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VLAS: Vacant Land Assessment System for Urban Renewal and Greenspace Planning in Legacy Cities

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Abstract: Vacant land in shrinking cities has long been associated with high crime rates and economic decline. While some efforts have been made to repurpose vacant land for tax revenue generation and temporary environmental restoration, a comprehensive framework for city-scale assessment and reprogramming remains lacking. To address this gap, our study introduced the Vacant Land Assessment System (VLAS), a multi-scale spatial analysis and planning tool that assesses the distribution and characteristics of vacant lots using publicly available spatial data. Taking Hartford, Connecticut as a case study, we assessed and categorized the characteristics of vacant lots into four typologies: Row House, Street Corner, Commercial/Industrial, and Main Street. Responding reuse programs for those typologies were generated and one design example of vacant lot greening was also provided based on identified sustainable goals and techniques. The VLAS serves as an effective planning support tool, enabling efficient assessment, classification, and planning for urban vacancy management across city, district, neighborhood, and site scales. This multi-scale planning and design approach to repurpose vacant lots with diverse physical characteristics offers valuable insights for transforming vacant land in other shrinking legacy cities for sustainability and neighborhood revitalization.

Keywords: vacant lots; shrinking cities; greenspace; sustainable urban design; multi-scale; spatial analysis

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1. Introduction

Starting from the 1950s, urban populations in the U.S. began to decline as residents from core urban areas migrated to suburbs in a racially driven process known as White Flight [1]. As globalization promoted manufacturing to move offshore in pursuit of lower wages, numerous prominent industrial cities in the United States were abandoned by globalizing and deindustrializing corporations, leading to disinvestment, depopulation, and decline [2]. Cities experiencing population loss, deindustrialization, and economic decentralization were often referred to as shrinking cities, post-industrial cities, or legacy cities [3]. In this paper, we primarily use the term "post-industrial cities" to emphasize their deindustrialized nature. Neglect and disinvestment in infrastructure and public service left post-industrial cities, such as Detroit, MI, and Cleveland, OH, with core urban areas filled with trash-laden vacant land, brownfields, and blighted structures [2]. Vacant land not only represents direct economic loss due to underuse but also results in community issues through perceptions of unsafety, diminished environmental aesthetics, and reduced community vitality [4]. To address the environmental degradation, neighborhood blight, and economic decline often linked to vacant land, planning efforts have been initiated in several shrinking and post-industrial cities, including Philadelphia, Youngstown, Cleveland, and Detroit. These efforts aim to transform vacant land through various means such as urban agriculture, selling vacant lots to private owners, reintroducing nature, and green space into cities, promoting public stewardship, and implementing planning policies like land banking and infill developments [5]. However, current programs for transforming vacant land are often driven by a single goal, either increasing economic revenue or promoting greening for ecosystem provision. A holistic framework and tools are lacking to support decision-making in the transformation of vacant land. Such a framework should consider the spatially explicit characteristics of vacant land and its surrounding resources to address multiple goals and inform diverse land-use decisions.

This paper presents a systematic and replicable spatial planning tool for vacant lot assessment and transformation, to comprehensively examine the characteristics of vacant land and repurpose them with maximized social, ecological, and economic sustainability.

Among various strategies for transforming vacant lots, greening through increased tree canopy coverage and the provision of community green and open spaces has been suggested as a strategy to stabilize the urban ecosystem, reduce fear of crime, and benefit residents' well-being [6–8]. Greenspaces offer urban residents essential outdoor areas for physical activity, and thus their accessibility and quality are linked to health equity. Moreover, there is growing recognition that vacant and abandoned land can serve as a nexus between urban shrinkage and long-term ecosystem services, functioning as opportunity spaces for enhancing regional greenspace networks [9–11]. Greenspaces provide important ecosystem services and functions such as improving air quality, mitigating the urban heat island effect, regulating flooding, and enhancing biodiversity [9,12–14]. Furthermore, greenspaces can foster human well-being by serving as social gathering points and local identity spaces, thereby increasing social connectedness and norms [15]. However, it has been found that green spaces are disproportionally inaccessible to low-income and disadvantaged populations and neighborhoods, which can result in health and environmental inequity [16,17]. Such disparities in greenspace access presented unique distribution in legacy cities and post-industrial cities: while the legacy greenspace network ensures the presence of greenspace for populations of different kinds, congestion and poor park quality and safety were usually prevalent in low social status and high vacancy neighborhoods [17]. Considering the association of high vacancy rate and high park crime rate found in post-industrial cities and other negative effects related to vacant lots, transforming vacant lots into safe greenspaces could be a win-win solution to simultaneously improve equal access to greenspaces and reclaim vacant and blighted properties to remediate environmental degradation and provide ecosystem services [18–24]. For example, a study in Philadelphia found significant improvement in terms of equal access to greenspaces among social-economic groups after vacant land greening programs [20]. In addition, public spaces support social life and community interaction as common ground and converting vacant lots into such spaces can encourage grassroots democracy and strengthen community spirit and commitment [5]. For example, greening vacant lots can help reduce the public's fear of crime within neighborhoods and improve safety, as specific vegetation characteristics and well-designed greenspaces can act as "cues of care," preventing crime and facilitating public gatherings—issues that are essential to address in post-industrial cities [22–26]. Additionally, greening vacant lots presents opportunities to optimize and enhance existing landscape networks and green corridors within urban ecosystems, which could contribute to increasing landscape connectivity and supporting biodiversity [27]. As vacant land is often concentrated in low-income and deteriorated areas, it serves as both a sign and a trigger for social inequity. Tactical urbanism is frequently adopted in these greening efforts to achieve cost-effective and culturally reflective features, such as the 'Black Lives Matter' plaza in Washington D.C., which emerged following the nationwide protests against police brutality in the U.S. in 2020.

However, challenges exist in the process of reclaiming vacant lots. One significant challenge is brownfield cleanup and redevelopment. Brownfields are defined by the US Environment Protection Agency (EPA) as "abandoned, idled, or underused industrial and commercial facilities where expansion or redevelopment is complicated by real or perceived environmental contamination" (1997, p. 1). Addressing brownfields is crucial for urban revitalization, environmental health, and the quality of life in urban areas with the goal of fostering sustainable development. For instance, the City of Toronto has been a pioneer in adopting a brownfield-to-greenfield approach by overcoming various barriers to greening brownfields, such as limited financial resources, lack of knowledge about appropriate methods for addressing soil contamination, and the absence of similar models to replicate [28]. In the pursuit of cost-effective and natural solutions, phytotechnology has emerged as an innovative technique for greening brownfields. This approach involves using vegetation to uptake, remove, and mitigate on-site soil pollutants [29]. Another challenge in harnessing vacant land is the ownership and stewardship of the land. City-owned vacant lands are more easily repurposed through governmental efforts, and community stewardship has been advocated as an effective way to maintain greened vacant lots and engage citizens to enhance social cohesion [5]. However, the reuse of privately-owned properties depends largely on the interests of the owners, which often prioritize economic revenue and benefits. As a result, it is less likely that vacant lot reuse will be leveraged to address social and environmental challenges on privately-owned vacant parcels. A third challenge is determining vacant lot reuse programs that adequately consider local residents' and community needs. Without integrating approaches such as participatory design and community engagement, transforming vacant land into greenspace may inadvertently lead to gentrification, particularly when neighborhoods with high vacancy rates are low-income and minority neighborhoods [30,31]. One example of this challenge is the High Line Park in New York City, which is renowned for its innovative and ecological redesign of abandoned railways in previously grassroots neighborhoods. However, it has also faced criticism for its gentrification impacts and loss of citizen advocacy [32]. A fourth challenge is the scale of vacant lot management. Although there has been significant attention placed on repurposing vacant lots in Rust Belt cities, existing efforts have mainly been focused on either tax revenue or temporary solutions [10]. This lack of long-term and broader-scale consideration in vacant lot transformation limits its potential for ecological benefits, which can only be achieved through larger-scale strategies such as enhancing and restoring ecological networks and greenspace planning [11]. To take these challenges into account, a thorough assessment and analysis of vacant lots and their contextual social, economic, and ecological factors is necessary to support decision-making processes for transformation.

GIS-based scientific support tools have been adapted for effective decision-making in spatial planning and management for green infrastructure planning in urban areas [22,33]. However, such tools have not been developed and used holistically in the context of vacant land assessment and management. In this regard, this study focuses on the establishment of a decision support tool for assessing and characterizing vacant lots in legacy cities during the spatial planning process. Consequently, the GIS-based Vacant Lots Assessment System (VLAS) was developed for integrated assessment of vacant lots, their distribution, and contextual characteristics, for use in urban renewal and greenspace planning. The capability and workflow of this system were demonstrated in the case study area—the North Hartford Promise Zone in Hartford, Connecticut, USA—at the district and neighborhood scale (Figure 1). And one site scale vacant lot greening design example was also provided, to demonstrate the application and use of VLAS to inform vacant lot site designs. In doing so, three research questions of this study were addressed as follows:

- What are the current distribution and characteristics of city-owned vacant lands in the North Hartford Promise Zone (NHPZ)?
- What are the potential strategies for reclaiming vacant lots systematically across the entire NHPZ?
- What kind of sustainable site design strategies can be utilized when transforming vacant/blighted lots into public greenspaces?

