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Original article

Regreening suburbia: An analysis of urban greening approaches in U.S. sprawl retrofitting projects

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ABSTRACT

Urban sprawl negatively impacts public health, societal well-being, economic prosperity, and environmental sustainability. Sprawl retrofitting projects aim to mitigate these issues by increasing density, diversifying land uses and housing options, and enhancing walkability and environmental amenities, with green space provision being vital to their success. But empirical evidence regarding the achievement of 'regreening' objectives is limited, with some studies showing considerable green space reduction during suburban densification. This study analyzes regreening strategies in 18 suburban sprawl retrofitting projects completed between 2008 and 2018 in the United States. Using a quasi-experimental approach, I first contrast vegetation changes in these projects to those in adjacent areas. Next, we examine the cases based on six regreening principles derived from the literature: 1) urban nature quality and quantity, 2) multi-modal access and walkability, 3) inclusive and authentic public spaces and programming, 4) local and regional green space connectivity, 5) environmental performance and ecological design, and 6) initial public sector leadership and investment. The findings show no significant pre- and post-project differences in vegetation levels for either project sites or control groups, indicating inconsistent regreening outcomes. Analysis of regreening principles reveals challenges and opportunities in sprawl retrofitting projects. The study emphasized the need for concerted efforts to ensure socially equitable and ecologically functional green spaces in suburban retrofitting projects.

1. Introduction

Urban sprawl is a consequence of suburban experiments where new growth occurs scattered on a large scale (Ewing & Hamidi, 2015; Marohn, 2016). Extensive research has shown that urban sprawl leads to negative impacts on public health, society, the economy, and the environment (Duany et al., 2000; Ewing & Hamidi, 2015, 2017; Frank et al., 2019; Sharifi, 2019; Silva et al., 2017). In response to these issues, recent efforts have focused on retrofitting projects to transform car-centric, mono-functional suburban areas into sustainable, diverse, and walkable environments. Such retrofitting projects come in various forms, from residential to retail spaces and office parks. In their book *Retrofitting Suburbia*, Dunham-Jones and Williamson (2012) provide three retrofitting principles: 'Re-inhabitation,' 'Redevelopment,' and 'Regreening.' These principles emphasize repurposing existing structures, renewing built environments through new construction, and enhancing green space provisions, respectively, as key strategies to counter the negative impacts of urban sprawl.

Preserving natural environments and providing more green spaces are essential to the success of retrofitting projects (Haaland & van den Bosch, 2015). The benefits of green spaces in suburbia include environmental, socioeconomic, and physical and mental health improvements. Green spaces provide habitats for wildlife, air purification, water and climate regulation, carbon storage, and stormwater detention and drainage (Pickett et al., 2011). Additionally, green spaces offer opportunities for immersive and active recreation, cultural heritage, and community events, among other social benefits, often lacking in suburban areas (Talen, 2011).

Despite the growing number of retrofitting projects, some projects have failed to accomplish their regreening goals, with some studies even showing significant losses of green space during the suburban densification process (Haaland & van den Bosch, 2015; Sivam et al., 2012). In practice, recent compact developments, labeled as sprawl retrofitting, new urbanism, or transit-oriented developments, have been criticized for their insufficient consideration of environmental sustainability and resiliency (Godschalk, 2004; Jepson & Edwards, 2010; Leger et al., 2013; Trudeau, 2013). There is a lack of comprehensive, empirical studies of sprawl retrofitting projects.

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This study aims to analyze regreening approaches in suburban sprawl retrofitting projects. I assess changes in vegetation across 18 projects completed between 2008 and 2018 in the U.S. and examine the individual regreening principles applied to each project through a comparative case study. This study asks two research questions: 1) Did the amount of vegetation change in suburban retrofitting projects? and 2) To what extent have regreening principles been integrated into these projects? A quasi-experimental approach compares changes in vegetation levels to those in nearby neighborhoods. The research findings underline the necessity for more dedicated and coordinated efforts to ensure the provision of socially and ecologically functional green spaces in the retrofitting of suburbia.

2. Literature review

2.1. Studies on suburban retrofitting

Urban sprawl, initially perceived as the new American dream, has since revealed a range of negative economic, social, environmental, and public health consequences. They include an increased reliance on cars, which leads to traffic congestion and higher greenhouse gas emissions, and reduced housing affordability, exacerbating income inequality and housing crises. Additionally, sprawl often results in limited access to healthcare facilities, schools, and public transportation (Duany et al., 2000; Ewing & Hamidi, 2015, 2017; Frank et al., 2019; Sharifi, 2019; Silva et al., 2017). In response to aging, out-of-date properties in old suburbs, market indicators and policy directions have recently shifted toward infill development and suburban retrofitting. State and federal policies, such as California Senate Bill 375 ("The Sustainable Communities and Climate Protection Act of 2008″) and the HUD-DOT-EPA Partnership for Sustainable Communities, promote regional planning and transportation improvements, along with many municipalities overhauling their zoning codes or adding overlay districts (Boarnet et al., 2011; Dunham-Jones & Williamson, 2012; Pendall et al., 2013; Puentes, 2006; Talen, 2013).

Sprawl retrofitting aims to mitigate the adverse effects of urban sprawl by converting automobile-oriented, single-use suburban regions into healthier, more diverse, and more pedestrian-friendly neighborhoods (Dunham-Jones & Williamson, 2012; Talen, 2011). These retrofitting projects have various types, based on their previous land uses and conditions, such as residential areas (e.g., garden apartment complexes or cul-de-sac subdivisions), retail spaces (e.g., dead shopping malls, declining strip malls), or office and business parks (Dunham-Jones & Williamson, 2012; Tachieva, 2010). Economically, retrofitting improves job access and can lead to real estate premiums as the area becomes more desirable. Socially, retrofitting may incorporate affordable housing options, create new public realms, and foster more diverse and inclusive communities (Immergluck & Balan, 2018; Talen, 2011). Regarding transportation and health, retrofitting sprawl promotes reduced auto-dependency, encourages physical activity, and supports active transportation and public transit use, contributing to healthier lifestyles (Ewing et al., 2014; Ewing & Hamidi, 2015).

Critiques of recent sprawl retrofitting projects also exist. Some argue that it oversimplifies the complex relationship between the built environment and human behavior by relying too heavily on environmental determinism and neglecting social, systematic changes (Day, 2003; Heins, 2015). Further concerns include design solutions that are internally focused and object-like, failing to address broader connections to the surrounding urban context (Kullmann, 2015; Trudeau & Malloy, 2011). Consequently, fragmented regreening efforts may perpetuate the dualistic view of the city and nature, hindering the development of an integrated, sustainable green network (de la Peña, 2015). Critics also highlight potential negative consequences such as gentrification, limited affordable housing, and increased traffic congestion as unintended outcomes of retrofitting efforts (Hanlon & Airgood-Obrycki, 2018; Immergluck & Balan, 2018; Jones, 2020; Loughran, 2022; Markley, 2018).

2.2. Regreening principles in sprawl retrofitting sites

The value of nature in suburban areas encompasses environmental, health, social, and economic dimensions. From an environmental standpoint, suburban green space contributes to air purification, water and climate regulation, carbon storage, stormwater detention and drainage, providing wildlife habitats, and preserving local ecosystems (Barron, 2018; Lynch, 2021). Green spaces in suburban areas offer immersive recreational experiences and opportunities for both passive and active recreation, promoting physical and mental well-being (Lynch, 2021). By providing safe and pleasant environments, these spaces encourage alternative transportation options, such as walking and cycling.

Socially, suburban green spaces enhance the quality of life by providing venues for recreation, aesthetics, cultural heritage, social interaction, and community or ceremonial events (Barron, 2018). Suburban green spaces can foster a sense of community and belonging, strengthening social ties and promoting social cohesion. Economically, the presence of green spaces in suburban areas can generate positive impacts on property values, attracting investments and contributing to the overall economic vitality of the region (Crompton, 2005; Nicholls & Crompton, 2005). Well-maintained green spaces can boost local tourism, generating additional revenue for the community.

This study establishes six regreening principles applicable to sprawl retrofitting projects based on the literature. Following qualitative content analysis methods (Cho & Lee, 2014; Elo et al., 2014), I examined the relevant literature using a combination of search keywords, including 'sprawl retrofitting,' 'suburban (suburbia),' 'green space (greenspace),' 'greening,' and 'open space.' The primary search engine was Google Scholar, given its wide accessibility and common use in the academic literature review (Gehanno et al., 2013), and the search comprised only English-language peer-reviewed studies or books. The search resulted in 13 publications (Table 1), from which I extracted all content related to regreening approaches (e.g., green spaces, ecological design, environmental performance), and categorized them, considering various disciplines (e.g., parks and recreation, transportation, ecology, governance) and benefits (e.g., health, social, environmental). The number and names of these categories were iteratively updated. This process resulted in the six principles serving as a framework for assessing case projects in this study (Table 1).

