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Application of GIS to Prioritize Brownfield Sites for Green Building Construction Based on LEED Criteria

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Abstract:

While there are many initiatives to create incentives for investors and developers to invest in and redevelop brownfield sites, efficient prioritization of brownfields by taking environmental, economic, and social constraints into account remains a challenge. The goal of this study was to introduce a method to screen numerous brownfields over large geographic areas by using Geographic Information Systems (GIS), and to assess and prioritize such sites for green building suitability based on Leadership in Energy and Environmental Design (LEED). A case study was completed for the greater Bridgeport region, in the state of Connecticut, U.S. With 279 brownfield sites, the city has one of the highest number of brownfields in the state. Variables chosen to determine suitability and prioritization were based on LEED version 4 for New Construction and Major Renovation. Chosen variables input into GIS make up 13 points on the LEED checklist. Over 6% of the brownfield sites received 10 LEED points, which has the potential to shift up the certification level. On the other hand, 15% of sites received 5 points, which was the lowest score found in the study. Nearly half of brownfield sites received 8 points. The developed method proved to be efficient to analyze large numbers of brownfields, making it a viable option for governments and developers alike to make informed decisions for brownfield redevelopment. The study

described herein demonstrates that GIS could be used to streamline prioritization of brownfield sites, while at the same time guiding site selection for green buildings.

Keywords: Geographic Information System; Leadership in Energy and Environmental Design; Green building siting; Urban redevelopment; Smart growth; Spatial analysis

Introduction:

On a global scale, human populations have been growing at an exponential rate in the past decades (Census 2014). A recent report by the United Nations estimates that 54% of the world's population lived in urban centers in 2014, and that ratio is expected to increase to 66% by 2050 (UN 2014). Rising human population combined with a migratory movement towards urban centers create immense pressure to develop adequate infrastructure in urban centers across the globe. With the amount of available land for development, and other environmental, economic, and social constraints for development, it is becoming more important that planning become more stringent and focused on sustainability.

Rather than developing new land, the focus could be shifted towards redeveloping previously developed properties or areas. Such a shift would save remaining open spaces at or around urban settlements, as well as strengthen communities and neighborhoods already in place. Such priorities are among the considerations included in what is being referred to as Smart Growth (APA 2012).

Brownfields are properties that are or are perceived to be contaminated by hazardous substances, pollutants, or contaminants. Such sites may be abandoned, closed, or underused industrial or commercial facilities. The U.S. Environmental Protection Agency (EPA) estimates that there are more than 450,000 brownfield sites in the U.S. These sites provide opportunities for reinvestment and redevelopment that protects or improves the environment, reduces blight in communities, uses existing infrastructure, and promotes smart growth. However, redevelopment of these sites may require additional time and monetary commitments compared to a conventional greenfield development (EPA 2015a; Brownfield Action 2014).

The EPA has recently come up with many initiatives for investors to redevelop brownfields such as tax breaks and grants. However, to prioritize brownfield sites among the many different brownfield sites available for redevelopment in a region or neighborhood remains a challenge. There are economic, environmental, and social factors that come into consideration when choosing a site to redevelop which makes the selection and prioritization process cumbersome. One of the challenges is simply how to quantify the value of redeveloping one brownfield site over another. Since the Leadership in Energy and Environmental Design (LEED) green building rating system also considers these same economic, environmental, and social factors, the LEED credit criteria provide a ready-made quantitative scale that could assist to prioritize brownfields.

Geographic Information Systems (GIS) allow one to logically select from and quantify relationships between multiple geographic datasets. Since some of the LEED credit criteria are based on site location relative to its urban surroundings, GIS could be used to assist with quantification of brownfield development if geographic data layers for brownfields and their urban surroundings were available. This GIS data analysis could assist investors and governments with screening for suitable sites quickly and cost effectively.

The goal of this study was to introduce a method to screen numerous brownfields over large geographic areas by using GIS and by using the LEED green building rating system to quantify the potential value of redeveloping each brownfield site relative to the priorities of smart growth and green building construction. The developed method has been applied to the city of Bridgeport, CT, and results reported herein to serve as a case study.

Background:

Brownfield Redevelopment

The potential benefits of cleaning up and reinvesting in brownfields are significant, as they could increase the local tax base, protect public health and natural resources, facilitate job growth, take development pressures off from undeveloped or greenfields by stemming urban sprawl, while at the same time utilizing existing infrastructure and hence avoiding costly infrastructure expansion and upkeep (Attoh-Okine 2001; Thomas 2002a). A study by Lange et al. (2004a) was aimed at quantifying the success factors for redeveloped brownfield sites. Evaluation of a survey of 75 redeveloped brownfield sites statistically concluded that successful redevelopment projects incorporated more green space into the development plan, were more likely to take advantage of existing infrastructure, were more likely to have financial incentives available to the developer, were better integrated into the neighborhood, had a positive impact on local businesses, and had considered the future use of the property to establish environmental cleanup levels. Frantal et al. (2013) arrive at a similar conclusion and identify local business activities, proximity to city centers and regional road network, and the quality of the existing infrastructure as factors contributing to the success of a redeveloped brownfield site. Another study indicates that the success of a brownfield redevelopment project carried out by developers depends on an interdisciplinary strategy that includes time to occupancy, community support, proposed land use, and number of jobs to be created, rather than a limited focus on environmental concerns alone (Lange 2004b). Walker et al. (2010) discuss the importance of a healthy relationship between developers and the community via committees and advisory boards, in addition to the financial incentives that may be present. Based on the outcomes of these studies, facilitating green building construction on brownfields should contribute to the success of the project as green buildings are known to decrease vacancy rates or turnovers, incorporate more green space in the development, and contribute positively to the local economy and community connectivity (USGBC 2015). Therefore, tying brownfield redevelopment with green building construction would be advantageous for all stakeholders.

Valuable both for local governments, developers, and existing property owners alike, De Sousa et al. (2009) demonstrate that brownfield redevelopment has a positive economic impact by raising surrounding property values by 2.7% to 11.4%. The reported values are in accordance with a 5.1%-12.8% increase in residential property values reported by the EPA Brownfields Program (EPA 2015b). The EPA Brownfields Program also identified reduced vehicle miles traveled, reduced stormwater runoff, as well as reduced crime in redeveloped brownfields, all in accordance with urban smart growth goals and policies (EPA 2015b).

Redeveloped brownfield sites were also found to have other indirect environmental benefits related to a decrease in transportation energy and intensity. Relative to a greenfield development, redeveloped brownfield sites were found to be closer to city centers, had higher public transportation use for commuting, and lower energy use and greenhouse gas emissions for commuting (Nagengast 2011). On average, brownfield redevelopment for residential construction purposes were found to reduce vehicle travel by 52% compared to conventional greenfield development (Mashayekh 2012). Reductions in vehicle travel also translate into economic savings for occupants, where a LEED certified average household was estimated to save between $3,500-$4,000 following brownfield redevelopment (Mashayekh 2015).

Smart Growth

Smart Growth is an approach to have environmentally, economically, and socially sustainable communities (APA 2012). As human populations continue to grow at an increased rate on a global scale, it has become ever more important to recognize and implement smart growth policies. Smart growth accumulates planned economic and community development that is meant to curb urban sprawl as well as worsening environmental conditions (Handy 2005; Williams 2007). The American Planning Association's Policy Guide on Smart Growth lists many benefits that were categorized under the following categories: economic; inclusive planning; transportation and land development; fiscal efficiency; social equity and community building; farmland and land conservation; and healthy communities (APA 2012). Smart growth principles aim to reduce the adverse impact of new development, raise residential densities, provide mixed use development and pedestrian-oriented layouts to minimize dependence on cars in general. Smart Growth was developed as a reaction to the continued growth of suburban sprawl and associated undesirable features that span environmental, economic, as well as social problems (Downs 2005).

One of the first uses of the term 'smart growth' occurred in 1997 in the Neighborhood Conservation and Smart Growth Act of the state of Maryland. The legislation had five main components to limit sprawl, one of them being implementing 'The Brownfields Redevelopment Programme' (Daniels 2001). Therefore, smart growth movement has identified the importance of brownfield redevelopment since its inception. Since 1995, the U.S. Environmental Protection Agency (EPA) has developed and managed a similarly named program with a national focus, *EPA's Brownfields Program* (O'Reilly and Brink 2006). As of September 2015, the program reported a total of 24,511 properties assessed and 228 km^2 (56,442 acres) made ready for anticipated reuse funded through grants and a revolving loan fund. The economic analysis of the program also indicate positive returns with $24.2 leveraged for every dollar spent by the program (EPA, 2015b).

Daniels (2001) explored Smart Growth options applicable in the U.S. by evaluating population growth and urbanization and suburbanization trends. The study revealed that reuse of older buildings increased attraction as well as revenue in the area, although initial costs may have been higher. Further building on work done in this field, Greenberg et al. (2001) went the more specific route of looking only at brownfield redevelopment. Associated environmental benefits, moral imperative, as well as government special interests and the economy were investigated as part of the study and the study concluded that brownfield redevelopment was beneficial for smart growth options in the U.S.

In order for a community to develop with smart growth policies, it is important to recognize the opportunities enabled by green buildings. Green buildings are included in smart growth policies as they encourage smart planning and efficient use of resources, while at the same time contributing to healthy communities.

Green Buildings and the LEED Rating System

Green buildings are structures that aim to reduce environmental impacts, and are resource efficient throughout the life cycle of the building; they help save energy, water, resources, and money over the life cycle of the building (EPA 2015c). In the U.S., the most widely accepted organizational body related to green buildings is the United States Green Building Council (USGBC), with its Leadership in Energy and Environmental Design (LEED) green building certification program (USGBC 2015).While there are other green building rating systems internationally, LEED has dominated the U.S. market for green buildings, and hence was analyzed in this study.