The development of VLAS is a co-design product under a community outreach and services project assigned by the City of Hartford Blight Remediation team and accomplished by the University of Connecticut (UConn) Program of Landscape Architecture graduate students and faculty. Therefore, VLAS is a true interdisciplinary system that links scientific tools and knowledge with real-world planning and design by involving true participation and collaboration from policymakers. There are different definitions for vacant land or vacant lots in different contexts. It could be land reserved by corporations, land overgrown and littered by trash, or land used as parking lots by adjacent properties. Bowman [5] defined vacant lots as temporarily obsolete, abandoned, or derelict sites that were formally either productive or unused. This study adopted this definition and focused on vacant lots without buildings and structures on them and owned by the City of Hartford to exemplify the application of VLAS.

Figure 1. Map of the study area and its geographical location.

2. Methods

2.1. Study Area

We use North Hartford Promise Zone as a case study to develop, refine and demonstrate the GIS-Based VLAS in evaluating, assessing, and repurposing vacant lots in legacy cities (Figure 1). Hartford is the capital city of the State of Connecticut and has a rich history dating back to the early 1600s when the Dutch settled along the Connecticut River. By 1790, it has become one of the 10 largest cities in the early nation [34]. With the Colt Firearm Factory and other iconic early industries, Hartford became a core area of industrialization in the Connecticut River valley region after the American Civil War and was the richest city in the country at that time. However, like other post-industrial cities, deindustrialization, population loss, and vacancy issues have seriously impacted the city's development and public welfare. Currently, Hartford is one of the poorest cities in the country, with almost 30% of the population living below the poverty line, according to the 2012–2016 American Community Survey [35]. The decline in industry, which started in the 1950s, has also brought about a dramatic change in the city's racial demographics. While Hartford had attracted immigrants in the early 1900s due to manufacturing job opportunities during the booming industrial era, the declining manufacturing industry in the 1970s led to white flight and redlining, causing white and middle-class individuals who were still offered jobs by the remaining, yet thriving insurance industry in Hartford, to move to wealthy suburban areas such as West Hartford, Wethersfield, and Glastonbury (Figure 2) [36]. Figure 3 illustrates the historical redlining map of Hartford once rating the credit risk and racial composition of neighborhoods, where the current Promise Zone was classified as having 'definitely declining' (C) and 'hazardous' (D) grades. These grades were associated with the presence of an 'undesirable population and infiltration of it' leading lenders to not or conservatively make loans in this area [37].

In addition, greenspace inequity was also evident in Hartford [17]. Nevertheless, low-income and minority populations and immigrants inherited the previous working- and middle-class neighborhoods where the greenspace network was once well designed, they still suffer from park congestion and only have access to parks with disproportionally higher crime rates [17]. Those areas and neighborhoods also happen to be the ones full of abandoned factories and vacant properties [17]. Therefore, Hartford, CT is an appropriate testbed for systematically evaluating vacant lots and repurposing them into greenspaces to solve the problems of both park inequity and environmental degradation due to vacant and blighted land [38].

North Hartford Promise Zone (NHPZ), designated by former U.S. President Barack Obama in 2008 as one of twenty-two high-poverty communities that were exposed to inadequate employment opportunities, educational resources, and a high rate of violent crime over a long period of time (U.S. Housing and Urban Development, 2008). The NHPZ is a 3.11-square-mile area that encompasses the Clay-Arsenal, Northeast, and Upper Albany neighborhoods, which are one of the poorest neighborhoods in Hartford, the state, and even the country (see Figure 1). According to the 2012–2016 American Community Survey, the NHPZ has a poverty rate of 38.1%, which is significantly higher than the state poverty rate of 10.1%. Additionally, Figure 4 shows the racial demographics in Hartford, indicating that African Americans and Hispanics are the major population groups. This racial segregation is also an indicator of previous redlining policies in the industrial era, which is a discriminatory practice of refusing housing financial services in and near African American neighborhoods that was established in 1934.

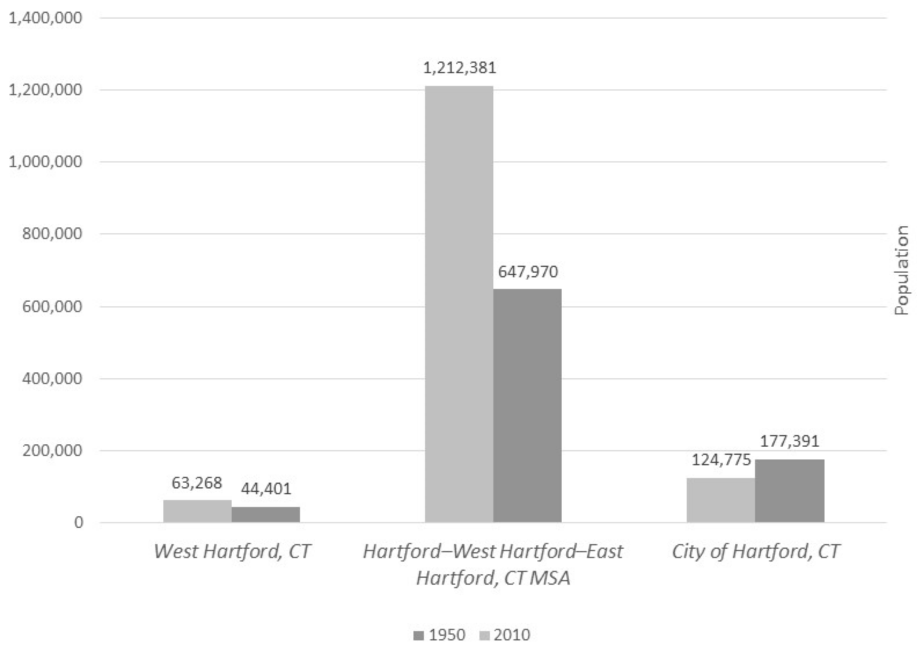


Figure 2. Population changes in the City of Hartford, Hartford metropolitan region, and suburban town of West Hartford from 1950 to 2010. Data source: 1950 and 2010 Census.

