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Local environmental impacts of alternative forms of residential development

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Abstract. New Urbanism is often presented as an improvement over conventional suburban development along economic, social, and environmental lines. While the economic and social claims of New Urbanism have been investigated, relatively little work has examined the potential environmental impacts of New Urbanism as compared with conventional forms of suburban development. One of the challenges of studying the environmental impacts of New Urbanism is that it is still too early to evaluate adequately many sites, since most New Urban development is less than a decade old but it often takes several decades for vegetation and related ecological processes to establish. This paper attempts to address the gap in our understanding of New Urban environmental conditions by examining the relationship between residential-parcel vegetation abundance and specific components of residential form across the Greater Toronto Area (Ontario, Canada). While not explicitly comparing New Urban sites with other locations, this analysis illuminates how many New Urban design principles are related to vegetation conditions by focusing on those aspects of residential form that are addressed by New Urbanism—road pattern, neighborhood land use, and site-level characteristics—across a region with heterogeneous form. The results indicate that locations aligned with New Urbanism design principles do not necessarily support more vegetation than those areas based on more conventional suburban patterns, with many design principles having no relationship to vegetation abundance. The paper concludes by examining the planning implications of the results, and outlines future research needed to understand more fully the long-term impact of New Urbanism on local environmental conditions.

1 Introduction

Since the start of the 20th century, urban growth in North America has increasingly taken the form of single-use, automobile-dependent, low-density development (Jackson, 1987; Squires, 2002). As a result, cities are often described as polycentric entities sprawling in fractal and spider-like configurations (Batty and Xie, 1996; Berry and Kim, 1993; Gottdiener and Klephart, 1991; Longley and Mesev, 2000; White and Engelen, 1993). In response to the 'sprawling' pattern that now dominates many metropolitan areas, alternative forms of development are being discussed by both academics and planners, with much of the attention being given to New Urbanism (Young, 1995). Proponents argue that unlike recent urban forms, New Urbanism integrates traditional urban morphological characteristics to create vibrant, pedestrian-friendly communities that have a relatively low environmental impact (Congress for the New Urbanism, 2000). Although carried out in a variety of ways, New Urbanism is often implemented through traditional neighborhood developments, which include high building densities, mixed uses, grid street patterns, narrow streets, and short setbacks (Ellis, 2002; Thompson-Fawcett and Bond, 2003).

Social and economic conditions have received significant attention in the literature on suburban sprawl, New Urbanism, and other forms (for example, see Bjelland et al, 2006), but considerably less research has investigated conditions of the physical environment (Berke, 2002). While adoption of New Urbanism and related development types may present a better environmental option than conventional suburban development (Ellis, 2002)—due to lower per person land consumption and the reduction in automobile dependency—most New Urban developments are still located on greenfields (Berke et al, 2003). Conversion of greenfield sites to even a 'smart' urban form radically impacts local conditions through increased water pollution, heat island effects, and the destruction and modification of vegetation (Sukopp and Hejný, 1990). In addition, the intensity of localized environmental impacts has the potential to be much greater in the higher-density developments associated with New Urbanism (Nilon et al, 1995).

One of the challenges of studying the local environmental impacts of New Urbanism is that it is still too early to evaluate many sites adequately (Ellis, 2002). Most New Urban developments are less than a decade old but it often takes several decades for vegetation to establish, making it premature to assess vegetation conditions and related processes (microclimate, surface hydrology, pollution filtration). As a result, an approach like the paired-case method, where each New Urban community is evaluated alongside a comparable conventional suburban development (Berke et al, 2003; Youngentob and Hostetler, 2005), is not necessarily appropriate when considering local environmental impacts. However, in the absence of empirical studies, we have no idea if the touted environmental benefits of New Urbanism exist, or if these communities perform no differently than conventional suburbs. While difficult, the need to better understand these issues in the short term is imperative as more and more communities adopt the principles of New Urbanism in an attempt to meet a variety of goals, including the protection of the physical environment.