The six principles derived from the literature include 1) quantity and quality of urban nature, 2) multi-modal access, safety, and walkability, 3) inclusive and authentic public spaces and programming, 4) local and regional connectivity of green space, 5) environmental performance and ecological design, and 6) initial leadership and investment from the public sector.

3. Data and methods

3.1. Sprawl retrofitting projects in the U.S

The research team compiled a list of recent sprawl retrofitting projects from multiple sources, including online databases and books. Two online databases provided a starting point: The Congress of New Urbanism's project database (CNU; https://www.cnu.org/resources/project-database) and The Town Paper's Traditional Neighborhood Development (TND) nomination lists (https://www.tndtownpaper.com/neighborhoods.htm). We also supplemented this list with literature on sprawl retrofitting cases, including Dunham-Jones & Williamson (2012), Tachieva (2010), and Williamson & Dunham-Jones (2021).

Next, we applied three selection criteria: 1) A project has a previous land use; in other words, we excluded greenfield developments on previously undeveloped land, 2) The finished project incorporates multiple land uses; for example, we removed residential development projects

Table 1
A summary of regreening principles drawn from the literature.

Principles	Key strategies	References
Quantity and quality of urban nature	• Set clear objectives for green space quality and quantity • Take a needs-based approach • Adopt local plans and regulations for preservation and provision of green space	Baycan-Levent & Nijkamp, 2009; Byrne & Sipe, 2010;Haaland & van den Bosch, 2015; McCrea & Walters, 2012;Sivam et al., 2012
Multi-modal access, safety, and walkability	• Improve walkability and safety of streets • Enhance infrastructure for alternative transportation modes (e.g., public transit, bike, micro-mobility) • Regreen streetscapes (e.g., trees, planting strips, parks, rain gardens, and parklets)	Dunham-Jones & Williamson, 2012
Inclusive and authentic public spaces and programming	• Promote residents' place attachment through existing trees and natural areas; • Accommodate needs of multiple groups (e.g., age groups, racial and ethnic minorities, low-income residents, families with children, and people with disabilities) • Create flexible, open-ended design and programming	Baycan-Levent & Nijkamp, 2009; Dunham-Jones & Williamson, 2012; Jim, 2013
Local and regional connectivity of green space	• Establish networks of parks and open spaces, such as greenways, boulevards, streams, and large parks • Avoid creating isolated communities • Integrate with transportation systems (e.g., boulevards, transit corridors, and multi-purpose trails)	Caspersen & Olafsson, 2010;Dunham-Jones & Williamson, 2012; Jim, 2013;Trudeau & Malloy, 2011
Environmental performance and ecological design	• Address existing environmental issues (e.g., air pollution, energy consumption and greenhouse gas emissions, forest fragmentation, and destroyed wildlife habitats) • Implement low-maintenance green infrastructure (e.g., rain gardens, bioswales, community gardens, and soil improvement) • Incorporate ecological design to restore landscape connectivity and wildlife habitats	Dunham-Jones & Williamson, 2012; Haaland & van den Bosch, 2015; Jim, 2013; Sushinsky et al., 2013
Initial leadership and investment from the public sector	• Emphasize public leadership and investment to overcome initial challenges (e.g., weak market demand, site contamination, regulatory constraints, and financial limitations) • Engage the public to build consensus and expedite troubleshooting and decision-making • Explore innovative financing mechanisms and sustainable management plan	Baycan-Levent & Nijkamp, 2009; Dunham-Jones & Williamson, 2012; Haaland & van den Bosch, 2015;Immergluck & Balan, 2018; Khoshkar et al., 2018;Talen, 2015

that do not contain any other uses (e.g., retail, public), and 3) aerial imagery data from the National Agriculture Imagery Program (NAIP) must be available before and after the project completion. In most cases, the NAIP data were available after 2008. Using the literature, online information, and historical satellite images from Google Earth Pro, the research team gathered data and assessed each project's eligibility.

We identified 18 sprawl retrofitting cases across 13 states in the U.S. (see Fig. 1, Table 2, and Appendix Fig. 1). The initial search, applying the first two criteria, yielded 68 project cases. But in most of these projects, we were unable to obtain high-resolution aerial imagery for the pre-existing conditions (criteria #3). The sizes of the 18 projects range from 2.5 acres (1.0 ha; The Lofts at Washington University, MO) to 108 acres (43.8 ha; Historic Fourth Ward Park, GA). Most of the retrofitted sites have undergone significant changes in the urban fabric, including new street patterns, buildings, and public spaces. Depending on the previous land use of the site, we identified four typologies: shopping malls (five sites), industrial uses such as business parks and warehouses (seven sites), residential uses such as public housing (two sites), and other uses (four sites; e.g., mixed-use, parking lot). The location of project sites varied: Six sites were adjacent to downtown (within one mile), six were between one and five miles, and four were more than five miles from downtown. The remaining sites, Promenade of Wayzata in Minnesota and Wyandanch Rising in New York, were isolated, being more than 10 miles from the nearest major city.

Appendix Table 1 shows the socio-demographic characteristics of the sites before development as of 2000. On average, the project sites have a lower percentage of older adults (at 7.4%), fewer non-Hispanic Whites (38.6%), more renters (69.7%), lower median household income ($49,307 in 2000 dollars), and fewer vehicles per housing unit (1.1), compared with the national average. A closer examination reveals diversity among the sites regarding demographic and socioeconomic status. Out of 18, eight sites (or 44%) can be grouped as low socioeconomic status (SES) areas, seven (39%) as medium SES areas (or mixed indications of high and low SES), and three (17%) as high SES areas.

We collected information about the 18 projects from the literature and online resources for a multiple case study. Key sources of information include Dunham-Jones & Williamson (2012), Williamson & Dunham-Jones (2021), Urban Land Institutes' case studies (https://casestudies.uli.org/all-case-studies/), Congress for the New Urbanism's project database (https://www.cnu.org/resources/project-database), and academic papers and theses that examine specific cases (e.g., Barnard, 2018; Chu, 2017; Savage, 2006; Sweere, 2020). Spatial data (e.g., vegetation, parks, street configuration) and statistical data (e.g., socio-demographics) before and after the development project were also examined.

3.2. Vegetation data

We collected vegetation data from aerial images generated by the U. S. National Agriculture Imagery Program (NAIP; via EarthExplorer) between 2008 and 2018. NAIP data are remotely sensed during the agricultural growing seasons and are available in one-meter resolution or finer. Thus, these leaf-on images can represent changes in vegetation at the project sites. We used the four color bands (red, green, blue, and near-infrared) included in the recent NAIP images to calculate the Normalized Difference Vegetation Index (NDVI), which we then used to measure vegetation. The NDVI, a widely used index in remote sensing, calculates the difference between near-infrared light (which plants predominantly reflect) and red light (which plants absorb and reflect to