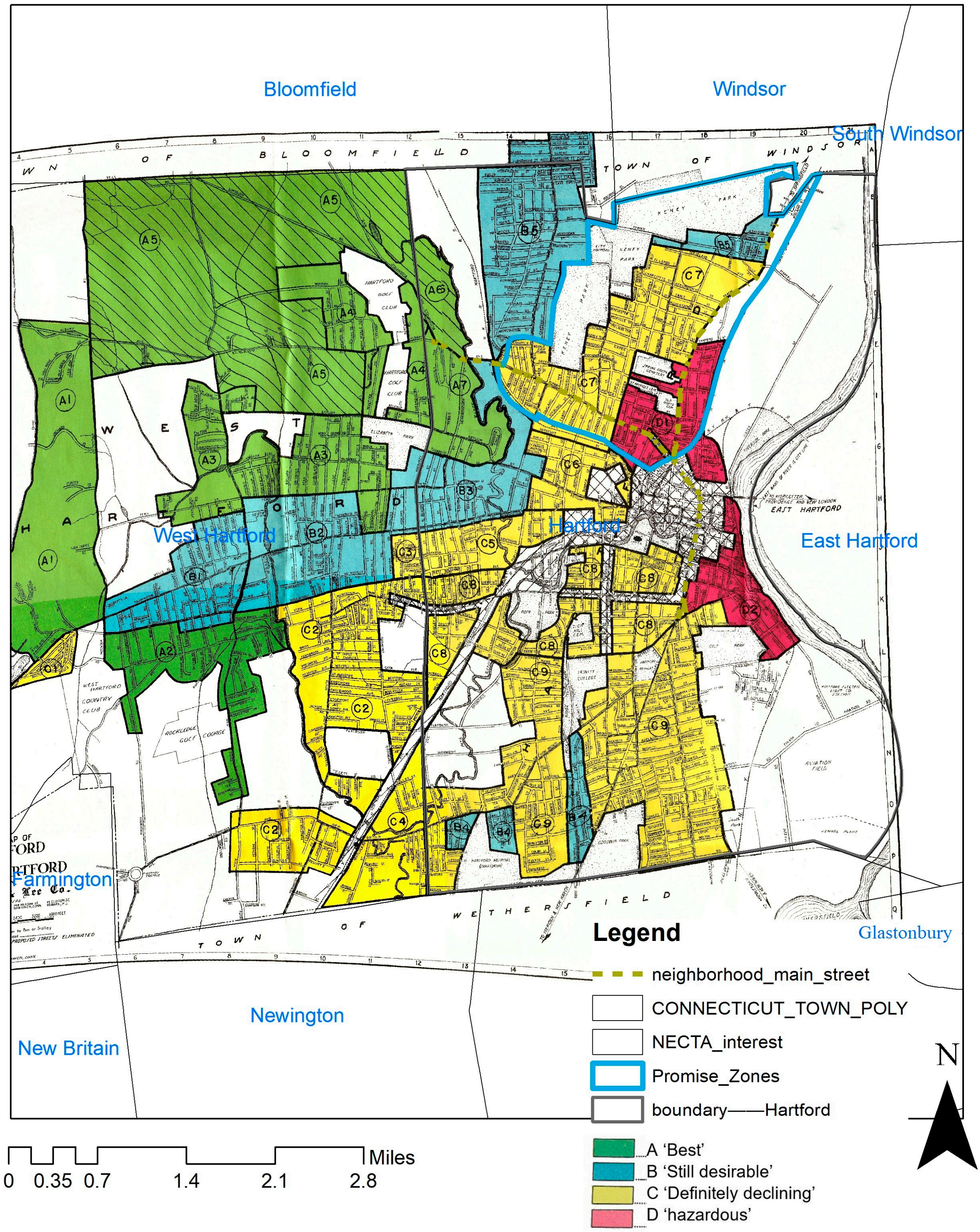


Figure 3. Historical redlining map in Hartford, CT. Mapped in ArcGIS using data derived from Robert et al. [37]. The grades were given to neighborhoods based on their credit risks and racial composition.

Figure 4. Racial distribution in the City of Hartford by Block Groups in 2016.

2.2. Multi-Scale Vacant Land Assessment System (VLAS)

The study presents a multi-scale GIS-Based Vacant Land Assessment System (VLAS) designed to inform vacant land transformation alternatives at the district, neighborhood, and site scales (see Figure 5). The VLAS focuses on district scale by assessing the distribution and associated resources of city-owned vacant land in NHPZ, leveraging publicly accessible GIS data and U.S. Census data (See Section 2.2.1 for details). This phrase evaluates the variation in size, location, previous land use, physical condition, and neighborhood contexts [38]. Additionally, planning regulations and documents at the municipal, county, regional, and state scales were reviewed, including the Municipal Plan of Conservation and Development (a ten-year strategic plan from the municipality), Downtown Redevelopment Plan, Regional Pedestrian and Bicycle Plan, and municipal sustainability documents. This step helps identify opportunities and constraints in the area and propose a vision plan for the Promise Zone to manage and reclaim vacant lands in North Hartford, ultimately achieving the neighborhood revitalization goal for the whole city (See Section 2.2.2). Secondly, a site-scale design example is proposed based on identified sustainable goals and neighborhood scale analysis, as a protocol for sustainable greening and placemaking (See Section 2.3).

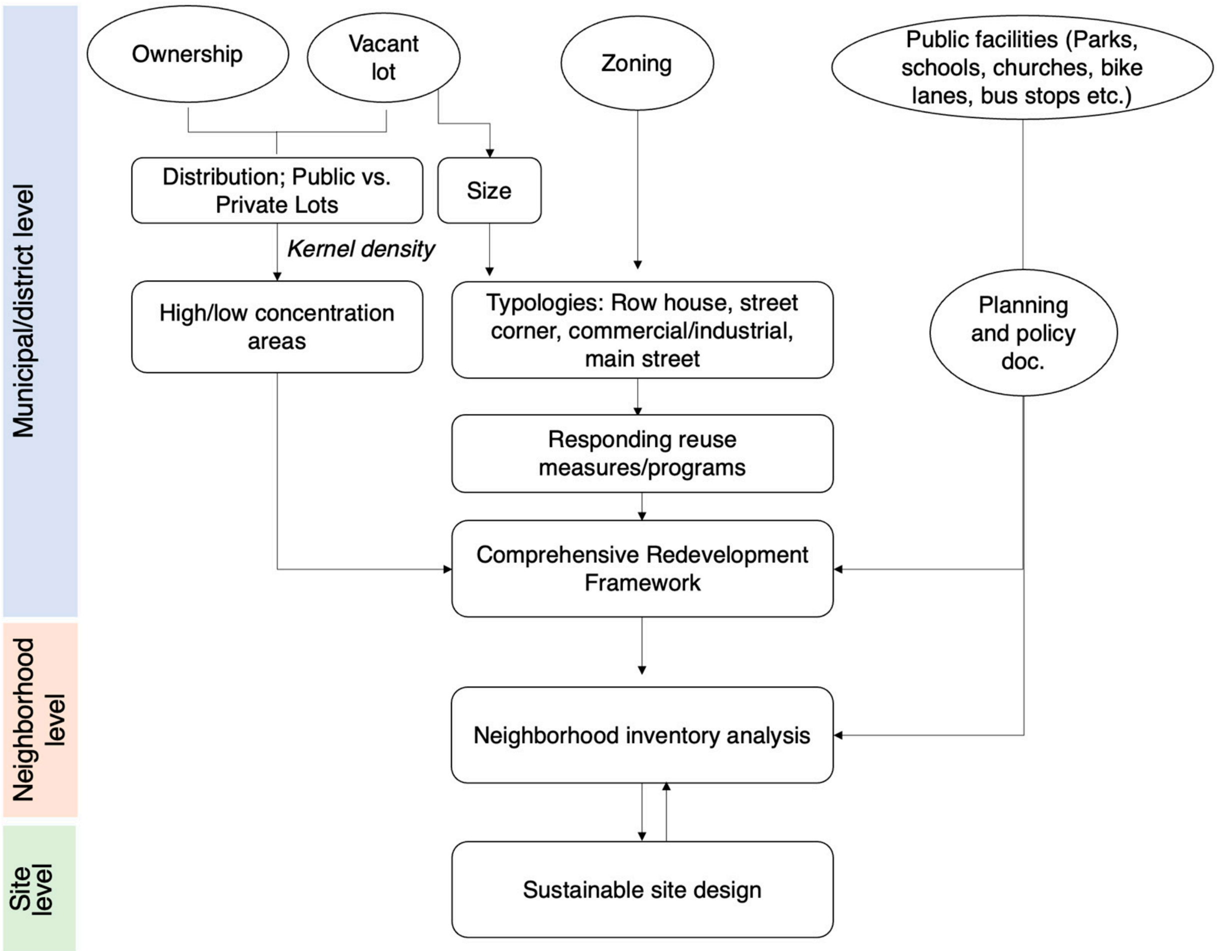


Figure 5. Multi-scale workflow of the study.

This study focuses on the vacant lots owned by the city that are not being utilized for any land use during the study period and may or may not have buildings/structures on them. Some of the land is directly owned by the city, while others were previously commercial, industrial, or residential land that was abandoned and then foreclosed by the city. Among these lots, some of the previous industrial sites were contaminated by chemical and toxic pollutants and were listed as brownfields by the city [39].

2.2.1. Vacant Lot Distribution, Characteristics, and Socioecological Contexts

Vacant lot data was obtained from property details data in the municipal public data portal, filtered by the property type of 'vacant'. City-owned property data were also obtained. The first step in the VLAS is to adopt 'geocode' tools in ArcGIS to generate a spatial inventory mapping of city-owned vacant lots by the data above. We imported

Excel spreadsheets that recorded street addresses of both vacant lots and city-owned properties into ArcMap and geocoded them using the geocoder published by the city's GIS server. The geocoding process generated point features from the inputted addresses, and we used 'selected by location' tool to generate a vacant parcel layer from the geocoded point layer and the city-level parcel layer. To reveal the density difference of city-owned vacant land across the city and inform planning strategies for vacant lot transformation in the entire district, we conducted a Kernel density analysis in ArcGIS 10.7, which is an analysis of the density of features across the landscape. Kernel density calculates the density of points in a unit of area and is widely used to calculate housing or crime density in community planning.

The second step of VLAS is to assess the characteristics of vacant lots. Even though they are underutilized, vacant lots retain their city zoning designation, which can restrict their future use. In addition to zoning, we also examined the diversity of vacant lots in size. The size of each vacant lot was calculated using Calculate Geometry function in ArcGIS. In addition, we also analyzed the zoning categories together with the vacant lot size to inform vacant lot programming in the next steps.

Inventory analysis is also included in this VLAS to better incorporate existing opportunities, strengths, and weaknesses in the studied area. Municipal public GIS data were obtained including parks, churches, bike lanes, bus stops, trails, schools, and brownfields. Using multi-layered cartography, we visualized and evaluated the accessibility and connectivity of public facilities, such as parks, churches, and healthcare facilities, that city-owned vacant lots could potentially have as opportunities and constraints for the vacant lot transformation framework in NHPZ.