LEED certification is based on a checklist that consists of a scalar point system. A point system has become commonplace for which green buildings are designed and evaluated across different rating systems internationally (Von Paumgartten 2003). For each green feature a building incorporates, it receives points that are predetermined and established on the LEED checklist. If points earned exceed a certain threshold, a building receives LEED certification.

The LEED rating system does not consist of one checklist, but multiple checklists are available depending on the project type. The 5 broad categories in which projects are divided are: Building Design and Construction; Interior Design and Construction; Building Operations and Maintenance; Neighborhood Development; Homes. However, there are further classifications under each of these categories. For example, the Building Design and Construction category provides different checklists for New

Construction, Core and Shell, Schools, Retail, Hospitality, Data Centers, Warehouses and Distribution Centers, and Healthcare facilities. The divergence of these checklists was a necessity as the design and impact of each of these facilities are distinctly different. While there may be common credits across checklists, the essence, mechanics, and weighing of each checklist is quite different. Credits under the LEED version 4 for New Construction and Major Renovation checklist, under Building Design and Construction category were used in this study. The Neighborhood Development category was not preferred due to the distribution and parcel size of the brownfields analyzed in this study.

Credits are grouped into categories on the LEED checklist. For New Construction and Major Renovation, these categories are: Location and Transportation; Sustainable Sites; Water Efficiency; Energy and Atmosphere; Materials and Resources; Indoor Environmental Quality; Innovation; and Regional Priority. Points are not distributed equally across these categories however, as each category has a different number of credits or prerequisites to be satisfied (USGBC 2015).

There are four levels of LEED certification: certified, silver, gold, and platinum. Project levels are determined by how many points are earned on the checklist. Based on LEED v4, the most current version of the rating system, a building would be approved as a certified green building by earning 40 to 49 points, with higher points leading to higher levels of certification: silver certification is approved by earning 50-59 points; gold certification is approved by earning 60-79 points; and platinum certification is approved by earning 80 or more points. The total number of points that can be earned is 100, with an additional 10 bonus points granted for Regional Priority, and Innovation (USGBC 2015).

Categories and evaluation criteria within the LEED checklist have been chosen as a basis to determine the variables to prioritize brownfield sites in this study. This study covers 13 points from the LEED checklist under the Location and Transportation category, out of a total of 16 points for that category. The number of credits covered is significant as the category is the only one that addresses spatial factors for the performance of a green building, and the awarding of the certification. The remaining three credits under this category are Bicycle Facilities, Reduced Parking Footprint, and Green Vehicles, which would be project specific and therefore could not be analyzed as part of the study.

Geographic Information Systems

Geographic Information Systems (GIS) is used in many ways to filter and analyze multiple types of spatial data. This tool can be used and applied to many datasets and areas across the globe and may also be used to measure and analyze environmental factors in communities. Given the wide range of potential applications within the tool, GIS can also be applied to prioritize brownfield sites to be invested in by governments and/or private companies.

Early studies by Thomas (2002a; 2002b) were aimed at using a multi-attribute site prioritization tool as well as GIS as a decision support tool for brownfields. However, proposed variables for the analysis were too coarse to differentiate between brownfield sites within a city (e.g. regional infrastructure and labor resources, financial incentives), while at the same time introducing subjectivity (e.g. local community acceptance). Also, a connection to green buildings was lacking altogether from the study. However, the study clearly identified the need for a method to differentiate among and prioritize brownfield sites for redevelopment. More recently, Nogues et al. (2015) developed a GIS-based multi-criteria decision analysis to prioritize brownfield redevelopment in a depressed post-industrial district and concluded that the primary factor determining brownfield redevelopment was availability of urban facilities and proximity to urbanized areas. Another study by Wang et al. (2015) was also aimed at developing a multi-attribute framework to support land use planning by using GIS, however, the study did not focus on brownfield redevelopment or green buildings.

Studies by Chrysochoou et al. (2011; 2012) proposed an indexing scheme to screen large areas to prioritize brownfield redevelopment where multiple variables were chosen based on three different criteria: socioeconomic, smart growth, and environmental. Variables chosen for the analysis included property values, unemployment, soil permeability, proximity to parks and open spaces, among others. These indices were ranked by users based on a scale from 0 to 2 for each brownfield site analyzed, potentially introducing subjectivity to results. Scores were then added and input into GIS to prioritize brownfield redevelopment in a region. Even though the study aims to prioritize brownfield redevelopment, the method used is distinctly different than the one used in this study, where the goal was to assess and prioritize brownfield sites for green building suitability based on LEED rating system. The connection between used variables and green buildings remains weak and no direct connection was attempted in the studies by Chrysochoou et al. (2011; 2012). Furthermore, the ranking system and selected indices were manually and arbitrarily formulated by the researchers.