This paper begins to address the gap in our understanding of local environmental conditions in New Urban and conventional suburban developments by examining the relationship between vegetation abundance and specific aspects of residential form across the Greater Toronto Area (GTA) (Ontario, Canada). While not explicitly comparing New Urban sites with other locations, this analysis will illuminate how many New Urban design principles are related to vegetation conditions by investigating the specific aspects of residential form that are addressed by New Urbanism—road pattern, neighborhood land use, and site-level characteristics—across a region with heterogeneous form. A similar approach has been employed by Greenwald (2003) to determine the potential influence of New Urban design principles on travel-mode choice. Given that many New Urban communities directly model themselves on historical development patterns, exploring existing areas with similar design features is reasonable.

The focus of this study is on vegetation because of the important role urban vegetation plays in local environmental conditions; vegetation contributes to air filtration, microclimate regulation, noise reduction, rainwater drainage, sewage treatment, habitat availability, and recreation opportunities (Bolund and Hunhammar, 1999). A simple vegetation index (NDVI, the normalized difference vegetation index) is used to represent vegetation abundance given the large spatial extent of the study area. The following sections describe the environmental impact of New Urbanism and the analysis of the GTA case study. The paper concludes with a discussion of the planning implications of the analysis.

2 New Urbanism and environmental impacts

The principles of New Urbanism have been outlined in a series of documents (Calthorpe, 1993; Congress for the New Urbanism, 2000; Duany and Plater-Zyberk, 1991) and implemented in a growing number of communities throughout North America (Bressi, 2002; Grant, 2006). New Urbanism is presented as an alternative to conventional suburbs, which are characterized as having relatively low densities, separation of land uses, a lack of housing variety, and reduced road connectivity.

To date, most evaluations of New Urbanism have focused on social and economic goals (Ellis, 2002; Grant, 2006). In addition to whole-hearted supporters (for example, see Bressi, 2002), there are several studies that have identified potential shortcomings of New Urbanism, including evidence that counters its central goals: New Urbanism may not create a stronger sense of community (Nasar, 2003), tends to support very homogenous populations (Grant, 2002; Talen, 1999), does not include housing for poor people and difficult-to-house populations (Al-Hundi, 2001), and mixed development, in practice, includes a relatively narrow array of uses (Grant, 2002).

In addition to social and economic benefits, environmental benefits are often tied to the design approach of New Urbanism (Ellis, 2002; see also Till, 2001). In many cases, environmental benefits are to the forefront in the selling of such development (Till, 2001), with ecological analogies used throughout the promotional literature describing New Urban communities (Grant, 2006). Calthorpe (1993, page 95) states that "nature should provide the order and underlying structure of the metropolis", while the Congress for the New Urbanism (2000) argues that development should respect the local climate and ecology. New Urbanism is often presented as a reaction to wasteful consumption of natural resources (Calthorpe, 1993), and the lack of connection between local ecology and the built environment typical of conventional suburbs (Hough, 1995; Kunstler, 1996). Some have suggested that New Urbanism is more sustainable than conventional suburban developments (for example, see Zimmerman, 2001), and many argue that it ensures resources are preserved for future generations (Calthorpe, 1993; Duany and Plater-Zyberk, 1991; Katz, 1994; Kuntsler, 1996; Langdon, 1994), echoing an oft-stated goal of environmental sustainability.

When the actual environmental benefits of New Urbanism are examined more closely, a mixed picture begins to emerge. Studies on environmental impacts have addressed regional and local-level effects. Touted regional benefits associated with New Urbanism are primarily the potential (1) to lower land consumption and create or maintain more public green space and (2) to reduce transportation-associated pollution and energy use through pedestrian-friendly design and (in some cases) transit access (Duany and Plater-Zyberk, 1991). These claims have received some criticism, with Skaburskis (2006) arguing that when New Urban developments are examined in the context of regional dynamics, the presence of such communities does not necessarily lead in the long run to more green space (or a smaller urban footprint). Because most New Urban development occurs on greenfields, Leung (1995) concludes it is nothing more than pretty sprawl.