2.2.2. Vacant Lot Typologies and Potential Programs

The third step in VLAS involves classifying the lots based on various factors including their location within the neighborhood block, accessibility to primary streets and facilities, and information gathered in previous steps. This classification can suggest a range of potential land use policies, from infill development to open space/green space, or a mix of both. To classify the lots, we adapted Anne Spirn's typology for vacant lots [38] and identified four typologies of vacant lots: Row House (i.e., Missing tooth or Swiss Cheese type in Spirn's classification), Street Corner, Commercial/Industrial, and Main Street (Table A1). This classification was further developed based on the lots' physical condition, size, zoning, and geographical location through field investigation. According to the classification, we proposed potential programs for repurposing those vacant lands, which can also be applicable to other geographic locations with vacant lots. In addition to the socio-economic context and vacant lot characteristics analyzed above, we also took into consideration long-term city planning goals and community desires in reprogramming the vacant lots.

While vacant lot transformation often occurs at a smaller site scale, it is important to expand VLAS to a district or municipal-scale development framework for highly concentrated vacancy areas. Therefore, in addition to exploring replicable potential programs for various vacant typologies, we also proposed a framework for repurposing vacant lots in NHPZ, due to the area's high concentration of vacancy lots. Such a framework has resulted from a thorough review of municipal and state plan documents and policies. In particular, the city's Plan of Conservation and Development, along with other targeted neighborhood planning initiatives such as the Complete Streets project and the Swift Factory Renovation project, have been integrated into the development of a comprehensive framework for managing all public vacant lots in NHPZ [40].

2.3. Neighborhood Scale Analysis and Site Scale Vacant Lot Greening Design Example

As vacant lot greening efforts are mostly at the site scale and there are urging needs in promoting sustainable site design strategies for the health of human beings and ecosystems, we also introduced a greening design example for common street corners and main street types of vacant lots. The design process was informed by VLAS neighborhood-level spatial inventory and analysis, as well as site visits to Hartford. Designs were developed using AutoCAD (AutoDesk Inc., 2017) (San Francisco, CA, USA) Adobe Photoshop (Adobe System Inc., 2017a) (Westminster, CO, USA), and Lumion (Adobe System Inc., 2017b) (San Jose, CA, USA).

A street corner vacant lot in the Clay-Arsenal neighborhood was selected to develop the design example of vacant lot greening. The site design was informed by the planning vision and sustainability goals outlined in the municipal and state planning documents [40], and the final phase of VLAS—analyzing neighborhood-scale socioecological opportunities and constraints of vacant lots. The social and ecological sustainability goals identified included sustainable stormwater runoff management via green infrastructure, increasing tree canopy, reconnecting to the Connecticut River, reducing violent crime, promoting bike and transit modes, and expanding parks [41]. Therefore, neighborhood social-ecological analysis in VLAS focused on these goals. Land cover, police incidents, and park data were obtained. Among these, police incident data were geocoded based on street address and categorized based on crime types. Impervious land cover was mapped, and the percentage of impervious land cover was calculated for the neighborhood to reveal its need for green infrastructure of stormwater management. A connectivity analysis of the site to its surrounding parks was also conducted by generating a 10 min walking/1 km buffer area around the site. The design model could serve as a blueprint for vacant lot greening protocols in other post-industrial cities, provided that the goals identified in this design were also commonly found in other legacy cities [22,24,42].

3. Results

3.1. Vacant Lot Distribution, Characteristics, and Socioecological Contexts

Figure 6 shows the spatial distribution of city-owned vacant lots, along with additional private vacant properties. In 2018, there were a total of 53 city-owned vacant lots in the North Hartford Promise Zone (NHPZ), comprising approximately 24 acres of land. Of the approximately 78 acres of vacant land in NHPZ, about one-third of them were owned by the city. There were 10.54 vacant lots per 1000 inhabitants in NHPZ, compared to figures in other post-industrial cities with similar population density, such as Detroit, MI (9.74), New Haven, CT (4.26) and Worcester, MA (0.29) [5]. These facts highlight the urgent need to address the issue of urban vacancy in NHPZ. According to the Kernel density analysis, NHPZ, and especially the Clay-Arsenal neighborhood, is the epicenter of urban vacancy agglomeration spots, compared to other parts of the city (Figure 7). Many vacant lots in NHPZ are concentrated in the Albany Avenue area, which is the main commercial street of the zone's two southern neighborhoods, Clay Arsenal and Upper Albany (Figure 6).

About three-quarters of the studied vacant lots were assigned as Neighborhood Mixed zone (NX), which allows for the most intensive residential building types, such as multi-unit houses, apartment buildings, and stacked flats (Figure 8a). Another major zoning category that vacant lots belong to is Main Street (MS), mostly located on and around Albany Avenue. This type of parcel represents the traditional pattern of mixed-use main street development in neighborhood centers, which includes a wide range of building types and scales, such as storefront buildings, apartment buildings and commercial center building types that facilitate a pedestrian-friendly sidewalk and commercial corridor, providing a variety of retail and service uses [40]. Since Albany Avenue is part of U.S. Route 44, connecting downtown Hartford and North Hartford Promise Zone to surrounding suburbs and interstate highways, these lots have opportunities to thrive through placemaking and/or reclaiming local business. Another noteworthy zoning category is the Commercial-Industrial mix type of lots (CX), which includes some of the largest vacant parcels owned by the city. These lots are situated along the commercial corridors that represent the historical industrial past and now remain as such. vacant and abandoned warehouse or factory structures. This indicates an opportunity and urgent need for adaptive reuse of the existing structures.

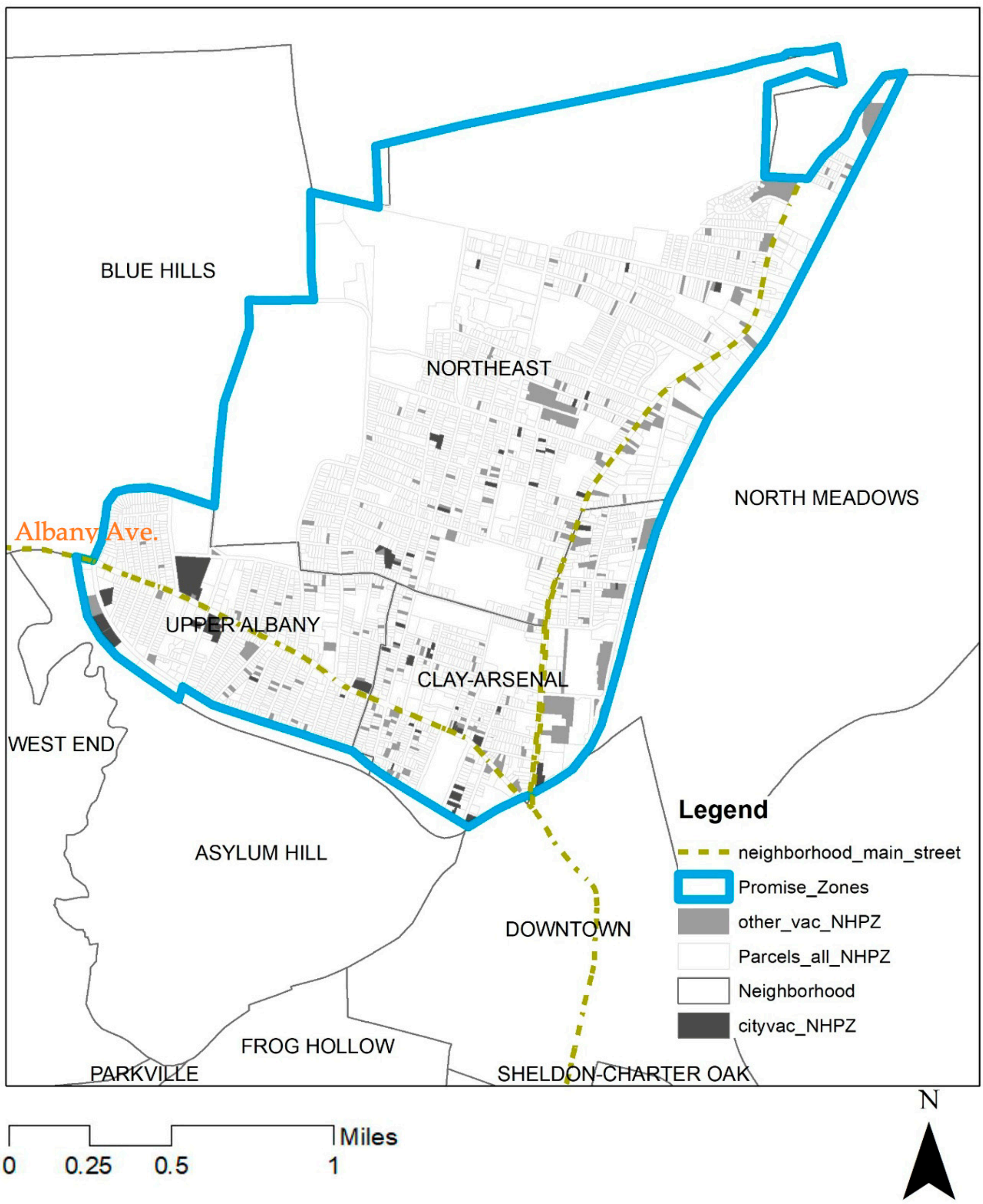


Figure 6. North Hartford Promise Zone Vacant Property Inventory.