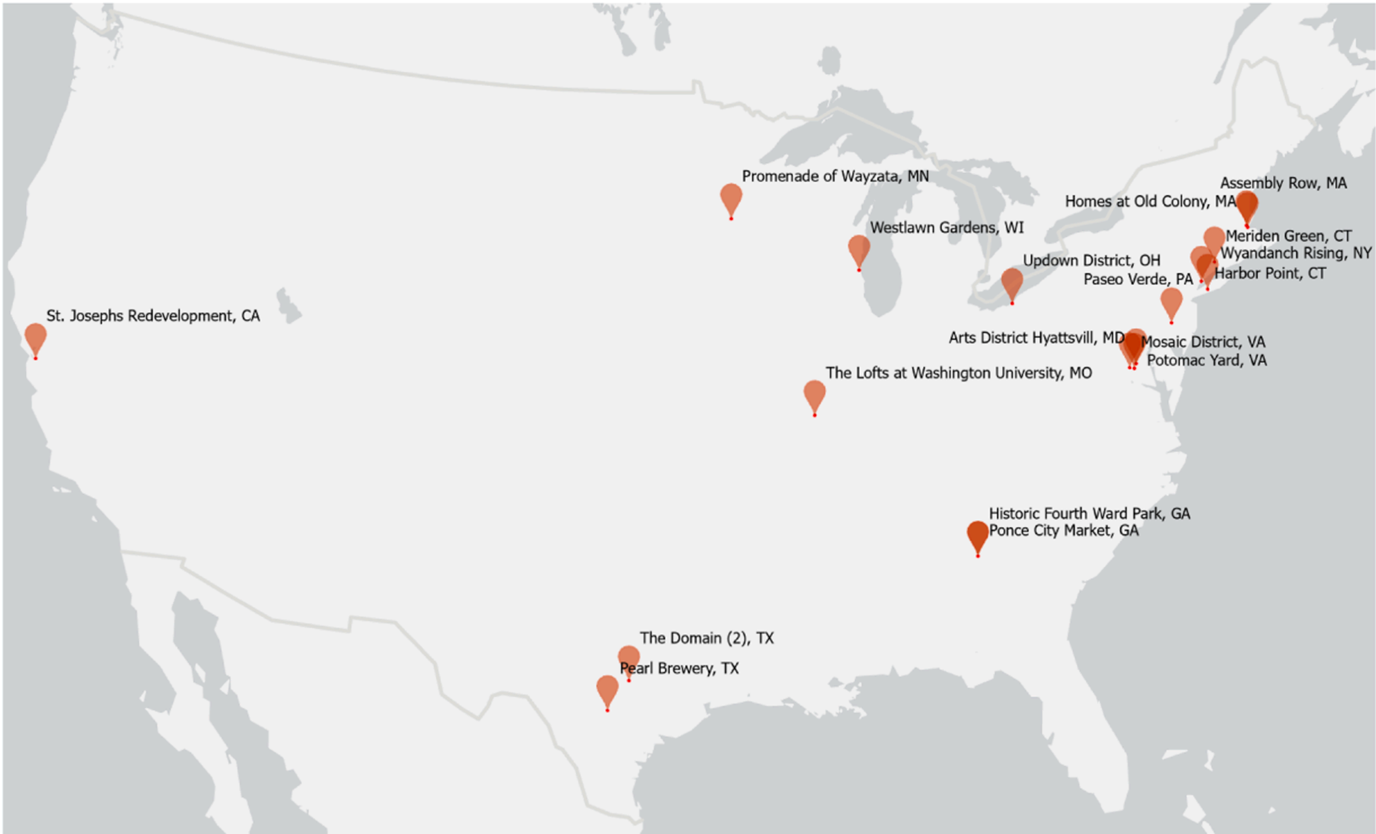

Fig. 1. Project location (n = 18).

a lesser degree) (Carlson and Ripley, 1997). This makes the NDVI a powerful tool for determining vegetation health and coverage, which are key elements in this research. The 'before' data were available for the years between 2008 and 2011, and the 'after' data were collected between 2018 and 2020. We also acquired NAIP data for control groups, which consisted of areas within a 0.5-mile (804-meter) radius adjacent to the project boundary.

Subsequently, we processed the aerial imagery data on four occasions for each project—before and after the project and for both the project and control groups. For each occasion, we calculated NDVI values for each pixel and reclassified each pixel as "mixed vegetation," "woody vegetation," or "non-vegetated area." We classified pixels with values of 0.12 or higher as 'mixed vegetation' and pixels with values of 0.3 or higher as 'woody vegetation' (McBride & Douhovnikoff, 2012; Nesbitt & Meitner, 2016).

3.3. Data analysis

This study consists of two parts of analysis. To answer the first research question about vegetation changes in suburban retrofitting projects, a quasi-experimental study evaluates changes in vegetation in 18 projects completed between 2008 and 2018. A difference-in-differences analysis calculates the variations in vegetation percentages in both project sites and control groups pre and post-development. The control groups consist of adjacent areas located within 0.5 miles (804 m) of the project boundaries. The analysis focuses on three vegetation types: total, mixed, and woody. A paired t-test is a statistical analysis used to compare two related samples (e.g., before and after cases, treatment and control groups) to detect differences between them (Ewing and Park, 2020). This study conducts paired t-tests to determine if there are any statistically significant differences in vegetation percentage changes before and after the project within the project sites and control groups, as well as between the project sites and control groups. Correlation coefficients (for continuous variables) and ANOVA (for categorical variables) are utilized to investigate the relationship between vegetation changes and various project characteristics, such as project area size, distance to city centers, year of completion, and the site's previous socioeconomic status.

To answer the second research question about the application of regreening principles, a multiple case study method examines the 18 projects based on six regreening principles drawn from the literature: 1) urban nature quality and quantity, 2) multi-modal access, safety, and walkability, 3) inclusive and authentic public spaces and programming, 4) local and regional green space connectivity, 5) environmental performance and ecological design, and 6) public sector leadership and investment. This study employs a cross-case synthesis approach, following the suggestion of Yin (2017). Initially, each case is assessed to determine the integration of the six principles into the project. This is based on multiple data sources, including the literature, online materials, spatial data (e.g., vegetation, parks, street configuration), and statistical data (e.g., socio-demographics). Subsequently, the collective examination of the cases through cross-case synthesis allows for identifying patterns, lessons learned, and best practices to inform future urban planning and design endeavours.

4. Results

4.1. Assessment of vegetation changes

Overall, project sites typically have less vegetation (17% on average before the project) compared to surrounding areas (31% on average) (Fig. 2 and Table 3). This gap remains after the sprawl retrofitting projects, with mean values of 11% and 27% for the project sites and control groups, respectively. Both project sites and control groups

Table 2
Project characteristics (n = 18).

Project Name	Area in acre (ha)	Previous land use (primary)	Year of major completion	Distance to a city center[a]
Arts District Hyattsville, MD	28.7 (11.6)	industrial	2014	5–10 miles
Assembly Row, MA	40.1 (16.2)	industrial	2018	1–5 miles
Harbor Point, CT	21.1 (8.6)	industrial	2014	Less than 1 mile
Historic Fourth Ward Park, GA	108.3 (43.8)	industrial	2016	Less than 1 mile
Old Colony, MA	8.4 (3.4)	residential	2015	Less than 1 mile
Meriden Green, CT	21.9 (8.9)	mall	2018	Less than 1 mile
Mosaic District, VA	38.6 (15.6)	mall	2014	1–5 miles
Paseo Verde, PA	2.6 (1.1)	others	2013	1–5 miles
Pearl Brewery, TX	18.8 (7.6)	industrial	2018	Less than 1 mile
Ponce City Market, GA	17.4 (7.1)	industrial	2015	Less than 1 mile
Potomac Yard, VA	63.2 (25.6)	industrial	2015	1–5 miles
Promenade of Wayzata, MN	12.7 (5.1)	mall	2018	More than 10 miles
St. Josephs Redevelopment, CA	3.5 (1.4)	others	2014	1–5 miles
The Domain (2nd phase), TX	78.8 (31.9)	mall	2016	5–10 miles
The Lofts at Washington University, MO	2.5 (1.0)	others	2014	5–10 miles
Uptown District, OH	12.4 (5.0)	others	2015	1–5 miles
Westlawn Gardens, WI	19.4 (7.8)	residential	2014	5–10 miles
Wyandanch Rising, NY	7.6 (3.1)	mall	2016	More than 10 miles

[a] . To calculate straight-line distances from the nearest Central Business District to each project site, we used the 1982 U.S. Census shapefile of CBDs. Then, we confirmed their current locations on Google Maps.

experienced a decrease in vegetation, with an average decline of 5.6%p (percent points) and 3.7%p, respectively.

Five of the 18 projects (Meriden Green, Paseo Verde, Pearl Brewery, St. Josephs, and Wyandanch Rising) experienced an increase in total vegetation. The most significant increase was observed at Meriden Green, CT (20%p increase), formerly a shopping mall site that has been transformed into a new park (Figs. 3 and 4). On the other hand, Westlawn Gardens, WI, an award-winning mixed-use community developed on a former public housing complex site, experienced the most substantial decrease in total vegetation (34%p decrease).

The paired t-test results in Table 2 reveal no statistically significant difference in the percentage changes in vegetation before and after the project for both project sites and control groups (Table 2). Furthermore, the paired t-tests comparing vegetation percentage changes (after minus before) between project sites and control groups showed no significant differences across all vegetation types. Hence, the success of regreening in sprawl retrofitting projects varies, indicating a mixed outcome across different projects.

I also investigated vegetation changes by project area size, distance to city centers, year of completion, and the site's previous socioeconomic status but found no statistically significant results. The increase in green space may not necessarily be more likely in larger sites, even though such sites might offer more opportunities for strategic, coordinated approaches.

Table 3
Vegetation percentages by vegetation type, time, and group.