Studies examining the impacts from travel behavior are also mixed. While Shay and Khattak (2005) found lower automobile ownership and usage in New Urban communities, several others did not (Crane, 1996; Crane and Crepeau, 1998; Hygeia Consulting Services and REIC Ltd, 1995; Pogharian, 1996). The lack of difference in travel behavior may be (1) due to factors that cannot be addressed through local-community design, the focus of New Urbanism (Crane and Crepeau, 1998), (2) a result of most New Urban communities lacking sufficient or suitable stores and employment to meet the needs of residents (Crane, 1996; Grant, 2002; Steiner, 1998), and (3) because many New Urban developments occur on the urban edge and are not well linked to transit facilities.

Local environmental conditions that may be affected by urban form are hydrology (including water quality), microclimate, vegetation patterns, and site-level biodiversity (Alberti, 1999). Few studies have compared conditions between conventional suburban development, New Urbanism, and other forms along these lines. Those that have done so tend to focus on the analysis of plans given that the actual communities were often still under construction.

Gordon and Tamminga (2002) evaluated ten New Urban communities' secondary plans in Markham (Ontario, Canada) in the light of a recently completed natural-features study conducted by the municipality. Markham, located in the northern section of the GTA, is the largest adopter of the principles of New Urbanism in North America. When development is complete over 20 000 dwelling units will be constructed across several communities based on New Urban designs.

In their study, Gordon and Tamminga (2002) identified several strategies that developers were encouraged, but not required, to adopt as a result of the natural-features study. Their analysis indicated that the majority of communities only minimally, or somewhat, incorporated the eight strategies under examination. The following strategies were least often adopted: ecological restoration of significant areas, having the urban edge influenced by natural-feature patterns, using open space to buffer natural features, and linking internal parks to natural-vegetation corridors. While these results may be better than those for conventional development plans, which were not examined in the study, clearly there was not wholesale support for the ecological principles articulated in the natural-features study.

Berke et al (2003), who compared site plans for conventional and New Urban developments, found that the plans adopting the principles of New Urbanism did a better job of protecting local hydrology, with the exception that the higher road densities would likely contribute to increased storm-water runoff. However, Brander et al (2006) argue that the adoption of specific mitigation practices, compatible with New Urbanism designs, can minimize runoff and increase infiltration. While microclimate in relation to New Urbanism has not been studied directly, extensive research has investigated urban microclimate conditions, primarily temperature fluxes and water balance. Not surprisingly, microclimate varies with urban form (for example, see Arnfield, 2006), and higher building densities, such as those found in New Urban communities, are usually associated with higher temperatures (Bonan, 2000; Golany, 1996).

Finally, studies examining vegetation conditions in New Urban communities are rare, although this issue has been considered indirectly. Grant (2006) shows that over time houses in New Urban developments have become larger, and are sometimes even larger than those in surrounding conventional suburbs (Brown and Cropper, 2001). Large houses on small lots may mean less area is available for vegetation, as well as a high consumption of fossil fuels (for heating and cooling) and a greater contribution to heat island effects.

Studies more generally evaluating the influence of alternative urban forms on vegetation patterns are also scarce. Those that exist tend to focus on the single variable of distance from the city center (Medley et al, 1995). Such studies are based on the assumption that metropolitan areas are linear gradients of urban (population, building, employment) densities, which decrease as one moves away from the city center (McDonnell and Pickett, 1990). Interestingly, this approach is parallel to the transect concept that has been proposed within the literature on New Urbanism, which attempts to create linear patterns of decreasing density as a means of separating rural and urban activities (Duany and Talen, 2002). While the urban – rural gradient research has illuminated ecological variations that exist along such gradients, the role of other urban-form components (for example street pattern and housing type) is not addressed through this approach.

Recently, a few studies have considered other aspects such as street pattern (Conway and Hackworth, 2007; Stone, 2004), lot density (Stone, 2004), zoning class (Wilson et al, 2003), current and past land use (Dow, 2000), and housing age (Hope et al, 2003), indicating that other urban-form components are related to urban vegetation conditions. This study explores more fully the relationship between urban form and vegetation, in order to highlight any differences between conventional suburbs and New Urban design features.