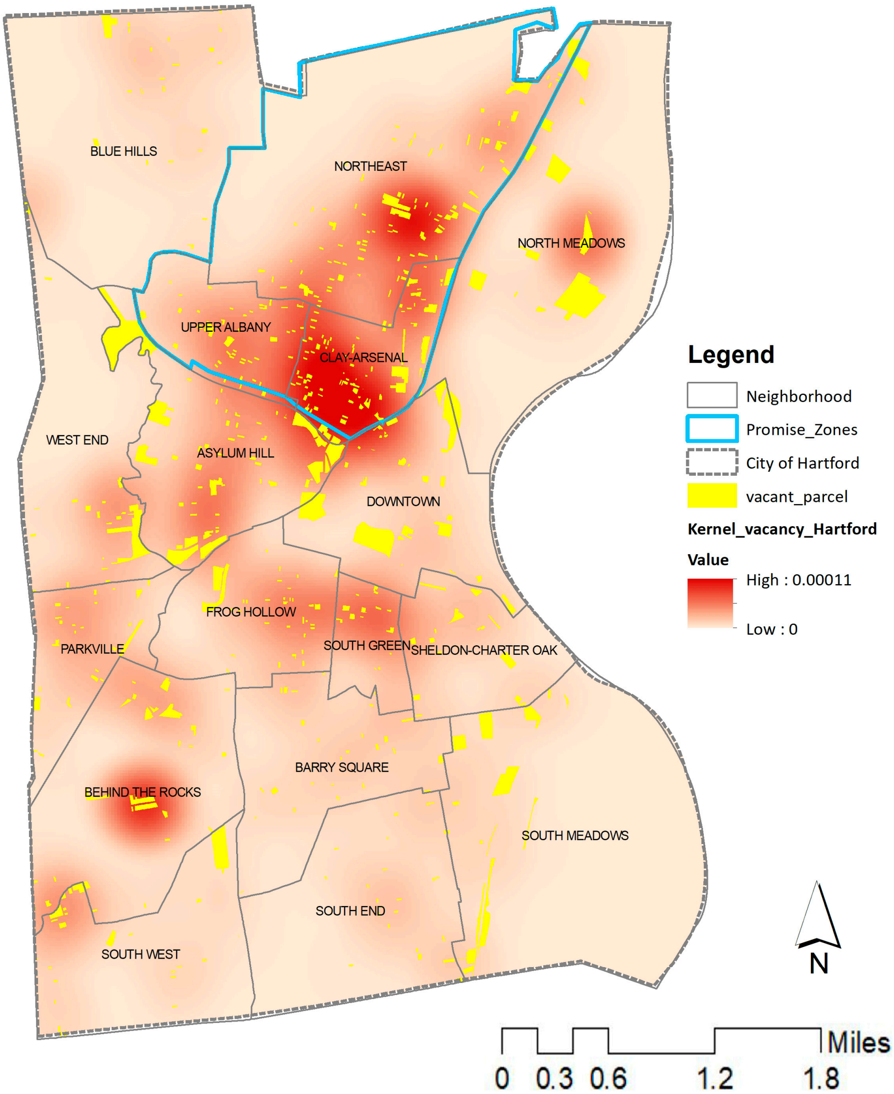


Figure 7. Kernel density of vacant lot distribution in the City of Hartford.

The mean area of the 53 city-owned vacant lots was approximately 19,178 square feet. Among the total of 53 city-owned vacant lots investigated in this study, 33 of them were less than 10,000 square feet, and 8 vacant lots were more than 30,000 square feet (Figure 9a). We also analyzed the zoning categories together with the vacant lot size (Figure 9b). As the majority of vacant lots were zoned as neighborhood mix, most of the parcels in this category were small (less than 10,00 sq ft) to medium (less than 30,000 sq feet) in size (Figure 9b). The large size (more than 30,000 sq ft) lots were variously zoned, including commercial–industrial, mixed-use, main street, as well as neighborhood mix. Using city public GIS data and multi-layered cartography, we visualized and evaluated the accessibility and connectivity of public facilities, such as parks, churches, and healthcare facilities, that city-owned vacant lots could potentially have as opportunities and constraints for the vacant lot transformation framework in NHPZ (Figure 8b–d). Firstly, we mapped public parks and open spaces with two categories: public parks and KNOX community gardens (a series of community gardens transformed from vacant lots by a non-profit organization to improve food security and community engagement) (Figure 8b). Secondly, we identified community assets and public facilities, including public schools, community centers, and public libraries, that provide services and space for public gatherings and community engagement (Figure 8c). Finally, we also considered the public transportation network by mapping all the bus stops and bike lanes, given the fact that low-income neighborhoods with relatively low car ownership would benefit from public transportation. The proposed green spaces transformed from vacant lots would be easier to access with the proximity to the public transportation network (Figure 8d). All of the community assets and infrastructures identified above can be leveraged as opportunities when prioritizing potential vacant lot use in different areas.

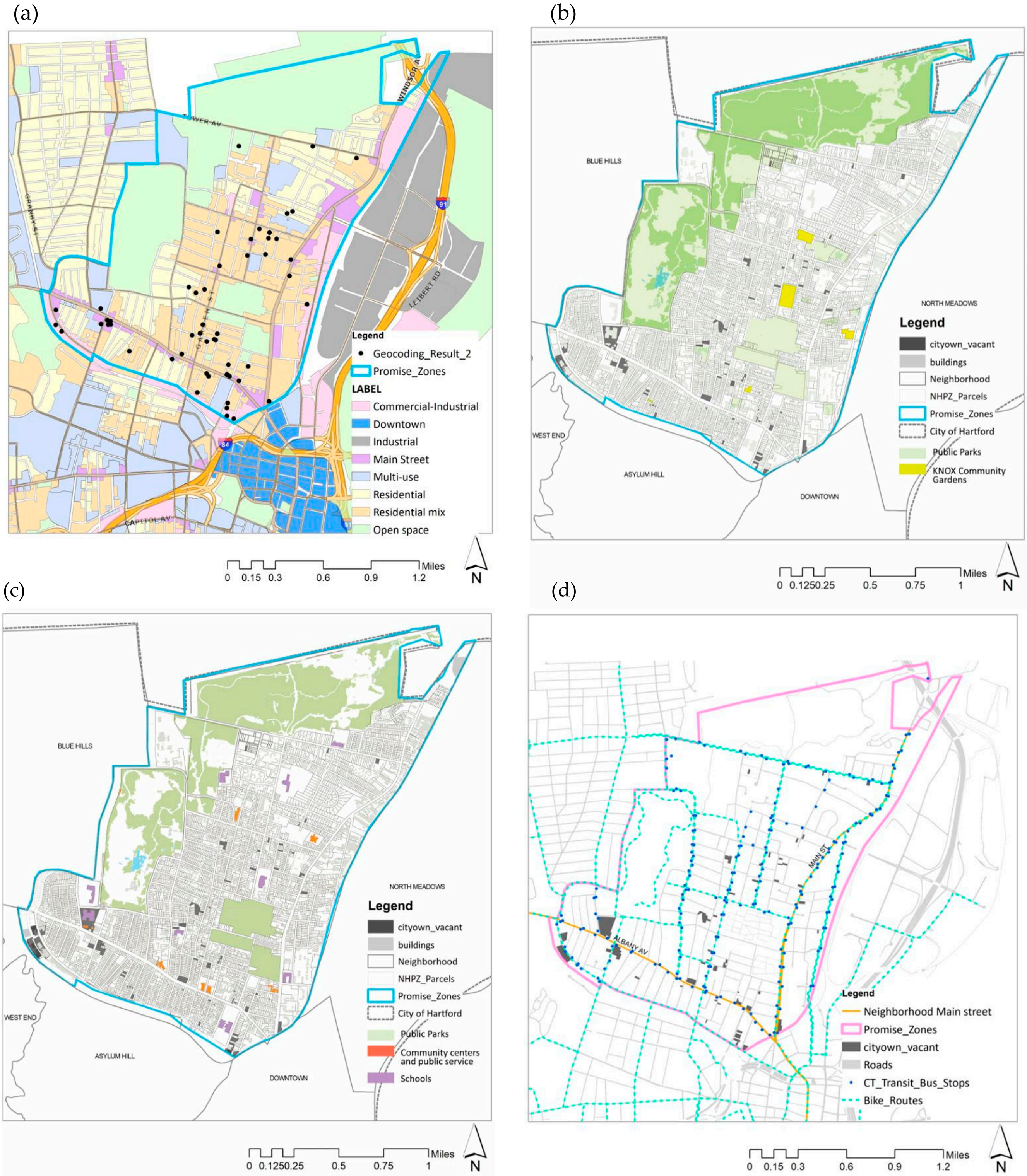
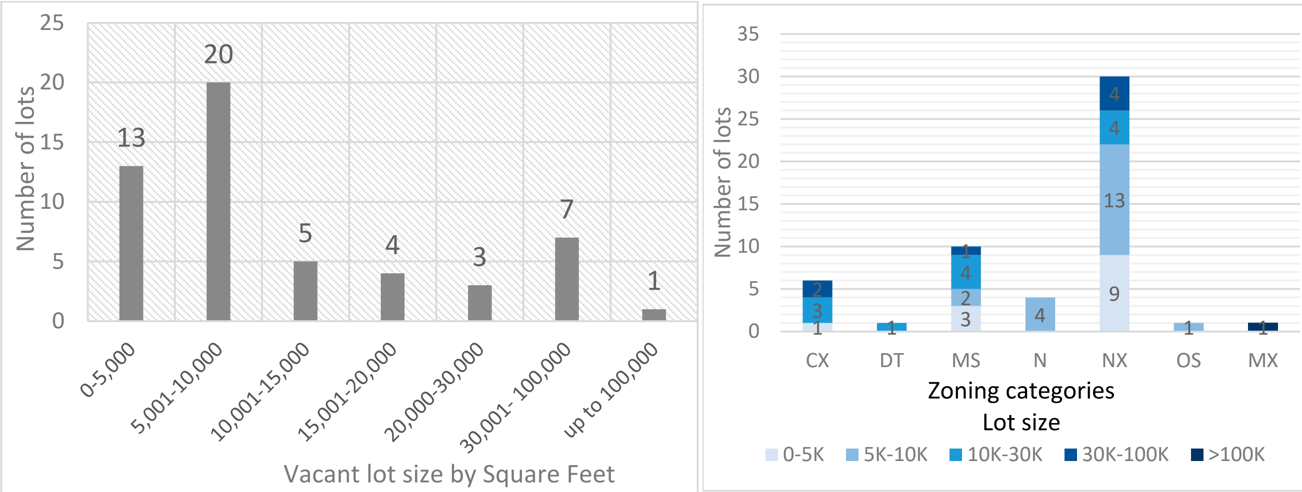