		Total vegetation	Mixed vegetation	Woody vegetation
Project sites	Before	17%	12%	5%
	After	11%	8%	3%
	t-statistic 1 (*p*-value)	1.78 (.09)	1.25 (.23)	1.76 (.10)
Control group	Before	31%	16%	14%
	After	27%	14%	13%
	t-statistic 2 (*p*-value)	1.37 (.19)	1.47 (0.16)	0.53 (.60)
Group-wise comparison	*t*-statistic 3 (*p*-value)	-0.70 (.49)	-0.69 (.50)	-0.26 (.80)

Notes:
t-statistics 1 and 2 compare vegetation percentages between before and after the project
t-statistics 3 compares vegetation percentage changes (after minus before) between project sites and control group

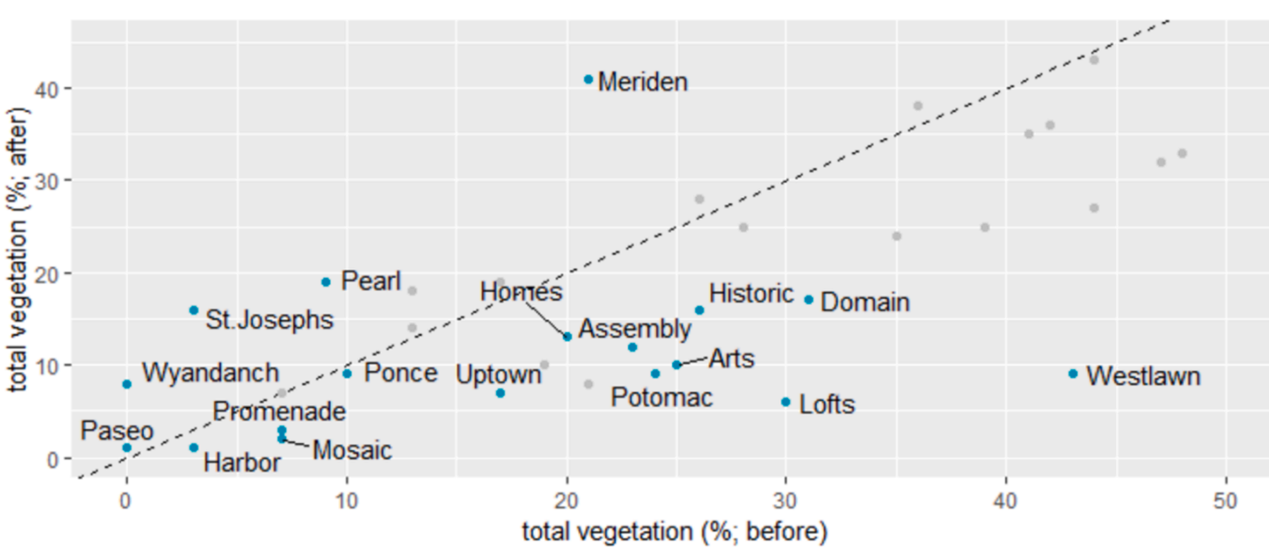

Fig. 2. Percentage changes of total vegetation: after (y-axis) against before (x-axis) (n = 18) (note: grey points indicate control group—areas within a 0.5-mile from project boundaries).

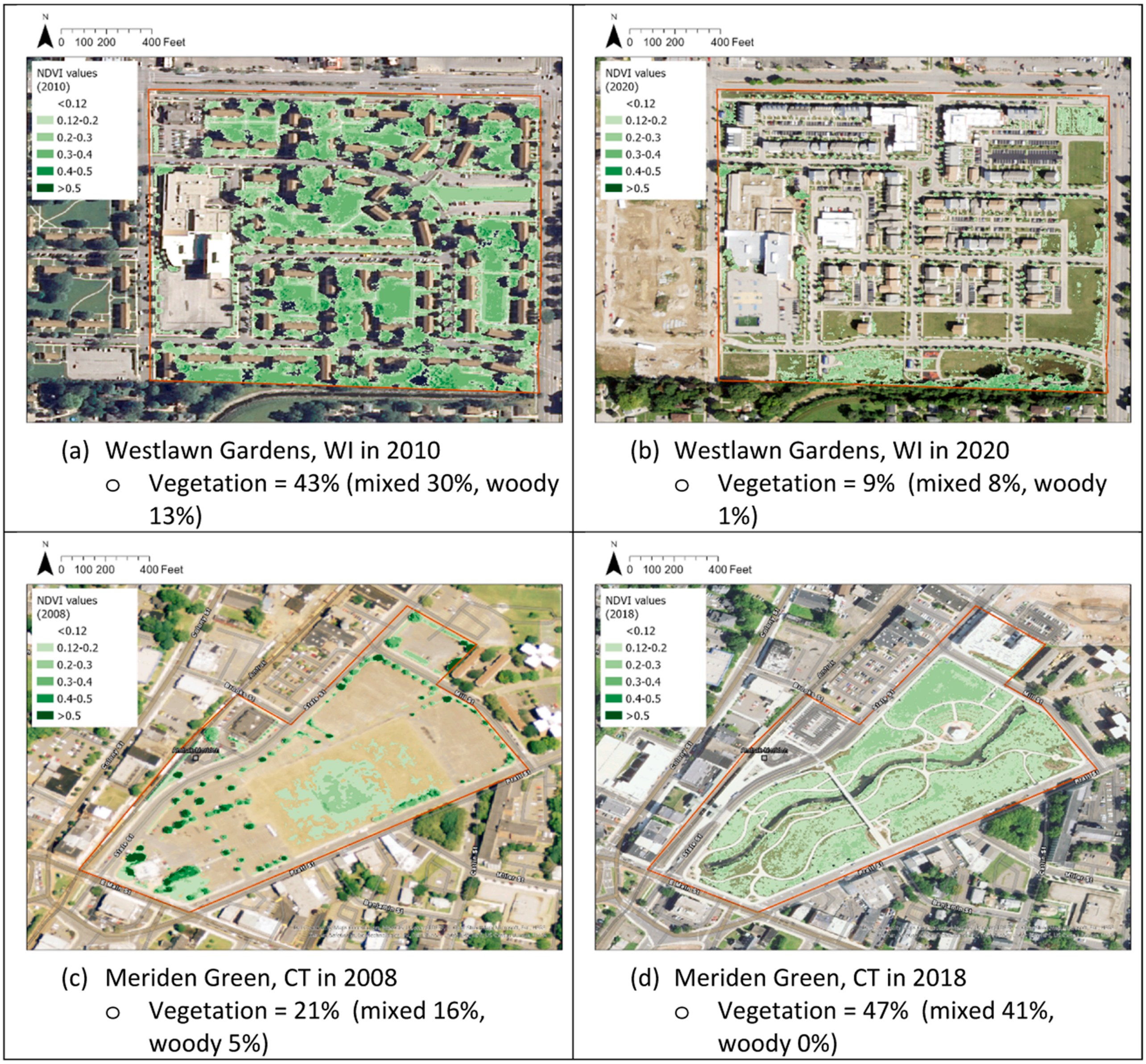

Fig. 3. Two extreme examples of NDVI value changes before and after sprawl retrofitting projects.

4.2. Analysis of regreening principles

Table 4 summarizes key findings from the cross-case synthesis of 18 projects.

4.2.1. The quantity and quality of urban nature

Sprawl retrofitting projects encompass various types of green spaces. Street trees are the most common type, featured in all 18 projects, followed by stormwater management elements (e.g., bioswales, rain gardens; 12 projects) and parks (11 projects) (Figure 4). Historic Fourth Ward Park (GA) and Meriden Green (CT) are prime examples of park-oriented development. In both instances, parks were constructed to protect neighboring properties from recurring flooding events while offering new communal spaces.

However, not all parks and green spaces are created equal. The 18 projects do not reveal any statistical associations between changes in vegetation levels and the presence of specific green space types, including parks. In some cases, such as Arts District Hyattsville (MD), a park was established as an open lawn with no distinct programs. It was positioned at the edge of the site boundary, which limited its accessibility. Conversely, Potomac Yard (VA) is an exemplary model for defining green space objectives. The Potomac Yard Urban Design Guidelines (City of Alexandria, 2012) outline quantitative criteria for open space provision (e.g., 10-year tree coverage goals, tree composition—shade, understory, and evergreen trees, proportions of active and passive uses for each open space). Additionally, the Guidelines detail the distribution of diverse parks, such as regional open spaces, neighborhood parks, and pocket parks. Promenade of Wayzata (MN) is another instance that integrates various green space types to accommodate different programs and user groups, including a one-acre park for social gatherings and events, green roofs and courtyards for senior housing, children's playgrounds, and wetlands and ponds for stormwater management.