3 Methods

3.1 Study area

The study area includes the five regional municipalities that make up the 5902 km^2 GTA (figure 1). The original city settlement and several other small towns were located on a sandy plain that stretches from the shore of Lake Ontario to 10 km inland. The majority of the region was cleared for agriculture in the 19th century, with only about 6% of the land still in woodlots by the 1940s (Chapman and Putnam, 1984). The 20th century saw rapid urban development expanding outwards from Toronto, converting agricultural land to the north and engulfing previously separate small towns.

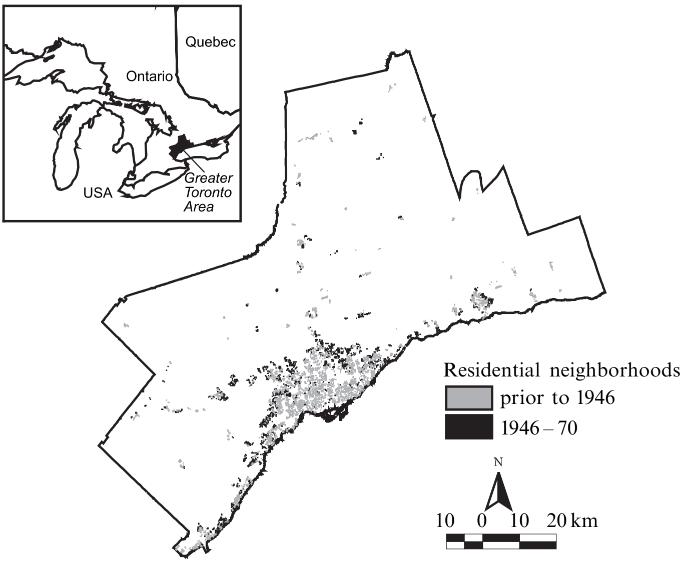

Figure 1. Urban residential development in the Greater Toronto Area, Ontario, Canada.

By 2001, the study area had a population of just over five million people. With an annual growth rate of 1.9% (Statistics Canada, 2001) the GTA is one of the fastest growing large metropolitan regions in North America. In the study area, approximately 13% of the land is used for urban residential purposes, 8% for commercial and industrial activities, and 3% is protected parkland. The remaining 77% is agricultural, rural residential development, forests, and wetlands. Today the region includes several commercial centers (often remnants of previously separate urban settlements), significant industrial and commercial strip development along highways and major roads, traditional older residential areas with neighborhood commercial establishments, and extensive areas of conventional suburban development.

3.2 Urban form variables

Fourteen variables were included in the analysis to reflect neighborhood or site-level design components associated with New Urbanism (table 1). Several variables representing urban density were included because of the focus of New Urbanism on increasing density. The first of the density variables is parcel size, with New Urbanism favoring relatively small residential parcels. Hough (1995) argues that parcel size is

Table 1. Urban development pattern and socioeconomic variables.

Variable Name	Description
Parcel_Size	The size of each parcel in m^2, using Teranet's 2002 Property Tax Parcel Map Data[a] for Halton, Peel, York, Durham, and Toronto Regions and The City of Toronto's 2002 Parcel Data for the City of Toronto.
Pop_Density	Population density, by dissemination area from the 2001 Census.
Roads_0.1	Road density within a 0.1 km neighborhood; proxy for view, derived from DMTI's 2004 CanMap Route Logistics 8.2 Ontario dataset.[b]
Road_Density	The density of roads within a 1.0 km neighborhood, derived from DMTI's 2004 CanMap Route Logistics 8.2 Ontario dataset.[b]
Land_Diversity	Number of land uses present within a 1.0 km neighborhood, derived from DMTI's 2004 CanMap Route Logistics 8.2 Ontario dataset.[b] Maximum value = 7.
Park_0.1	Percentage of parkland within a 0.1 km neighborhood; proxy for view, derived from DMTI's 2004 CanMap Route Logistics 8.2 Ontario dataset.[b]
Park_1.0	Percentage of parkland within a 1.0 km neighborhood, derived from DMTI's 2004 CanMap Route Logistics 8.2 Ontario dataset.[b]
Green_0.1	Percentage of land that is open or parkland within a 0.1 km neighborhood; proxy for view, derived from DMTI's 2004 CanMap Route Logistics 8.2 Ontario dataset.[b]
Green_1.0	Percentage of land that is open or parkland within a 1.0 km neighborhood, derived from DMTI's 2004 CanMap Route Logistics 8.2 Ontario dataset.[b]
Ind-Comm_0.1	Percentage of land used for industrial or commercial purposes within a 0.1 km neighborhood; proxy for view, derived from DMTI's 2004 CanMap Route Logistics 8.2 Ontario dataset.[b]
Ind-Comm_1.0	Percentage of land used for industrial or commercial purposes within a 1.0 km neighborhood, derived from DMTI's 2004 CanMap Route Logistics 8.2 Ontario dataset.[b]
Per_Renter_Occ	Percentage of dwelling units occupied by renters, by dissemination area from the 2001 Census.[c]
Per_Single_Fam	Percentage of dwelling units that are detached, single-family homes, by dissemination area from the 2001 Census.[c]
Apt $\geqslant$ 5	Percentage of dwelling units in apartment building five storeys or higher, by dissemination area from the 2001 Census.[c]