In this study, the criteria used in the analysis were based on the LEED rating system and were ranked based on the point scale used in the LEED certification checklist. In addition to aiding optimal site selection for green building construction, another reason as to why the credits from the LEED rating system were used was to provide an objective set of criteria to be analyzed, with clearly defined thresholds for point assignments. The methodology employed here can be applied to other locations by preparing and substituting in geographic data layers specific to each location.

The Site Selected for GIS Methodology Testing

Bridgeport is a coastal city in the state of Connecticut, and with 237 brownfield sites has one of the highest concentration of EPA registered brownfield sites in the state. The city has an industrial heritage and is known for its old industrial factories, while currently is taking steps to reverse the impacts of its industrial past. Bridgeport is also currently the highest populated city in the state with a population of approximately 147,000 people (Census 2013). Due to its comparatively high population combined with an abundance of brownfield sites, there are efforts by the local government and developers to redevelop brownfield sites. Bridgeport was chosen as the city to apply the developed model in this study for these reasons.

Methods:

The GIS tool used in the study was ArcMap v10.1 produced by Environmental Systems Research Institute (ESRI 2012). The criteria for specific LEED credits were taken from LEED V4 for Building Design and Construction (USGBC 2015). The geographic data layers employed were obtained from the municipality of Bridgeport, from public domain sources, and from one private source (see Table 1). The specific data layers, data preparation actions, and GIS tools that were employed was distinct for each specific LEED credit included in this study. The details are provided below organized by the LEED criteria.

Table 1. Data layers employed for GIS analyses and their sources.

Data Layer	**Description and Source**
Bridgeport Brownfields	A polygon feature dataset provided by the city of Bridgeport. Only the boundaries of brownfield areas were included – no data regarding the history or contamination type were included.
Transit Stops	A point feature dataset provided by the city of Bridgeport representing the bus stops and commuter transit stations within the city limits. Attributes identified each stop and the travel direction of each stop.
Public Parks	A polygon feature dataset provided by the city of Bridgeport.
2010 US Census Blocks	A polygon feature dataset and Summary File 1 (SF1) demographics data table were downloaded from the University of Connecticut "Magic" Map and GIS data library (UConn Magic 2016).
Connecticut Roads	A Connecticut subset of the 2000 Census TIGER/Line address-ranged street

	network dataset from UConn Magic was used to develop the GIS methods (UConn Magic 2016). Re-evaluation of GIS results using a 2010 dataset from the same source resulted in identical results.
Connecticut Town Boundaries	A polygon feature dataset downloaded from UConn Magic (UConn Magic 2016).
2012 US Business Database	A CSV file business list database with Standard Industrial Classification (SIC) coding purchased from BusinessesDatabase.com (BusinessesDatabase 2016)

Data Extents: To improve data processing performance those datasets covering the entire state of Connecticut were clipped or filtered down to the Bridgeport region. Since Bridgeport is surrounded by other urbanized areas and since some of Bridgeport's brownfields are near the town boundary, the datasets were clipped to an area including the next town adjacent to each of the Bridgeport boundaries.

LEED Credits

All of the LEED credits included in this case study were taken from the Location and Transportation section of LEED V4. Some opportunities to include additional LEED credits including some from the Sustainable Sites section are discussed below as well. LEED V4 assigns different amounts of LEED points to the various credit types. Some of the LEED credits have single criteria – awarding all of the related points if these criteria are met. Other LEED credits have quantifiable criteria and award a different amount of points for specific ranges of these quantities. Many of the LEED credits have differing criteria and even slightly differing point values depending upon classes of development such as general New Construction, Core and Shell, Healthcare facilities and Schools. Since construction type cannot be generalized in advance of a particular development project, this case study was conducted using only the general New Construction criteria and points. While the study can be extended to other categories, it must be noted that the specific credits and points vary across different checklists.

Credit: Sensitive Land Protection. LEED Points: 1

Description: Locate the development and footprint on land that has been previously developed or is not a designated prime farmland, floodplain, habitat for endangered or threatened species, or is at a certain distance away from water bodies or wetlands.

Application Notes: All brownfields qualify for this credit.

Credit: High Priority Site. LEED Points: 2

Description: A brownfield site requiring remediation qualifies for high priority site points.

Application Notes: All brownfields qualify for this credit.

Credit: Surrounding Density. LEED Points: 2-3

Description: Surrounding Density points are awarded by the average residential, nonresidential or combined density within 400 meters (¼ mile) of the project area.

Application Notes: The LEED criteria for nonresidential density requires data on the floor area of nearby buildings. Such data were not available for Bridgeport. However, the US Census includes a count of dwelling units (DU) which is directly useable for calculating residential density. LEED V4 awards 2 points for at least 17.5 DU per hectare and 3 points for 30 or more DU/hectare.

Data Preparation: An additional attribute column was created for the Census Block layer and residential density in dwelling units per 10,000 m^2 was calculated for each census block from existing attributes.