4.2.2. Multi-modal access, safety, and walkability

Green spaces, vegetation, and landscape design play a crucial role in achieving mobility and accessibility goals in sprawl retrofitting projects (Dunham-Jones & Williamson, 2012; Talen, 2011). Most projects aim to achieve multi-modal access (e.g., public transit, walking, biking, micro-mobility), safety, and walkability. Certain projects aim for

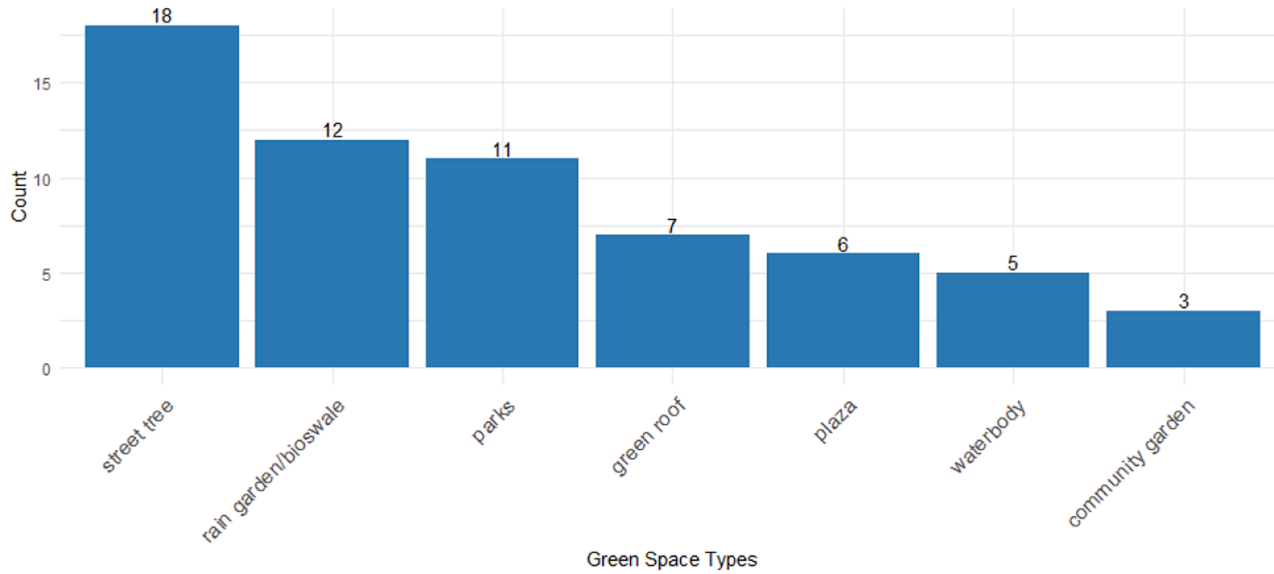

Fig. 4. Number of projects implementing specific green space types (n = 18).

transit-oriented development (TOD), featuring dense, mixed-use, and walkable environments near well-connected public transit stations, such as Assembly Row (MA), Meriden Green (CT), Paseo Verde (PA), and Wyandanch Rising (NY). Bike paths and multi-purpose trails are connected to the sites to promote regional connectivity (see Section 4.2.4) (e.g., Assembly Row (MA), Historic Fourth Ward Park (GA), Pearl Brewery (TX), and Ponce City Market (GA)).

Often, these projects deploy green spaces and vegetation as traffic calming strategies, utilizing techniques like vegetated curb extensions, parklets, multi-layered vegetation on streets, and green stormwater management practices such as bioretention swales. Parking lots are typically limited or constructed as structured parking to make room for more public spaces.

Projects like the Domain (TX) and the Mosaic District (VA) prioritize internal walkability, focusing on creating pedestrian-friendly zones within the development itself, while overlooking the area beyond it. Both projects are surrounded by highways or high-speed boulevards, making driving the most desirable option to access the site. In The Domain (TX), separating car-oriented streets from pedestrian-oriented streets may result in increased automobile dependence rather than reducing it, as the site provides easy and fast driving and parking (Williamson & Dunham-Jones, 2021). A common issue identified in some projects is the lack of adequate vegetation along the new pedestrian paths. In The Lofts at Washington University (MO) and Uptown District (OH), newly inserted alleys function solely as mid-block pedestrian passageways rather than as green spaces with diverse activities. They may be perceived as unsafe at night.

4.2.3. *Inclusive and authentic public spaces and programming*

Suburban malls and residential areas often lack public spaces where community members can interact, gather, and host events (Parlette & Cowen, 2011). Most of the 18 projects in this study initially had vast parking lot areas but lacked noticeable public spaces. After the development, almost all projects added community spaces, such as parks, plazas, and community gardens.

Developers and public authorities involved community members in programming and designing the new public spaces. In Historic Fourth Ward Park (GA), residents' inputs were incorporated into creating a lawn, festival space, and playground with a splash pad inside the new stormwater park. Some projects used public charrettes, which are collaborative sessions where planners and designers draft solutions to a design problem while engaging with the stakeholders, as seen in Westlawn Gardens (WI) and Wyandanch Rising (NY). In Wyandanch Rising (NY), a one-acre green plaza was built as the centerpiece of Phase 1 and accommodated an ice-skating rink and space for festivals and cultural events. These new, inclusive public spaces serve as catalysts, demonstrating alternative futures for suburban communities. Adaptive reuse, which is the process of redeveloping buildings for new purposes while retaining their historical value, is another tactic employed in sprawl retrofitting projects (e.g., Arts District (MD), Harbor Point (CT), Pearl Brewery (TX), St. Josephs Redevelopment (CA), Westlawn Gardens (WI)). In Harbor Point (CT), developers preserved a historic industrial building and repurposed it as loft spaces for art studios.

However, in some cases, like Paseo Verde (CA), Ponce City Market (VA), and The Lofts at Washington University (MO), the newly built green spaces are restricted to residents using private courtyards or customers on rooftops. Open-mown lawns with limited programming or poor access may not provide engaging community spaces. Additionally, it is not clear how these projects addressed the diverse needs of socio-demographically marginalized populations, such as older adults and people with disabilities.

4.2.4. *Local and regional connectivity of green space*

Despite the potential of green spaces to connect to regional open space systems, most sprawl retrofitting projects feature them as isolated areas. As mentioned earlier, some projects, such as the Domain (TX) and the Mosaic District (VA), are internally focused and surrounded by highways or high-speed boulevards, making them primarily accessible by car.

On the other hand, certain projects illustrate how green spaces can enhance local and regional connectivity. These green spaces are integrated into transportation systems, such as multi-way boulevards, transit corridors, and multi-purpose trails. In Atlanta (GA), both Historic Fourth Ward Park and Ponce City Market are located next to the Beltline, a 22-mile-long rails-to-trails project. The Historic Fourth Ward Park (completed in 2011) was the first major investment to spur the Beltline project since the city established Atlanta Beltline Inc. in 2006. In Ponce City Market, a pedestrian bridge connects the site to the Beltline trail. In Old Colony (MA), the master plan emphasizes the site's connectivity to neighboring streets, downtown Boston, and adjacent recreational areas and schools.

Establishing connections beyond the project site takes time and requires long-term planning. In Wyandanch Rising (NY), the city made the Wyandanch Open Space Master Plan, which identified a network of open spaces comprising existing and proposed natural vegetation and water, streets, parks, and plazas. Harbor Point (CT; 21 acres) is another project

Table 4
Key findings from a cross-case synthesis of 18 projects.

Principles	Key Findings	Notable projects
Quantity and quality of urban nature	• Parks and stormwater infrastructure are more common than green roof, plaza, waterbody, and community garden • Some green spaces are isolated and underused	Historic Fourth Ward Park, Meriden Green, Potomac Yard, Promenade of Wayzata
Multi-modal access, safety, and walkability	• Green spaces and vegetation play crucial roles in traffic calming strategies (e.g., vegetated curb extensions, parklets, multi-layered vegetation, and green stormwater management) • Transit-oriented developments feature mixed-use buildings, walkable streets, and various green spaces • Internal focus and auto-dependency persist in some cases	Assembly Row, Historic Fourth Ward Park, Old Colony, Meriden Green, Paseo Verde, Pearl Brewery, Potomac Yard, The Domain (2), The Lofts at Washington University, Uptown District
Inclusive and authentic public spaces and programming	• New, inclusive public spaces and adaptive reuse of existing buildings serve as catalysts • Developers and governments involve community members in programming and designing new public spaces • Some green spaces are restricted to residents or customers	Arts District, Harbor Point, Historic Fourth Ward Park, Mosaic District, Pearl Brewery, St. Josephs Redevelopment, Westlawn Gardens, Wyandanch Rising
Local and regional connectivity of green space	• Green spaces are integrated into transportation systems (e.g., multi-way boulevards, transit corridors, and trails) • Many projects are internally-focused and primarily accessible by car • Establishing connections beyond the project site is a long-term planning issue	Harbor Point, Historic Fourth Ward Park, Old Colony, Meriden Green, Ponce City Market, Wyandanch Rising
Environmental performance and ecological design	• Many projects face challenges related to contaminated sites and inadequate flood and stormwater management • Stormwater management tactics are varied (e.g., infiltration basins, sidewalk rain gardens and bioswales, detention ponds, rainwater reuse, and wetlands) • Ecological design includes planting drought-tolerant and native species, creating green roofs, and using renewable energy sources	Historic Fourth Ward Park, Meriden Green, Paseo Verde, Pearl Brewery, Potomac Yard, Promenade of Wayzata, The Lofts at Washington University, Westlawn Gardens
Initial leadership and investment from the public sector	• The role of municipalities is varied (e.g., purchasing properties, applying regulatory permits, and setting design guidelines) • Some projects showcase strong partnerships among the public sector, developers, and community • Most projects were led by developers or non-profit organizations with governmental support (e.g., grants, tax credits, and administrative support)	Assembly Row, Harbor Point, Old Colony, Meriden Green, Paseo Verde, Potomac Yard, Promenade of Wayzata, The Lofts at Washington University, Uptown District, Westlawn Gardens, Wyandanch Rising

awaiting the realization of a network of public open spaces and waterfront access, as outlined in the original master plan for an 82-acre transit-oriented development.