[a] http://www.utm.utoronto.cal/library/gisdata/gis.html

[b] http://www.lib.uoguelph/ca/resources/data_resource_center/geospatial_data_resources/DMTI_Canadian_geospatial_data.cmf

[c] Statistics Canada (2001).

likely to be a key factor limiting vegetation abundance in built-up environments due to physical space limitations. However, the study by Robbins et al (2001) of parcel-size effects in suburban Ohio found that as parcel size increases, so does building size, suggesting that there may not be proportionally more room for vegetation on larger parcels.

The literature on New Urbanism is not as explicit about population density, although one may assume that as the density of building lots increases so would the number of people. However, this is not always the case, as some studies indicate that single people or couples without children are more likely to live in New Urban communities than in conventional suburbs (Bookout, 1992). As a result, population density is examined separately from building parcel size, represented by the number of people per square kilometer in each census dissemination area. Dissemination areas contain a population of 400 to 700 people, and are the smallest geographical unit for which all census data are released by Statistics Canada (2001).

In North America, road patterns within residential neighborhoods have changed from the basic grid pattern primarily used in the early 20th century to the curvilinear streets and cul-de-sacs that dominate postwar development. This change is associated with a decrease in road length and intersection density, leading to less connectivity (Southworth and Owens, 1993). A central tenet of New Urbanism is an increase in connectivity through the use of a grid road network. Because increased connectivity is usually associated with an increase in road density this measure was included. Road density was defined as the length of road, in kilometers. Neighborhoods were defined using a 1.0 km radius, following Geoghegan et al (1997), to represent a walkable distance around each residential parcel. As the variable is defined, most grid networks will have a higher neighborhood road density than curvilinear and cul-de-sac patterns.

Several other variables are included in the analysis in order to represent additional aspects of neighborhood land-use pattern. The number of different land-use classes within a neighborhood is a broad measure of the diversity of functions, with a higher number of land-use classes suggesting a mixed-use development pattern over a more segregated configuration. This variable reflects the emphasis on mixed-use communities in New Urbanism.

Even when mixed uses are emphasised, in practice this can still mean a variety of land-use patterns. As a result, the percentage of different land uses within a 1.0 km neighborhood were also considered: (1) percentage of neighborhood in parkland; (2) percentage of neighborhood green space (open area and parkland); and (3) percentage of neighborhood used for industrial or commercial purposes.

The percentage of renter-occupied dwelling units and two measures of housing-structure type (percentage of dwellings that are detached or semidetached single-family houses and percentage of dwellings in apartment buildings five storeys or more) were included as measures of diversity in residential options. The literature on New Urbanism often promotes variations in housing styles as a way to support a diverse community, although housing types are often limited to single-family or low-rise structures.

At the site level, several variables reflecting the view from residential properties were identified. View variables were included because previous research into urban landscapes has suggested that residents prefer a view of certain features over others (Kaplan, 2001). Communities with mixed uses or integrated green space provide different views from those in areas that consist only of residential development. Given the lack of topographic variation across much of the study region, viewsheds were defined using a 0.1 km neighborhood around each sample point, following Geoghegan et al (1997). Views of both parkland and green space (parkland and open land) were examined.