GIS Methods: After creating a 400 meter buffer around the Bridgeport Brownfields a spatial join with the Census Block layer was used to identify the census blocks contained in or intersecting the brownfield buffers and to calculate the average residential density (ARD) for these census blocks. An additional attribute column was created to then contain the LEED points warranted by values of ARD.

Credit: Diverse Uses LEED Points: 1-2

Description: Diverse Uses points are awarded based on proximity from the proposed entrance of the new construction, to publicly available diverse use facilities and amenities. Table 2 shows the five categories of diverse use defined by LEED V4 and the use types assigned to each category. The award of Diverse Uses points is based upon how many examples of these use types are within 800 meter (1/2 mile) walking distance of the proposed construction. No more than 2 examples of each use type can be counted and at least 3 of the categories must be represented. One (1) point is awarded if the resulting count of Diverse Uses examples is 4 to 7 and 2 points are awarded for 8 or more.

Application Notes: The business database employed lists both private businesses and public and government institutions. Table 2 shows how SIC coding was used to associate specific businesses with the LEED use types. The limits encountered for this system of assigning use types based upon SIC coding are as follows:

- One SIC code for "Grocery Stores" contains businesses corresponding to 3 different LEED use types. Assignment of businesses within this group to LEED use types was performed manually.
- No clearly corresponding SIC code was found for the "Community or Recreation Center" LEED use and therefore no examples of this use type were assigned to any of the Bridgeport brownfields.
- Public Parks are not represented in the business database. A separate Public Parks data layer was employed to associate this LEED use type with the brownfields in this study.
- Both use types under the "Community Anchor" LEED use category require additional information that is not generally part of a business listing. Accordingly, no examples of either of the use types in this category were associated with any of the brownfields in this study.

Data Preparation: The business database was filtered to produce a subset of businesses located only in Bridgeport and the surrounding towns and this subset was geocoded into ArcGIS using the Connecticut Roads as reference data (BusinessesDatabase 2016; ESRI 2012). Attribute columns were created for each of the LEED use types and populated with a binary flag (0,1) using attribute queries for each group of SIC codes (see Table 2). Businesses which were not flagged for any of the

LEED use types were then deleted. A number of duplicate records (generally variations in the spelling of business names) were manually identified and deleted and government offices located at the same address were also treated as duplicates.

GIS Methods: After creating a 800 meter buffer around the Bridgeport Brownfields a spatial join with the LEED Businesses layer was performed using the Sum statistic for numeric attributes. This produced a count of each use type which fell within the buffer. All use type counts greater than 2 were re-assigned a value of 2 using a Python conditional assignment command within the ArcGIS Field Calculator. Another spatial join between the 800 meter buffer and the Public Parks data layer produced a proximity count for the public parks LEED use type. Additional attribute columns were created and populated for the total proximity count for each LEED category and the total Diverse Uses count for each brownfield. For the Bridgeport example every brownfield qualified for 2 Diverse Uses points.

Credit: Access to Quality Transit LEED Points: 1-5

Description: Access to Quality Transit points are awarded based upon the availability of bus, streetcar, or rideshare stops within 400 meters (¼ mile) walking distance or commuter transit (light or heavy rail, commuter rail or ferry) stations within a 800 meter (½ mile) walking distance. Points are assigned based on the number of daily trips offered on these transit routes.

Application Notes: Only transit trips in one direction are counted and only one distinct transit route is counted for each construction site. However a transit stop serving more than one transit route is counted as representing the total number of transit trips offered by those transit routes. While the LEED criteria require that the number of transit trips on the weekend be a certain minimum proportion of the weekday trips, all Bridgeport transit routes were found to meet this criteria. The LEED points awarded are 1, 3, or 5 if the number of transit trips available are at least 72, 144, or 360, respectively.

Data Preparation: Attribute columns were created for each distinct bus route and commuter transit route served by the location points in the Transit Stops layer. Duplicate stops serving transit trips on the same route traveling in opposite directions were manually identified and removed. While the stops serving each individual transit route were selected the corresponding rows of the attribute column created for that route were populated with the number of daily trips offered on that route. All of the transit stations serving commuter rail and ferry stations were selected and exported as a separate data layer since the LEED distance criteria for these transit types is distinct.

GIS Methods: The 400 meter buffer for the Bridgeport Brownfields layer previously created was spatially joined with the Bus Transit layer using the Maximum statistic for numeric attributes. This resulted in the number of trips associates with each bus route stopping within each buffer being counted only once. The 800 meter brownfields buffer was then joined in the same manner with the Commuter Stations layer. A table join between the two spatial joins then allowed the total number of transit trips available to each brownfield to be calculated into an additional attribute column. The brownfields were then sorted by this Total Trips column and assigned the appropriate number of LEED points.

Table 2. LEED use categories and use types and their corresponding SIC codes. A SIC code entry of "none" indicates that no matching SIC classification/code could be found or the use type is not generally listed in a business listing. See text for application notes.