4.2.5. *Environmental performance and ecological design*

Many sprawl retrofitting projects face significant issues with environmental contamination (Rome, 2001). For example, Meriden Green (CT) and Harbor Point (CT) faced challenges associated with contaminated sites from previous commercial or industrial land uses. In both instances, remediation and redevelopment took place concurrently, enabling the developer to achieve a synergy that reduced the cost of the remediation process.

Flood control is crucial as most suburban sites were previously covered with impervious surfaces and had poorly designed stormwater management infrastructure (Dunham-Jones & Williamson, 2012; Talen, 2012). Techniques employed for stormwater management include infiltration basins, sidewalk rain gardens and bioswales, detention ponds, rainwater reuse, and wetlands, which also serve as habitats. Potomac Yard (VA) and Promenade of Wayzata (MN) are two notable examples that use context-specific techniques for stormwater management, such as active wetland edges, floating wetland islands, and under-building wet ponds.

The incorporation of planting strategies using drought-tolerant plants, as seen in Pearl Brewery (TX), or native plants, as in The Domain (TX), contributes towards ecological design and sustainability. Other sustainable design features found in the projects include green roofs and renewable energy. In Paseo Verde (PA), blue roofs were installed to collect water during storms of up to a 100-year magnitude and then slowly release it afterwards. Renewable energy is essential to environmental performance in some projects, such as Old Colony (MA) and The Lofts at Washington University (MO). In Old Colony (MA), solar panels and renewable energy credits yielded a 68% reduction in energy use between 2009 and 2016 (Better Buildings, n.d.). I could not identify any elements promoting environmental or ecological performance in five of the 18 projects.

4.2.6. *Initial leadership and investment from the public sector*

Leadership and investment from the public sector often play a crucial role in the early stages of many sprawl retrofitting projects (Talen, 2015). The role of municipalities varies but can include property purchases, regulatory permits, and design guidelines. As part of the downtown transformation and flood control efforts, the City of Meriden acquired the entire lot in Meriden Green (CT) and navigated complex regulatory permits to convert the vacant shopping mall site into a park-oriented mixed-use development. In Wyandanch Rising (NY), the city acquired over 70 properties for public improvements, including water and sewer lines, streets, structured parking, health and youth centers, new parks and sports fields, and greenways. In Potomac Yard (VA), city planning efforts led the project from the beginning, including the Urban Design Guideline and the Potomac Yard Design Advisory Committee.

Strong partnerships among the public sector, developers, and the community are evident in some projects, as seen in Assembly Row, Old Colony, Westlawn Gardens, and Wyandanch Rising. In Assembly Row, a citizen's advocacy group—Mystic View Task Force (MVTF)—developed a plan for a walkable mixed-use town center and organized a charrette with designers and residents. Later, with political support from the new mayor, an agreement was made among the City of Somerville, MVTF, and the developer (FRIT) to abandon the original idea of an auto-oriented shopping mall and big-box stores in favor of a walkable, transit-served, waterfront-oriented district.

On the other hand, developers or non-profit organizations led many projects with additional support from the government in the form of grants, tax credits, and administrative assistance. Paseo Verde showcases a partnership between a non-profit community organization, Asociación Puertorriqueños en Marcha (APM) and a developer. APM focused on gaining political support and public subsidies for the project, while the developer structured financing and implemented design and construction.

The sprawl retrofitting projects examined in this study highlight the need for innovative financing mechanisms. Examples include tax credits (e.g., low-income housing tax credits, historic tax credits), Tax Increment Financing (TIF; e.g., Mosaic District and Promenade of Wayzata), brownfield programs (Harbor Point), community development block grants (Old Colony), infrastructure funds, zoning incentives (The Domain), and funding from the Department of Housing and Urban Development (HUD) (Westlawn Gardens and Wyandanch Rising).

5. Discussion

5.1. Summary of findings

This study examined changes in vegetation levels and regreening principles in 18 sprawl retrofitting projects. The findings suggest mixed results concerning regreening success, with vegetation levels not significantly different before and after the project for both project sites and control groups. Five projects showed an increase in total vegetation, while the remaining 13 experienced a decrease. Although not directly addressed in this study, variations in results could be influenced by numerous factors, including the species and age of trees, the size of their canopies, and the preservation of existing trees.

The regreening principles analysis revealed the following insights. First, the quantity and quality of urban nature varied among projects, with no statistical association between vegetation changes and specific green space types. Some projects like Potomac Yard and Promenade of Wayzata are exemplary models, providing diverse green spaces with clear objectives. Second, multi-modal access (e.g., public transit, bike, micro-mobility), safety, and walkability were common goals in projects, with some focusing on transit-oriented development. Green spaces and vegetation are crucial in traffic calming strategies and enhancing walkability. However, due to limited vegetation or pedestrian access, some projects resulted in automobile dependence or reduced safety. Third, engaging community members in the design and programming process ensured inclusive public spaces and programming through which diverse needs were met. However, some projects featured restricted or poorly designed green spaces, limiting their potential as community spaces. Fourth, some projects successfully integrated green spaces with transportation systems, while others featured isolated green spaces or were primarily accessible by car. Fifth, many sprawl retrofitting projects addressed contamination, flood control, and stormwater management issues. Last, the initial leadership and investment from the public sector played a crucial role in the early stages of development. Some projects demonstrated strong partnerships between the public sector, developers, and the community and creative financing strategies.

5.2. Practical implications

The first practical implication for sprawl retrofitting projects is the creation of diverse and context-specific green spaces. This goal requires a keen understanding of local context, community spaces, vegetation, and community needs and preferences, which guides the design of various green spaces such as parks, green roofs, courtyards, and stormwater management elements tailored to different user groups. One effective approach would be to begin the process by creating a gathering place, no matter how small. If designed well, this space can serve as a catalyst for community building and foster a sense of belonging among residents, as seen in the Mosaic District and Wyandanch Rising.

Inclusive citizen participation is essential in this process. International studies (Haaland & van den Bosch, 2015; Jim, 2023) have shown that residents are more likely to support sprawl retrofitting projects when they are involved in the design and planning process, sharing the project's long-term values and goals. Also, in considering changing demographics and marginalized populations, inclusivity and representation should guide community engagement. Through a review of international literature, Byrne and Sipe (2010) advocate for a needs-based strategy that combines auditing existing green spaces with surveying residents' needs as part of a comprehensive assessment.

The second recommendation is prioritizing multi-modal access, walkability, and connectivity within and beyond project sites. This can be achieved by integrating newly built or retrofitted green spaces into existing transportation systems, multi-way boulevards, transit corridors, and multi-purpose trails. Walkability and connectivity should be promoted not only within the project site but also beyond it, to create more sustainable and accessible communities. The 'Finger Plan' of Greater Copenhagen, Denmark, established an exemplary metropolitan-scale green space network. Its distinctive configuration of 'green wedges' and 'green rings' integrates multifunctional green spaces within urban and suburban development corridors (Caspersen & Olafsson, 2010).

The third practical implication is prioritizing environmental performance and ecological design. Acknowledging that many project sites may be contaminated, it is essential to allocate extra time and resources for cleanup, including remediation programs for brownfield development. Brownfield development programs can assist in site remediation, improvement, and providing core infrastructure, as demonstrated in the Harbor Point, CT project. Two international review studies show that green infrastructure, such as parks, rain gardens, bioswales, community gardens, and soil improvement, can improve a suburban site's environmental performance (Haaland & van den Bosch, 2015; Jim, 2013). Moreover, it is crucial to address the maintenance and management of green spaces from the development stage. Incorporating maintenance budget allocations and providing staff training for managing stormwater parks and other green spaces ensures the long-term success and sustainability of these projects.