3.3 Vegetation data

The NDVI was chosen to represent vegetation abundance because it is a good measure of the amount of green biomass present (Tucker, 1979), and it correlates with urban land-cover type (Fung and Sui, 2000) and leaf-area index (Xavier and Vettorazzi, 2004). The index is a ratio of near infrared (NIR) and visible red (R) reflective values defined by the following formula:

$$\mathrm{NDVI} = \frac{\mathrm{NIR} - \mathrm{R}}{\mathrm{NIR} + \mathrm{R}} .$$

Heavily vegetated areas have a NDVI value closer to 1, while locations dominated by water, impervious surfaces, or bare soil have values closer to -1.

In this study, NDVI was calculated from Landsat 7 ETM+ satellite imagery (http://www.landsat.usgs.gov/). The imagery has a cell size of 30 m, an appropriate resolution for metropolitan-wide studies of NDVI variation (Wilson et al, 2003). Two images were needed to cover the study area. Images collected two weeks apart were used to minimize cloud coverage: path 18, row 29 on 3 September 1999 and path 18, row 30 on 19 September 1999. The images were georeferenced using the roads data layer from the CanMap Route Logistics 8.2 dataset (http://www.lib.unb.ca).(1)

3.4 Analysis

For this study, only areas of residential land uses were included in the analysis. Hough (1995) notes that age of construction is one of the most important factors in determining urban vegetation because the construction process usually represents the last major disturbance of the land, with most vegetation removed from the site and new vegetation planted. When trees and other woody species are considered, vegetation levels may continue to increase for the first few decades after development through natural growth processes. To try to account for these growth processes two analyses were conducted: (1) in residential neighborhoods where the dominant age of construction was prior to 1946 and (2) where the dominant age of construction was from 1946 – 70 (figure 1). The first time period likely represents only those neighborhoods with mature vegetation, while the second includes the postwar period when significant suburban development occurred in the GTA. The first time period includes 6723 data points, while the second includes 26 733 data points. These numbers reflect the relative proportion of residential areas in the two time periods, with specific sites selected on the basis of a random sample spatially separated above the level of spatial autocorrelation for NDVI.

The dominant age of construction for each neighborhood was determined on the basis of Statistics Canada (2001) census data at the dissemination level. First, the percentages of dwellings constructed prior to 1946, from 1946 – 60, and in 10-year spans through to 2001 was calculated. The most active period of construction was then assigned as the dominant age of construction for each dissemination area, and subsets of prior to 1946 and 1946 – 70 neighborhoods were created. For each sample of residential parcels rights-of-way and water bodies were removed to ensure that NDVI values reflect conditions on residential property. In both samples, residential areas with very low population densities were excluded. Thus, the analyses were conducted within only those areas that have a population density above 400 people per square kilometer, the definition of an urban area used in Statistics Canada (2001).

A correlation analysis between NDVI and the urban-form variables was conducted. All variables listed in table 1 were used in this analysis. The first step was to examine the relationship between the urban-form variables, to determine if certain features (that is, high road density and low green space) are found in the same location in order to assist with the interpretation of the vegetation results. The second step looked at the relationship between NDVI and each urban-form variable. On the basis of hypothesized relationships between the urban-form variables, partial correlations were calculated to control for certain variables. In particular, four questions were addressed. (1) What is the relationship between neighborhood percentage of single-family homes and NDVI when controlling for parcel size? (2) What is the relationship between neighborhood percentage of renter-occupied dwelling units and NDVI when controlling for road density? (3) What is the relationship between the industrial or commercial land-use variables and NDVI when controlling for neighborhood housing type? (4) What is the relationship between neighborhood green space and NDVI when controlling for road density?

(1) All data layers were projected in UTMs (Universal Transverse Mercators), and, where necessary, georectified to align with the CanMap Route Logistics 8.2 dataset.

4 Results

Table 2 shows the summary statistics for the two time periods. Using the Kolmogorov–Smirnov test, all variables have significantly different means and distribution shapes between the two time periods. The most notable differences are for average parcel size and population density, with both variables having higher means in neighborhoods primarily built before 1946. These seemingly contradictory conditions exist because there are fewer detached single-family houses and more (low-rise) apartment buildings in areas developed before 1946. Thus, the average parcel developed before 1946 is used more intensively.