Category/Type	**SIC Codes**
Food Retail	
Supermarket	5411
Grocery with produce section	5411
Community-Serving Retail	
Convenience store	5411
Farmers market	5431
Hardware store	5211, 5231, 5251, 5261
Pharmacy	5912
Other retail	5271, 5311, 5331, 5399, 5421, 5441, 5451, 5461, 5499, 5511, 5521, 5531, 5541, 5551, 5561, 5571, 5599, 5611, 5621, 5632, 5641, 5651, 5661, 5699, 5712, 5713, 5714, 5719, 5722, 5731, 5734, 5735, 5736, 5921, 5932, 5941, 5942, 5943, 5944, 5945, 5946, 5947, 5948, 5949, 5992, 5993, 5994, 5995, 5999
Services	
Bank	6011, 6019, 6021, 6022, 6029, 6035, 6036, 6061, 6062, 6081, 6082
Family entertainment venue	7832, 7833, 7933, 7993, 7996
Gym, health club, exercise studio	7991, 7997, 7999
Hair care	7231, 7241
Laundry, dry cleaner	7211, 7212, 7215, 7216
Restaurant, café, diner	5812
Civic and Community Facilities	
Adult or senior care (licensed)	8051, 8361
Child care (licensed)	8351
Community or recreation center	none
Cultural arts facility	8412, 8422
Education facility	8211, 8221, 8222, 8243, 8244, 8249, 8299, 8331
Government office that serves public on-site	9111, 9121, 9131, 9199, 9211, 9311, 9411, 9431, 9441, 9451, 9511, 9512, 9531, 9532, 9611, 9621, 9631, 9641, 9651
Medical clinic or office that treats patients	8011, 8021, 8031, 8041, 8042, 8043, 8049, 8052, 8059, 8062, 8063, 8069, 8092, 8093, 8099
Place of worship	8661
Police or fire station	9221, 9224, 9229
Post office	4311
Public library	8231
Public park	none
Social services center	8322, 8399
Community Anchor	
Commercial Office	none
Multi-Unit Housing	none

Results & Discussion:

Results of the study indicate that about 6%, or 14 out of 237 brownfield parcels in Bridgeport, Connecticut could potentially receive 10 points out of a total of 13 points considered on the LEED checklist based on spatial factors alone. The potential 10 points would be significant if a building were to seek LEED certification, as depending on overall points earned, these 10 points could shift the level of certification by a category (e.g. from certified to silver, or from silver to gold), thus underscoring the suitability of identified sites for green building construction. Only one parcel was identified that could potentially receive 11 points. The parcel was located in an area of high surrounding density and had access to quality public transportation, but was not particularly special in other ways. No parcels were identified that could receive 12, or the full 13 points analyzed in the study.

Around 15% of the brownfield parcels received 5 points. These points were earned by receiving the full 1, 2, and 2 points for Sensitive Land Protection, High Priority Site, and Surrounding Density credits, respectively. The first two of these can be expected to apply to all brownfield sites, whereas Surrounding Density credits were received due to Bridgeport being a densely populated and urbanized city.

Nearly half of all brownfields analyzed received a LEED score of 8, which was also the highest frequency of number of credits earned. Figure 1 presents the distribution of potential LEED points earned by brownfield sites analyzed. Cumulative points for each of the 237 brownfield sites analyzed are presented spatially in Figure 2.

Beyond total points, analysis of the point distribution yielded some interesting results. While Bridgeport may be considered to be a dense urban environment, only 3 out of 237 parcels received the full 3 points for Surrounding Density credit, with another 34 receiving 2 points, which indicates the vast majority of parcels did not benefit from this credit. Similarly, while Bridgeport has an established public transport system with many bus routes active during the day in addition to a commuter ferry and commuter rail stations, only 9 parcels qualified for the full 5 points under the Access to Quality Transit credit. These results indicate that such credits may not be easily fulfilled even in a densely urbanized city and a thorough analysis regarding site selection for green building construction is important.

It needs to be pointed out that GIS screening such as that presented here needs to be treated as an estimate of the potential to obtain the relevant LEED credit points. Some aspects of the GIS analysis are not as accurate as a detailed evaluation of a specific site. For example, the GIS quantification of Surrounding Density uses the residential density of census blocks that intersect the buffer boundary (line of constant distance from the outer brownfield boundary) at the required proximity distance and may not accurately represent the actual dwelling density of only the region completely inside the required proximity distance. Also, the criteria language of many of the LEED credits specifies "walking distance from the entrance of the proposed construction" while what the GIS analysis produces would be characterized as "straight line distance from all boundaries of the site to be developed". A good example of the potential for the GIS analysis to, at times, miss the intent of the LEED criteria can be seen in the map of LEED point potential (Figure 2). One brownfield site having one of the highest LEED point potential sites is on the east side of a river as it opens out into the Bridgeport harbor. This site has benefitted from points for proximity to transit stops/stations that are on the west side of this river, which defies the intent of the Quality Transit credit that the transit stops being counted are within *walking* distance. This does not imply that the GIS screening process for this type of distance criteria is inherently incorrect, it just means that it needs to be taken as a first pass estimate. The actual LEED points achievable for a specific site would have to take into account where the walkable routes around the site are, and could end up depending partially on where the entrance to the construction was positioned. In that respect, LEED point potential could even be a factor in planning the layout and orientation of the construction entrance. Note that, if the GIS installation being used has the optional (at additional cost) Network Analyst ArcGIS extension and the GIS practitioner is trained in its use, the "walking distance" criteria could potentially be employed as part of the initial GIS screening process, or brought into play when final LEED point potential is being evaluated for specific target sites.