Figure 8. (**a**) Zoning map, (**b**) Open spaces and gardens in NHPZ, (**c**) Civic buildings and public service infrastructure, (**d**) Public transportation facilities.



(**a**) (**b**)

Figure 9. (**a**) Histogram of city-owned vacant lots by area (Square feet); (**b**) Number of city-owned vacant lots by parcel size and zoning type. CX = Commercial-Industrial Mix; DT = Downtown; MS = Main Street; N = Residential; NX = Residential mix; OS = Open space; MX = Multi-Use Mix.

3.2. Vacant Lot Typologies and Potential Programs

Row houses are characterized by small and narrow lots located in the middle of residential blocks (Figure 10). Typically, these lots are zoned as neighborhood residential, and their surrounding lots are also small-scale residential houses. Given the shortage of affordable housing in Hartford NHPZ, row houses were proposed as infill developments to restock the housing supply and residential neighborhoods in vacant lots. In addition to the traditional economic benefits such as increasing tax revenue, infill development for row houses can also improve the aesthetics of the neighborhood, increase population density, and promote the efficiency of public infrastructure [5,40]. Transforming this type of vacant land into housing units through an infill program can also diversify the demographics and the housing types of these neighborhoods, helping to mitigate social segregation, while increasing the percentage of owner-occupied homes. This, in turn, can help the city combat blight and vacancy issues in this area [36].

Street corner lots are typically small to medium-sized lots located at the corner of a street block, with two sides adjacent to streets and two sides adjacent to other parcels. These lots are often located in residential or residential mixed zones, and they have high visibility (Figure 10). Given their location and accessibility, street corner lots are ideal for repurposing as community greenspace and open space. This can provide numerous benefits to the community, including improved aesthetics, increased access to green space, and enhanced opportunities for community engagement and social integration.

The commercial/industrial lots are typically large industrial or commercial-zoned lots located on commercial corridors (Figure 10). These lots were historically used as factories, warehouses, and other heavy industrial uses, and some of them have abandoned structures on them. Some are even contaminated and identified as brownfields. The location of these lots is usually at the periphery of neighborhoods but along important transportation corridors. For brownfields, repurposing them as greenspace using ecological remediation techniques to detoxify the land is one option. Another repurposing program includes reusing the existing abandoned industrial structure and creating indoor-outdoor combined public facilities such as museums, amphitheaters, and galleries. Successful precedents included Urban Outfitter Headquarters in Philadelphia, which kept a historical legacy while reclaiming the neighborhood with new programs, as well as Gas Works Park in Seattle, WA, and Domino Park in NYC, which were both redeveloped from old factory ruins. Several placemaking programs were also proposed to transform the public space alternatives created from the main street as well as street corner types of vacant land, according to the city planning visions aiming to mitigate stormwater flooding, increase tree canopy coverage, and promote equal, diverse, and healthy public open space for well-being [40].

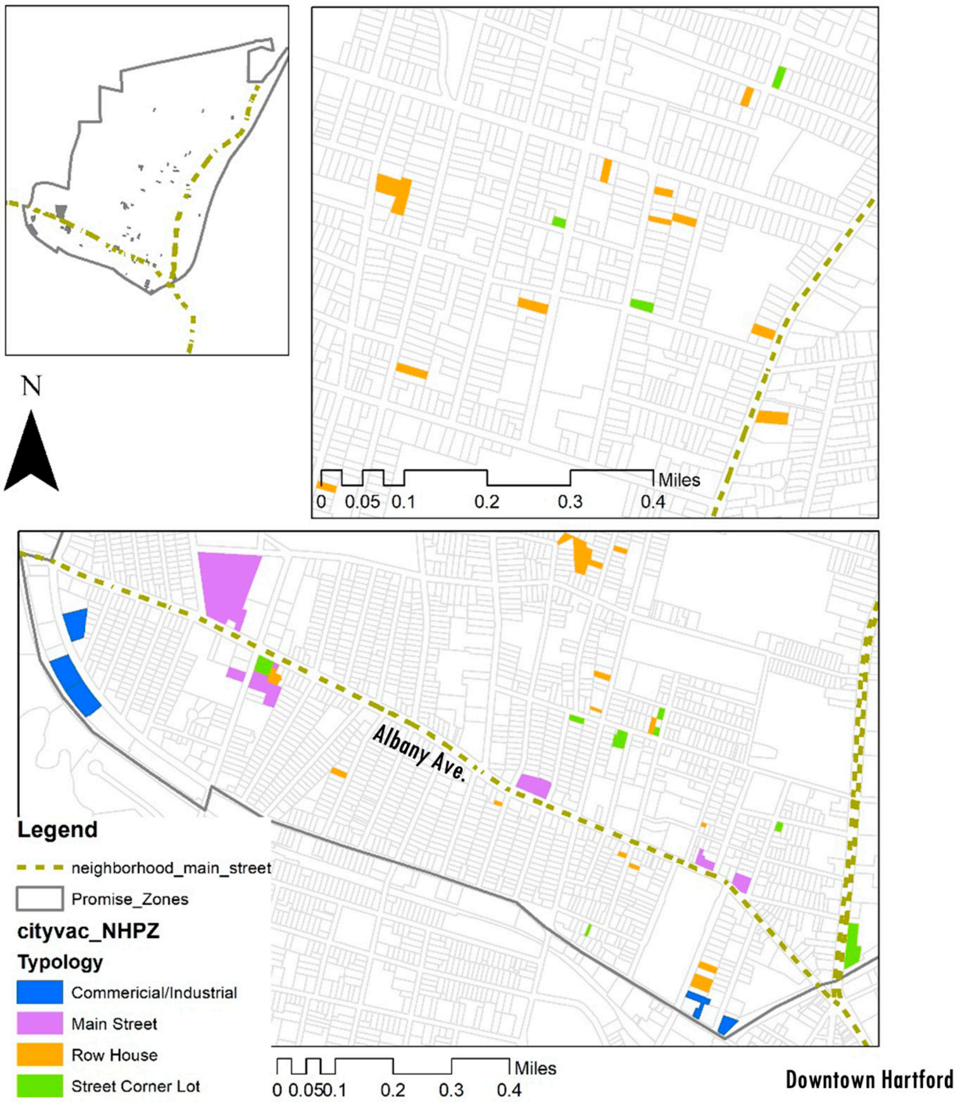


Figure 10. Spatial distribution of city-owned vacant lots by typologies in NHPZ.

