a lack of information on what happens to demolition waste and whether any material is salvaged. To reiterate, changes to the permit data collection process that could facilitate sustainability and circularity research include the addition of fields that specify the extent of demolition and the introduction of building material management planning. Thus, we find room for improvement in the coordination of building adaptation and demolition permits at the building-level scale and the district, and the potential for long-range planning at the district or neighborhood and community-wide scales that many planners focus on. A transition to conserving embodied carbon and the reduction or elimination of construction and demolition debris will require new data systems and approaches that account for the stockpiles of embodied carbon and potentially valuable reusable materials within the existing building stock.

We recognize the data and modeling limitations recounted in this discussion point and suggest that the protocol be replicated and improved upon by application in other cities, both within the United States and outside, to validate these findings. Specifically, we recommend conducting these in cities of different sizes, with different demographic and economic profiles, and with different regulatory approaches to evaluate the influence of various factors on property reinvestment and decarbonization. An interesting direction for future modeling could be to evaluate how reinvestments in property vary by owner-occupied versus rented-out property.

4.3. Implications and Research Directions for Circularity in the Built Environment

While these tools are useful for examining and responding to redevelopment, they represent only a first step in the movement towards circular cities and circularity in the built environment [73–76]. The quantities of embodied carbon in building materials, estimated landfill waste, and potential for recirculation are not examined here but are important for further study. Larger cities, such as Portland, Oregon, and San Antonio, Texas, which have adopted policies to incentivize and require deconstruction and reuse, studied demolition activity as a first step to be [77]. As more communities prioritize the conservation of embodied carbon, there is likely to be greater demand for methods that successfully estimate and predict building reinvestment and demolition activity to analyze carbon savings.

This study does not focus on the relative costs and benefits of preservation of existing buildings relative to new construction. It is important to note that reinvestment in existing buildings may be cost prohibitive and that other incremental tools to work toward circular

cities may take the form of incentives. Some of these incentives at the local, national, or state/provincial level may already exist or could be enhanced. An additional caveat is that this article does not focus on nongovernmental programs or certifications such as LEED. Efforts to improve existing certification programs to incorporate greater circularity in the built environment could be another fruitful research direction.

Finally, the models in this paper treat reinvestment activity at the neighborhood level as occurring independent of other neighborhoods, but that is unlikely to be the case. Moreover, redevelopment and reinvestment are not mutually exclusive. As the hotspot analysis shows, spatial shifts in redevelopment or reinvestment hotspots over time are at least partially likely to be in response to neighborhood-level government regulations. There is thus a need for modeling frameworks that accommodate these spatial and temporal interdependencies. The research team would have liked to offer deeper insights into redevelopment pressures; however, the limited number of demolition permits issued precluded meaningful spatial analysis.

5. Conclusions

This article introduces the idea of the potential for existing city policies associated with historic preservation and land use regulations to aid in work toward circularity in the built environment. In an era when city officials may feel constrained in adopting new policies to work toward either the reduction or conservation of embodied carbon or the prevention and diversion of waste, commonly utilized urban policies that are aimed at guiding urban development can be potential tools (or barriers) in the quest to build a circular city. This article discusses the preservation of existing building stock as a sustainable alternative to building demolition. In this article, we introduce greater nuance in the characterization of building permits by theorizing a difference between redevelopment with new construction as indicated by demolition permits and the intention to reinvest in existing building stock as indicated by adaptation permits. This difference is important for the purposes of sustainability since building reinvestment also known as adaptation in this study can increase building longevity and reduce the carbon impacts associated with new construction and the waste associated with demolition.

We conducted a series of spatial analyses on adaptation permits issued by the City of Ithaca, New York, to evaluate the underlying neighborhood-level factors that contribute to reinvestment in existing building stock, especially its associations with local planning tools. Our findings demonstrate that national historic districting is significantly associated with fewer demolitions and increased adaptation permits, suggesting its potential in preempting demolition. Mixed-use zoning and those with high economic potential saw more permits being issued, even for younger buildings, suggesting the need for cities to deploy tools that can manage these development pressures and their downstream embodied carbon and waste impacts. We find that conventional explanatory factors such as building age and zoning are more informative when contextualized with local information and can better support the use of local government tools. We believe that some of our findings are likely to be unique to Ithaca; however, the main contribution of this work is a mixed-methods protocol—spatial analysis contextualized by a qualitative understanding of local processes using a rich dataset that other cities can replicate.

In conducting it in a small town, we acknowledge that there exist considerable data and modeling challenges. We suggest opportunities and data management strategies that other cities can leverage to strengthen their circularity and sustainability efforts. In addition to replicating our analysis protocol, future studies could delve into the quantification of embodied carbon and construction and demolition debris that is prevented through reinvestment that prolongs the lifespan of existing buildings, as well as analysis of embodied

carbon and waste flows associated with demolition and subsequent new construction. This would be further enhanced through nuanced analysis in cities that have adopted other alternatives to demolition, such as deconstruction and building material reuse.

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Abbreviations

The following abbreviations are used in this manuscript:

GWR Geographically Weighted Regression
GRF Geographically Weighted Random Forest Model

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