It is worthwhile to note that additional LEED credits could potentially be considered while performing GIS based screening based upon data availability and how important green building is to the investor/developer. One additional Location and Transportation LEED credit that could be evaluated by GIS is the Bicycle Facilities credit. This credit could be included in the GIS analysis if the region being evaluated has a network of bicycle routes and these routes are available as a GIS data layer. Obtaining this credit requires a commitment to provide for bicycle storage as well, but the potential to obtain this credit could be evaluated with GIS.

In addition, the potential exists to use GIS to assist in evaluating the potential to obtain two credits in the Sustainable Sites section of LEED V4. Since brownfields generally contain no original greenfields the LEED criteria for preserving greenfields does not apply. However, if the investor/developer is willing to administer habitat restoration for 30% of the brownfield site they can qualify for both the Protect or Restore Habitat and the Open Space LEED credits, which when combined would provide another 3 potential LEED points. The role of GIS here would be, given the construction footprint already under consideration by the developer, to quickly show on a map which brownfield are large enough to contain the planned construction footprint and have at least 30% of their total area remaining. This GIS analysis could easily be combined with the LEED credit potential analysis illustrated above.

From a local government perspective, it is in their and their residents best interest to locate and develop sites that provide the maximum benefits. Both smart growth principles as well as the green building rating system encompass social and environmental benefits in addition to economic gains. Therefore, knowledge on which brownfield sites are more advantageous to attain such goals could lead to more effective incentives at the local government level.

From the perspective of a developer interested in constructing a green building, part of their economic interests lie in obtaining the highest green building rating that would be feasible within the project budget. As was demonstrated by the results, different numbers of credits can be attained at different brownfield sites in the same city. Therefore, prioritization of available brownfield sites can be factored into their economic decision making, or should they own multiple sites, aid the decision on which to develop first.

Overall, we do not see a conflict or a concern among the differing interests of the public-commercial spheres, as is common in urban planning and development decisions. Both the public and commercial spheres would benefit from the presented method and analysis. However, urban planning involves multiple stakeholders and different locations around the globe should be expected to have a wide range of approaches and legislation for managing and planning brownfields.