In addition, the Main Street category comprises medium-sized lots located on the main streets of the neighborhood, adjacent to commercial and mixed-use lots. These lots. are designated to provide services, retail options, and recreation for the community. They enjoy high visibility and are accessible via pedestrian-friendly streets. In the city's land use planning, they are zoned as mixed-use and Main Street categories (Figure 10).

A district masterplan for publicly owned vacant lots in NHPZ has been proposed, with four distinct development action areas (Figure A1). In the North End neighborhood, which has relatively dense housing units and numerous row-house-type vacant lots, a Neighborhood Revitalization theme has been envisioned. Infill development is proposed to increase density and create a cohesive neighborhood, complementing the newly completed Swift Factory project—a rehabilitated historical factory building in the heart of the North End neighborhood that brings job opportunities to residents [43]. In Southeastern NHPZ, the Downtown Gateway District is proposed, situated along a critical transportation corridor connecting Downtown with the northern city and surrounding suburbs via state routes. This proposal incorporates streetscape enhancement initiatives and historical building highlighting initiatives from the Downtown North/West Plan, focusing on Albany Ave. as the neighborhood's main street and connector [44]. Main Street Development is proposed for similar reasons but with an emphasis on developing mixed-use commercial and residential buildings. This approach aims to support local businesses and attract residents by offering various retail and service options. Lastly, the Reclaiming the Park River plan proposes an ecological connection through environmental remediation and green space transformation of the current commercial and industrial-type vacant lots along the historical Park River on Homestead Ave. This plan improves ecological sustainability and enhances the cultural identity of the historical Park River, which was obscured by interstate highway construction and rapid urban development over the past seventy years.

3.3. Neighborhood Scale Analysis and Site Scale Vacant Lot Greening Design Example

This system relied on gray infrastructure for stormwater drainage, leading to flooding threats and non-point water pollution problems. In the Clay-Arsenal neighborhood, impervious surfaces account for more than 53% of the total land area largely due to extensive surface parking. Consequently, incorporating sustainable stormwater management concepts into design solutions is necessary.

Another constraint identified by geospatial analysis is the problem of youth crime. All three neighborhoods in NHPZ have been recognized as high crime rate areas. With around 36% of the population in the Clay-arsenal neighborhood being under 18 years old, one sample site in this area was identified as a youth crime hotspot due to its proximity to the neighborhood's main street, a playground, and a magnet school across the street (Figure A2b). Introducing additional greenspace in the neighborhood could help reduce crime by providing teenagers with a stronger cultural and social identity and stabilizing neighborhoods through mental remediation for residents [45,46]. For instance, a difference-in-differences analysis of the effects of a vacant lots greening program in Youngstown, OH, on crime in and around newly treated lots, compared to crimes in and around randomly selected and matched, untreated vacant lot controls, revealed that the greening program was significantly associated with reductions in burglaries and assaults crimes [24].

Opportunities identified in the neighborhood include its proximity to various community facilities and an existing open spaces network, such as historical landmarks, the Keney Clock Tower, and the Old Cemetery where Frederick Law Olmsted is buried, as well as the reclaimed riverfront park at the city's edge. Adding new green space can connect existing green spaces into a network, improve public access to these spaces, and in turn, help mitigate environmental inequity (Figure A2).

At the site scale, graphic analysis of the site characteristics (Figure A3) revealed that the site is situated at a transportation node, located at a five-street intersection connecting the neighborhood to Downtown Hartford and Interstate Highways. Considering that the main street is opposite a magnet high school, pedestrians are exposed to an unsafe transportation environment due to the lack of clear crosswalks and sidewalks. Furthermore, the streetscape is another weakness, as the littered site and unvegetated sidewalks detract from the neighborhood street's identity and aesthetic value.

The design concept development process proposed four sustainable design strategies in alignment with city planning goals and visions to address various problems:

- Brownfield Phytoremediation Technique: Given that the vacant site was a brownfield contaminated with the chemicals from an old gas station, phytoremediation was adapted into the design concept. This method uses selected plants to degrade organics, extract pollutants in the 0–5′ deep soil zone and stabilize non-bio-available inorganics [29]. The technique was applied to the northwestern part of the site, which was moted as a brownfield and designed as a remediation urban forest;
- Eco-revelatory Design Strategy: This strategy was incorporated into the design plan through a proposed rain garden at the southeastern corner of the site, complete with demonstration signages explaining how the rain gardens work. The rain garden

design includes a daylight micro-water channel near benches, which reveals the water flow and stimulates public awareness and children's curiosity about natural processes;

- Green Stormwater Infrastructure: In addition to the rain garden, the Green Street Program, inspired by the City of Portland, OR [47], was adopted into the design concept. By incorporating vegetated facilities on the sidewalk and increasing tree canopy, stormwater runoff can be reduced by natural systems, which in turn improves water quality and enhances watershed health [47]. This approach also encourages public stewardship by allowing residents to contribute to vegetation clean-up and occasional weeding;
- Tactical Urbanism: This strategy involves temporary design installations that are low-cost and low-maintenance. To promote pedestrian safety and strengthen community identity, the Dots Street Painting idea was proposed in the design (Figure A4). The street painting highlights the pedestrian routes in complex transportation crossing areas, increasing drivers' caution. The painting process can engage public participation and community organizations' efforts through neighborhood events or volunteer activities.

4. Discussion and Conclusions

Rapid deindustrialization, followed by population loss, disinvestment, and decentralization, has left many industrial legacy cities with abandoned factory structures and extensive areas of urban blight and vacancy. The urgent task of transforming these vast vacant lands to revitalize historical legacy cities calls for a holistic tool that can comprehensively assess and categorize vacant lots for various transformation alternatives based on contextual and geographical data. In response to this need, this study proposed a GIS-Based Vacant Land Assessment System (VLAS) as a protocol for repurposing vacant land on multiple scales while pursuing ecological, social, and economic benefits.

VLAS started with district/municipal level assessment of vacant lots leveraging publicly available datasets. The size, density, distribution, zoning categories, and proximity to public infrastructure for all the vacant lots at the scale were analyzed and four typologies were summarized: Row House (i.e., Missing tooth or Swiss Cheese type in Spirn's classification), Street Corner, Commercial/Industrial, and Main Street. Responding to these categories, reuse programs were also proposed. As legacy cities often aim for increasing tax revenue and attracting more urban dwellers, infilling development for row house type is a feasible reuse program and has also been adopted by other cities such as Columbus and Detroit [5,48]. Street corner and main street types of vacant lots obtain high visibility and accessibility via transportation network and therefore, are suitable for greening and public open space. In addition, commercial/industrial type was abandoned large factory and industrial sites and are suitable for mixed-use retrofit office building + open space development. Examples of this type of program included Urban Outfitter headquarters in Philadelphia, Gas Work Park in Seattle, Brooklyn Bridge Park and Dumbo District in NYC, and the Steel Yard in Providence RI. The reuse programs for the four vacant lot typologies were grounded in the case studies of awarded and successful projects for vacant lot transformation and thus replicable and applicable for other cities.

The significance of this study is demonstrated in three aspects: (1) Applicability: VLAS is applicable to other post-industrial and legacy cities since it only requires publicly available data and consists of replicable classifications. (2) Multi-scale thinking: VLAS adopts a multi-scale approach, providing a comprehensive assessment framework for vacant lot evaluation. (3) Consideration of various factors: a thorough review of ongoing municipal planning visions, social-ecological contextual data, and the physical condition of vacant lands are essential for achieving sustainable development goals.

Compared to other studies that analyze the impact of specific designs or programs on particular neighborhood improvement goals such as crime, public health, or access to greenspace [11,19,24,39,49], this study offers several insights: (1) Multi-scale thinking: VLAS focuses on district or municipal scale assessment of all vacant lots to inform neighborhood and site scale repurpose programs; (2) Community awareness: Raising community awareness about the significance of sustainable development strategies from economic, social, and environmental aspects in the process of vacant lot transformation is imperative. Achieving sustainable goals while pursuing urban development has been accepted as a global consensus given the threats of urbanization to the natural environment, social inequity, and future generations [50]. However, sustainability is often pitted against development instead of working in tandem with it. (3) optimized ecological-economic approach: This study's focus on balancing greening and open space programming with infill development programming for vacant land aims to address the aforementioned issue. Doing so not only improves environmental degradation and ecosystem services in the area but also enhances social norms and living quality in low-income areas, leading to social justice.

Other shrinking cities, post-industrial cities, and legacy cities can learn from this study in repurposing vacant land at multiple scales. This study introduced an approach and framework for reclaiming vacant land through spatial analysis and inventory, integrating existing public facilities and municipal planning initiatives with vacant lot management at the district scale. The categorization of vacant lots, which combines size, zoning, and spatial location characteristics, is also replicable in other shrinking cities. Moreover, this study presents a site-scale example of vacant lot placemaking, demonstrating how transforming a vacant and blighted land into community open space can boost social cohesion and environmental benefits. This transformation serves as a catalyst for positive changes at the site, neighborhood, and regional levels. By learning from this study, other cities facing similar challenges can develop and implement strategies for repurposing vacant land in a sustainable and community-oriented manner.