Finally, effective governance and innovative financing mechanisms can support and facilitate these projects. Effective collaboration among public sector entities, developers, community members, and non-profit organizations is crucial for project success. Non-traditional financing strategies include site assessment funding from the EPA Brownfields program, HUD Brownfield Economic Development Initiatives and Sustainability Community Initiative grants, and constructing a financing plan tailored to the project's context and end-use (Hersh, 2012). Such financing includes low-income housing tax credits, housing subsidy programs, and historic tax credits. Additionally, remediation assistance is available in several U.S. states, which reimburse some brownfield remediation costs. In suburban Stockholm, Sweden, planners and developers established a platform for dialogue and shared responsibility, thereby creating a more efficient and agreeable plan for retrofitting (Khoshkar et al.,2018). By considering these practical implications, stakeholders involved in sprawl retrofitting projects can work towards creating more sustainable, inclusive, and environmentally responsible communities.

5.3. Limitations and suggestions for future research

This study presents a comprehensive analysis of the role of green spaces in sprawl retrofitting projects. However, there are some limitations, and further research is needed to address these gaps. First, the social equity implications of suburban greening in sprawl retrofitting projects remain understudied. Future research should investigate the role of public spaces as both administrative tools for public welfare and sustainability and as marketing ploys or ideological tools that might perpetuate environmental injustice (Mitchell, 2003; Wolch et al., 2014). A critical question to explore is, "Retrofitting suburbs for whom?" Practitioners, including urban planners, landscape architects, and urban foresters, must address this question to ensure equitable outcomes. The potential for environmental gentrification as suburbs transform into greener and more walkable places should be investigated in future studies (Checker, 2011; Curran & Hamilton, 2012; Gould & Lewis, 2016; Loughran, 2022; Rigolon & N é meth, 2018). This research should also examine efforts to avoid such gentrification and its consequences.

Second, this study focused on a limited number of cases to analyze the role of regreening practices in sprawl retrofitting. Future research should explore a broader range of case studies, encompassing different geographies, socioeconomic contexts, and project scales, to enhance the findings' generalizability and develop more comprehensive recommendations. In addition, longitudinal studies that track the long-term effects of sprawl retrofitting projects on social, environmental, and health outcomes would offer valuable insights into the sustainability and equity of such interventions.

The third limitation pertains to the data and measures regarding the quantity and quality of vegetation and green space. Beyond human activities, NDVI values are also subject to climate factors (e.g., precipitation, soil moisture, and temperature) (Cui & Shi, 2010; Wang et al., 2003) and potential contaminations (e.g., atmospheric disturbance, cloud cover, sensor failure) (Li et al., 2021). While the paired t-tests between project and control groups are unaffected by temporal conditions, future research may account for temporal variables more explicitly in before-after comparisons. Recent advancements in NDVI time series analysis may be applied to such tasks, including spatiotemporal combination, multi-source fusion, and machine learning adoption (Li et al., 2021).

6. Conclusions

Densifying sprawled suburban neighborhoods can often lead to a considerable decrease in green spaces, adversely affecting the environment and residents' quality of life. This comparative case study has provided an in-depth exploration of the role of regreening strategies in suburban sprawl retrofitting projects. It has highlighted their potential to foster more sustainable and livable communities. This study finds how regreening principles can contribute to improved walkability, increased green spaces, and enhanced connectivity in suburban environments. These changes offer various benefits, such as reducing automobile dependency, fostering social interaction, and promoting environmental sustainability.

The discussion of the limitations and suggestions for future research underscores the need to consider social equity and environmental gentrification when designing and implementing sprawl retrofitting projects. Given that green spaces and other natural elements significantly shape suburban environments, decision-makers and practitioners must understand how their work can impact the distribution of resources, opportunities, and amenities within communities. Urban planners, urban foresters, landscape architects, and policymakers must collaborate to create suburban environments that promote sustainability and social equity, ensuring that all members of the community enjoy the benefits of retrofitting projects.

Author Statement

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During the preparation of this work, the author(s) used ChatGPT (GPT-4) for checking grammar and spelling. After using this tool/service, the author(s) reviewed and edited the content as needed and take (s) full responsibility for the content of the publication.

Declaration of Competing Interest

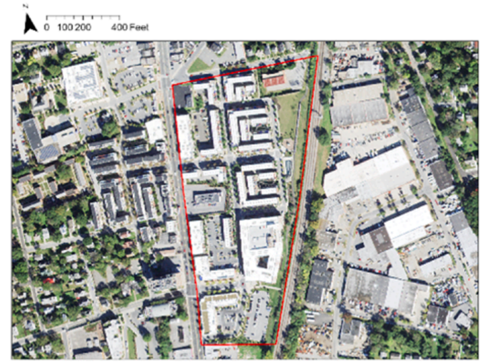
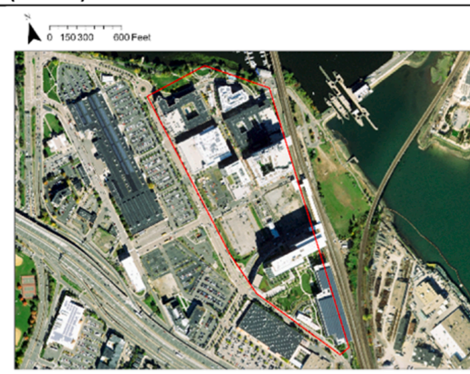
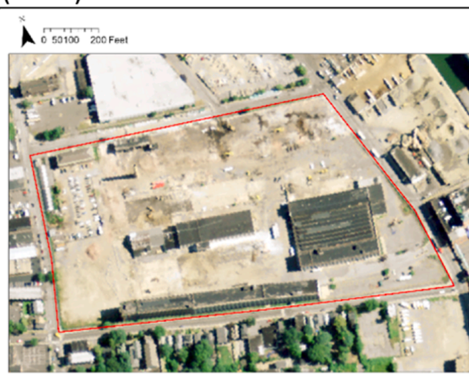
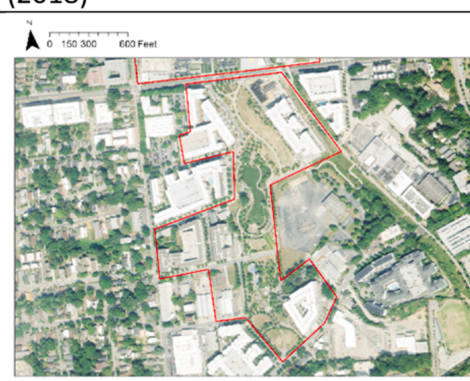
I declare that I have no competing interests to disclose. I have no financial or personal relationships with other people or organizations that could bias our work.

Appendix

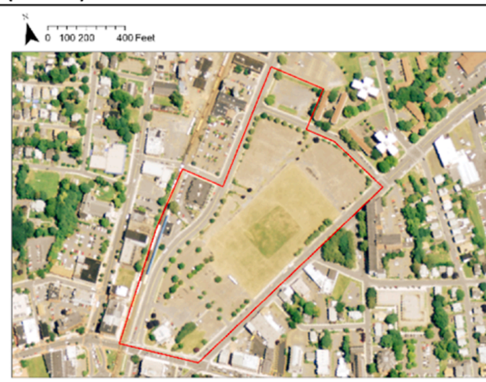
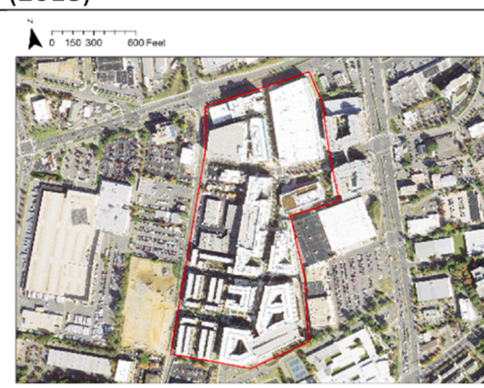
Appendix Table 1
Socio-demographic data of sprawl retrofitting projects (Data: 2000 Census).