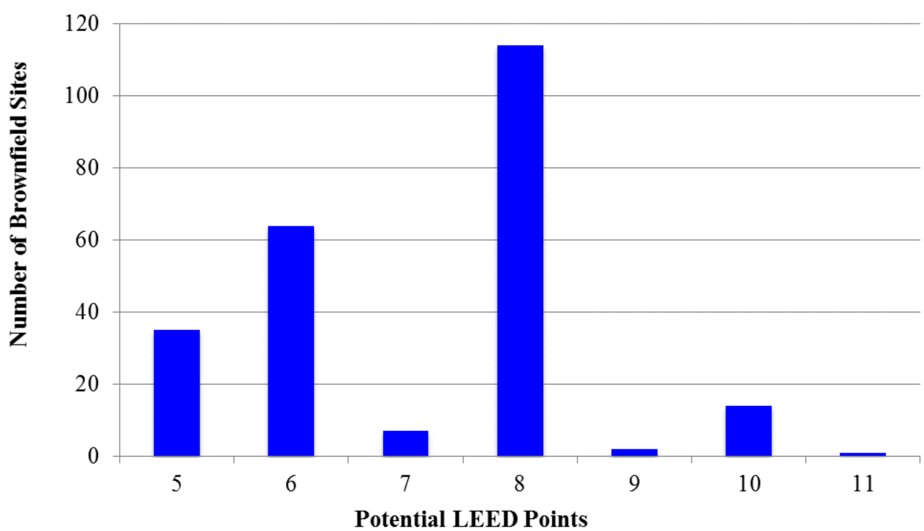

Figure 1. Distribution of Brownfield Sites Based on Potential LEED Points

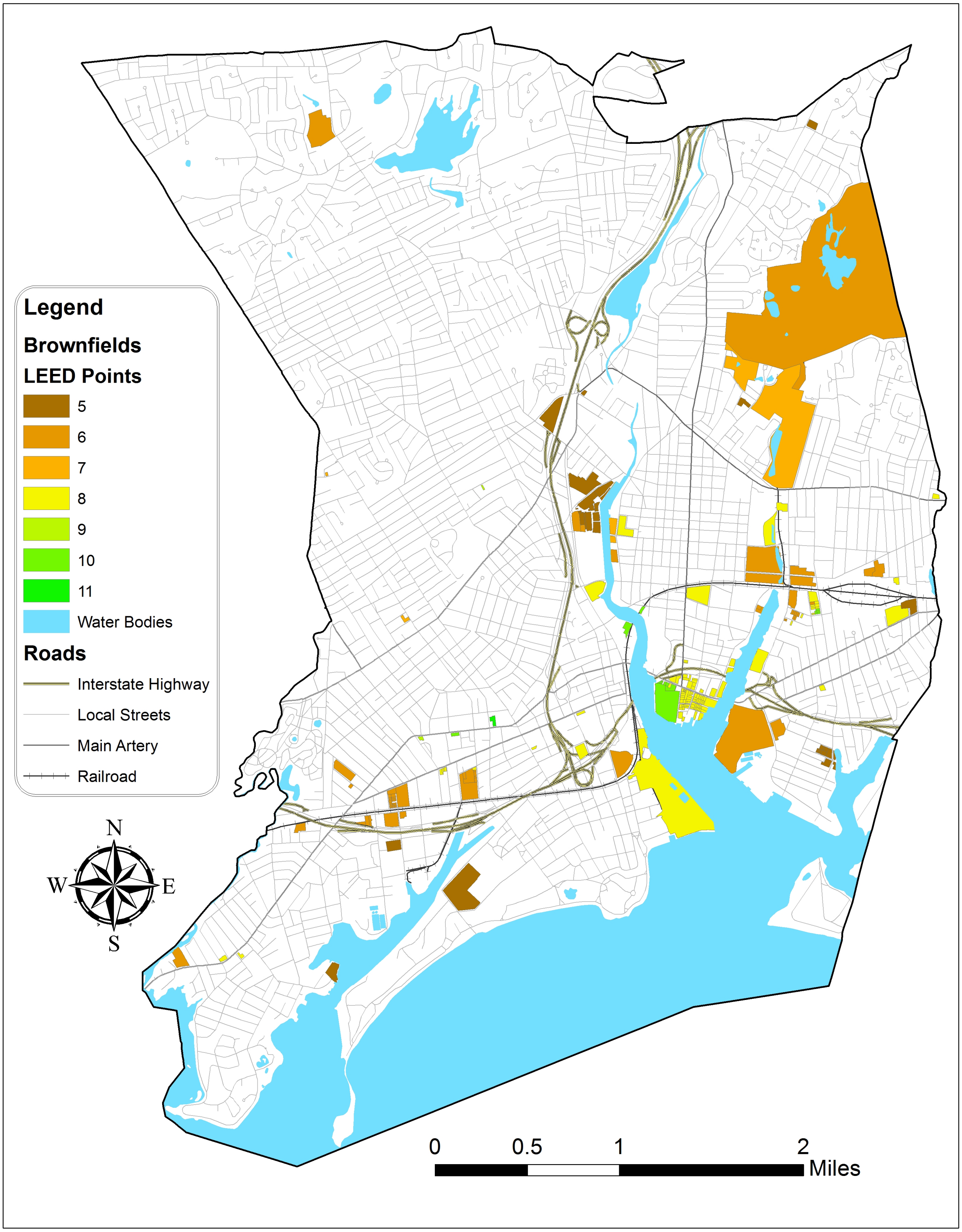

Figure 2. Map of Bridgeport, Connecticut, with Brownfield Sites Prioritized for LEED Points

Conclusion:

The study described herein presents a methodology to streamline prioritization of brownfield sites for green building construction by using GIS. Large numbers of brownfield sites can be analyzed by the proposed method. A case study for Bridgeport, Connecticut was carried out, and 237 brownfield parcels were analyzed. The method developed in this study together with variables used could be a viable way for both state and local governments as well as investors alike to use when evaluating brownfield sites for redevelopment. As smart growth options become ever more important moving into the future, tools and methods to efficiently identify the best opportunities for urban development increase in importance. The method developed in this study is based on and closely tied to the LEED checklist for green building construction.

Over 6% of brownfield sites analyzed were qualified to potentially receive 10 points out of a total of 13 points analyzed based on the LEED scorecard. The analyzed 13 points were solely based on site selection, and do not include improvements associated with building design, construction, or operation. The potential 10 points is significant as it could result in a jump in the rating of a green building, from certified to silver, or from silver to gold. Nearly half of brownfield sites were found to receive 8 points.

It is possible to analyze additional variables and LEED points than the 13 credits used in the study. Should data exist, it would be possible to add a layer for bicycle paths and facilities to analyze an additional LEED credit. Similarly, if a developer has plans to provide open space or restore habitat as part of the redevelopment project, or if local government has such requirements, then the presented methodology can be expanded to include 3 additional LEED points.

The developed method together with identified variables can be used to map out specific areas to quickly determine sites that are advantageous for green building construction. The same model can be applied to different cities or states, providing an efficient way to prioritize brownfield sites by objective criteria.

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