This study has certain limitations, despite being a multi-partnership effort and being presented to the public. First, it lacks a participatory design process that would have allowed for the collection of local residents' comments and concerns during the planning and analysis phase. Additionally, the sample design selection was directly assigned by city planners, taking into account their own planning priorities, leading to a potential lack of objective analysis in prioritizing vacant lots based on the feasibility and necessity of transforming them into green spaces. Factors such as property value and the social-economic status of the surrounding neighborhood should also be considered when reclaiming vacant lots as green spaces. Gentrification, a potential disadvantage of transforming vacant lots into well-designed public spaces in low-income neighborhoods, has been noted in previous studies [51]. To prevent gentrification, some scholars have proposed the concept of "just green enough" in the placemaking process [52]. Furthermore, although this study's example design incorporates tactical urbanism techniques like street painting and phytoremediation as cost-effective features, more attention is needed to minimize construction and maintenance costs, given the city's limited funding and budget for park conservation and planning, and the need for increased tax revenue. Striking a balance between creating green spaces for long-term ecosystem services and environmental benefits and developing taxable properties for maximizing economic benefits remains a challenge [21]. Future studies could expand the scope of research by including privately owned vacant lots and blighted properties to more comprehensively examine urban decay in post-industrial cities and explore potential revitalization frameworks.

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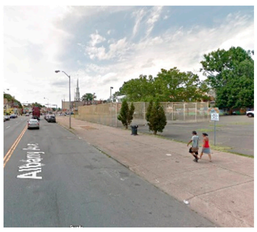
Appendix A

Table A1. Vacant Lot Typologies.

Typology	Aerial Map	Exampled Lots	Example Images	Potential Reclaimed Use
Row House				Infill Redevelopment
Street Corner Lot				Public Open space
Commercial/ Industrial				Public Mixed-Use: Retrofitted Buildings + Open Space
Main Street				Public Open space with a variety of site programs: -Community Garden -Stormwater Management -Nature in city/Biodiversity -Health and Wellness -Cultural Landscape

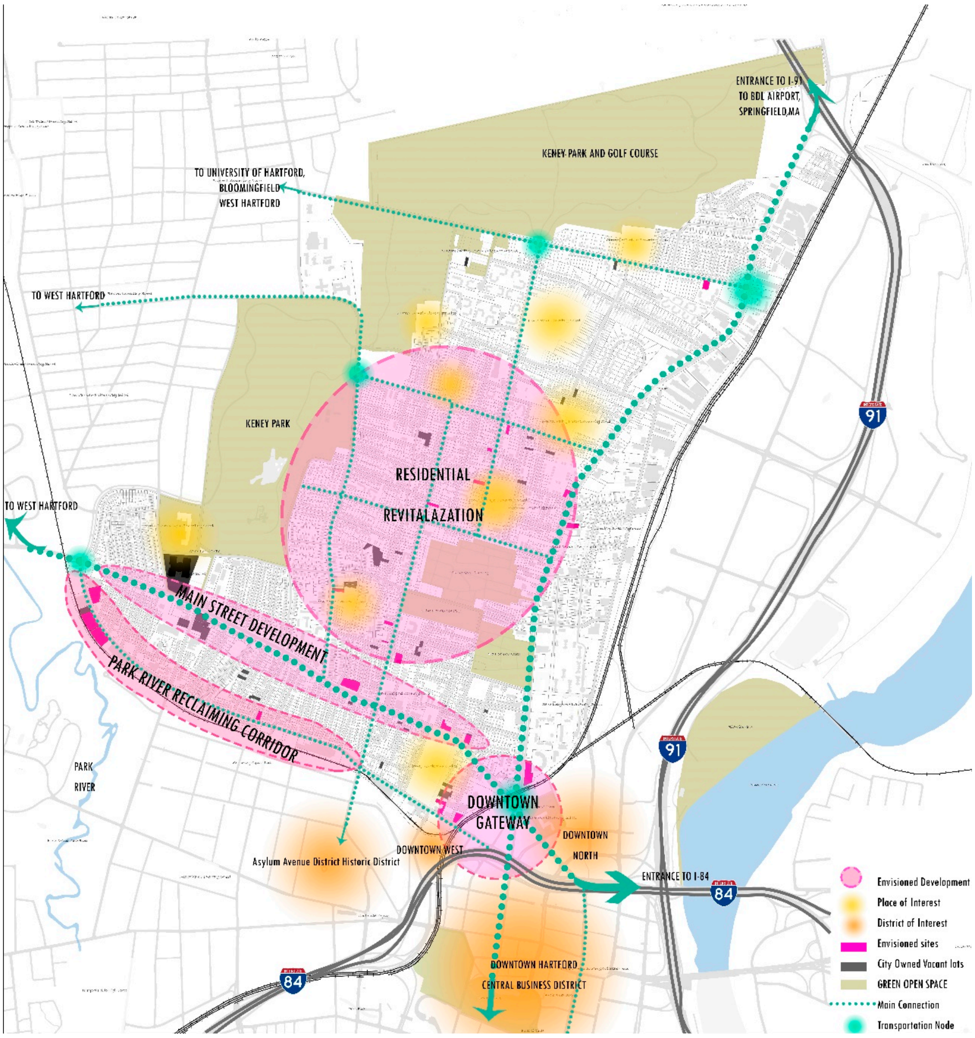
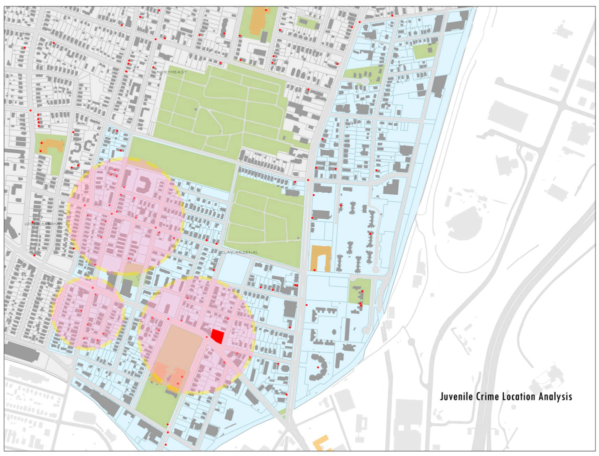


Figure A1. Master plan framework of city-owned vacant lot transformation.

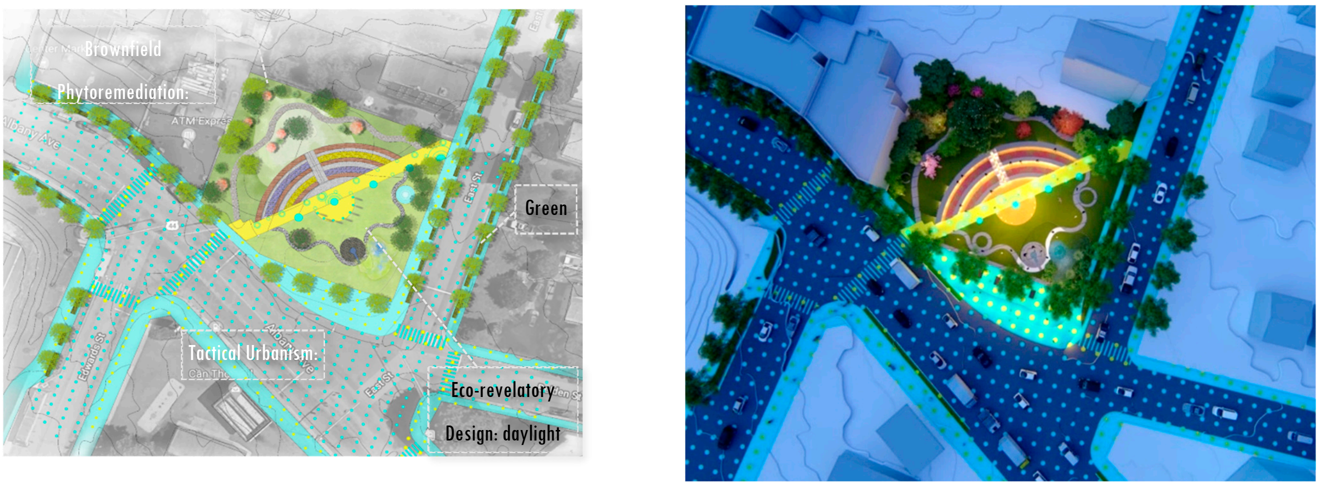
(**a**)



(**b**)

Figure A2. (**a**) Open space network at the neighborhood scale; (**b**) Juvenile Crime Hotspot analysis.

Figure A3. Site analysis graphics.



(**a**) (**b**)

Figure A4. Illustrative site plan (**a**) daytime (**b**) nighttime.

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