Project name	total population	% children (18-)	% older adults (65 +)	% Non-Hispanic White	% renters	Gross rent ($)	Housing value ($)	Median houshold income ($)	average number of vehicles	% Bachelor's degree
Arts District Hyattsville, MD	1940	24.9	7.6	46.8	33.1	1033	189,398	77,563	1.7	28.0
Assembly Row, MA	1162	19.4	13.3	64.7	58.5	1278	238,615	63,096	1.2	12.0
Harbor Point, CT	3122	27.0	4.2	17.4	84.0	1284	254,157	56,034	1.1	7.6
Historic Fourth Ward Park, GA	2506	22.0	11.0	12.4	77.5	634	127,423	24,888	0.8	16.5
Old Colony, MA	1011	38.9	7.5	34.2	99.3	282	NA	11,556	0.3	7.9
Meriden Green, CT	1009	41.7	6.0	22.7	95.6	639	110,130	27,533	0.8	9.5
Mosaic District, VA	1187	25.3	4.0	25.2	67.4	1373	403,810	51,089	1.2	21.8
Paseo Verde, PA	598	48.5	2.5	1.5	98.4	266	NA	11,180	0.1	0.0
Pearl Brewery, TX	509	32.2	7.9	15.7	68.1	452	41,409	22,911	1.0	8.9
Ponce City Market	1743	12.4	7.5	60.4	65.9	1116	468,273	62,442	1.2	54.2
Potomac Yard, VA	1654	4.8	2.7	88.0	39.7	1248	390,741	106,296	1.5	80.3
Promenade of Wayzata, MN	865	13.3	25.0	93.3	50.1	1026	424,808	60,668	1.5	38.6
St. Josephs Redevelopment, CA	1688	36.1	3.1	7.9	69.9	871	186,193	52,905	1.4	11.2
The Commons, CO	1842	23.0	6.9	29.0	73.3	755	343,209	45,258	1.1	22.6
The Domain (2), TX	2581	8.9	1.1	65.1	98.0	1308	NA	73,053	1.5	49.9
The Lofts at Washington University, MO	2123	20.1	6.3	61.2	62.3	744	399,025	58,706	1.5	60.6
Uptown District, OH	2639	11.4	13.6	49.5	80.5	768	101,326	26,881	0.9	34.3
Westlawn Gardens, WI	950	46.9	4.8	8.8	86.4	392	63,435	25,468	0.8	0.0
Wyandanch Rising, NY	621	33.5	5.3	19.6	19.2	2057	241,405	75,256	1.8	10.0
Total (average)	**1566**	**25.8**	**7.4**	**38.1**	**69.9**	**922.4**	**248,960**	**49,094**	**1.1**	**24.9**

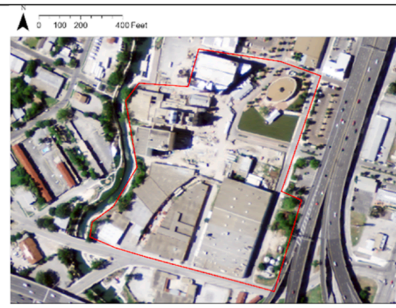
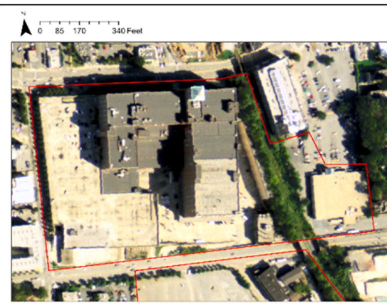
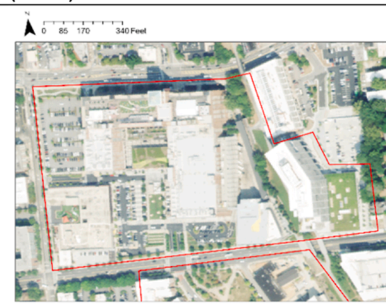
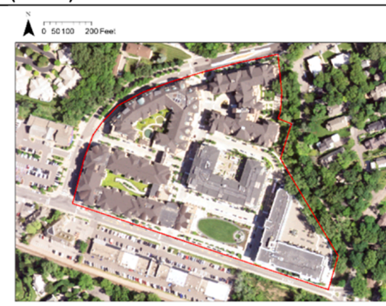
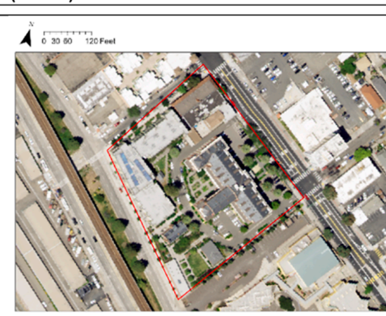
.

Project Name	Before (year)	After (year)
Arts District Hyattsville, MD	 (2009)	 (2018)
Assembly Row, MA	 (2010)	 (2018)
Harbor Point, CT	 (2008)	 (2018)
Historic Fourth Ward Park, GA	 (2009)	 (2019)

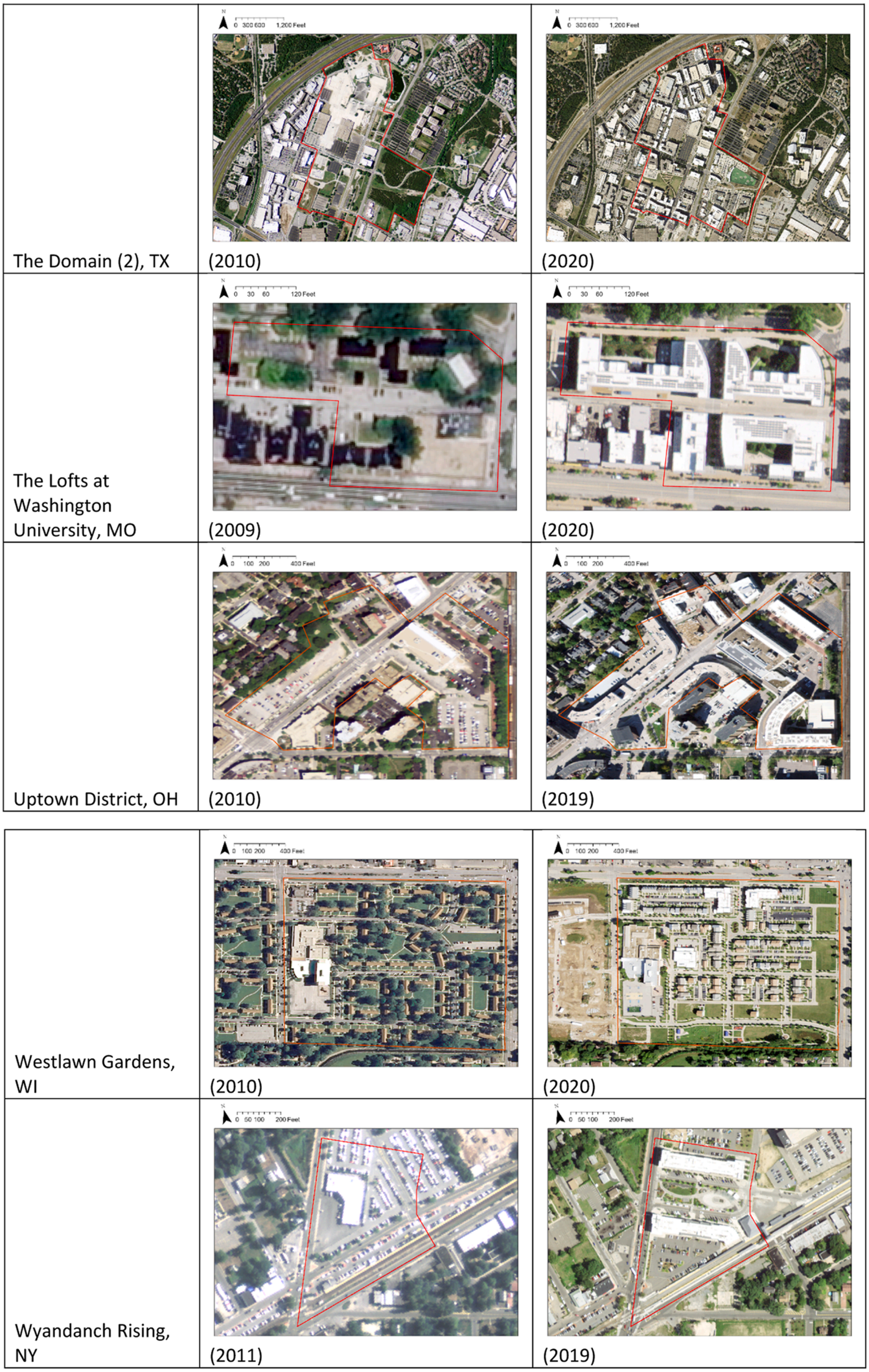
Appendix Figure 1. Satellite images before and after the 18 sprawl retrofitting projects.

Old Colony, MA	 (2010)	 (2018)
Meriden Green, CT	 (2008)	 (2018)
Mosaic District, VA	 (2008)	 (2018)
Paseo Verde, PA	 (2010)	 (2019)

Appendix Figure 1. (*continued*).

Pearl Brewery, TX	 (2010)	 (2020)
Ponce City Market, GA	 (2009)	 (2019)
Potomac Yard, VA	 (2008)	 (2018)
Promenade of Wayzata, MN	 (2010)	 (2019)
St. Josephs Redevelopment, CA	 (2009)	 (2020)

Appendix Figure 1. (*continued*).



Appendix Figure 1. (*continued*).

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