Table 2. Descriptive statistics for normalized difference vegetation index (NDVI) and urban form variables.[a] The Kolmogorov–Smirnov test shows all variables are significantly different for the two time periods.

	Residential neighborhoods constructed prior to 1946			Residential neighborhoods constructed 1946–70		
	min	mean	max	min	mean	max
NDVI	−0.27	0.05	0.49	−0.29	0.07	0.45
Parcel_Size	6	7442	435057	4	5222	383545
Pop_Density	401	5798	150200	417	3841	150300
Roads_0.1	1	18	42	1	17	42
Road_Density	1	545	815	6	510	900
Land_Diversity	2	6	7	2	5	7
Park_0.1	0	3	94	0	4	100
Park_1.0	0	7	53	0	8	69
Green_0.1	0	4	100	0	6	100
Green_1.0	0	14	97	0	15	95
Ind-Comm_0.1	0	2	73	0	1	90
Ind-Comm_1.0	0	3	30	0	3	60
Per_Renter_Occ	0	32	100	0	22	100
Per_Single_Fam	0	54	100	0	73	100
Apt $\geqslant$ 5	0	22	100	0	14	100

[a] All variables are significantly different between the two time periods based on the Kolmogorov–Smirnov test.

Tables 3 and 4 show the correlations between the urban-form variables. As might be expected, the strongest correlations for both time periods are between the three housing-type variables (percentage of renter-occupied, percentage of dwelling units that are single-family houses, percentage of dwellings in apartments with five or more storeys). Interestingly, population density and parcel size are not correlated with the housing variables or each other. The housing-type variables are also correlated with neighborhood industrial or commercial land use and views of those land uses. A strong negative relationship exists between road density and neighborhood green space, suggesting that the road density variable is not only picking up changes in road patterns but also differences in areas used more or less intensively for urban purposes. Finally, there were only weak correlations between neighborhood land-use variables and the corresponding view variables, suggesting that land-use patterns are not related at these two scales (0.1 km and 1.0 km).

The correlations between NDVI and the urban-form variables are given in table 5. In residential areas primarily built before 1946, parcel size and the percentage of single-family homes are positively correlated with NDVI. When parcel size is controlled for, the relationship between NDVI and the percentage of single-family homes remains (0.414, $p < 0.001$).

Table 3. Spearman's rho for the normalized difference vegetation index and urban form variables in neighborhoods dominated by residential development built before 1946 in the Greater Toronto Area, Ontario. All values are significant at the $p = 0.001$ level.

	Parcel_Size	Pop_Density	Roads_0.1	Road_Density	Land_Diversity	Park_0.1	Park_1.0	Green_0.1	Green_1.0	Ind-Comm_0.1	Ind-Comm_1.0	Per_Renter_Occ	Per_Single_Fam	Per_Apt ⩾ 5
Parcel_Size		−0.246	−0.062	−0.439	−0.069	0.076	−0.005	0.256	0.365	−0.068	−0.340	−0.091	0.372	−0.062
Pop_Density			0.074	0.189	0.051	0.013	0.129	−0.135	−0.218	−0.011	0.115	−0.040	−0.097	−0.038
Roads_0.1				0.079	0.009	0.011	0.019	−0.021	−0.061	0.020	0.063	0.008	−0.055	−0.005
Road_Density					0.010	−0.123	−0.243	−0.311	−0.685	0.150	0.413	0.670	−0.337	0.103
Land_Diversity						0.075	0.291	0.033	0.099	0.099	0.268	−0.238	−0.202	0.242
Park_0.1							0.308	0.671	0.205	−0.073	−0.066	0.023	−0.013	0.023
Park_1.0								0.108	0.538	−0.056	−0.059	−0.034	−0.017	0.070
Green_0.1									0.405	−0.080	−0.193	−0.055	0.103	−0.036
Green_1.0										−0.125	−0.384	−0.089	0.219	−0.028
Ind-Comm_0.1											0.306	0.276	−0.281	0.254
Ind-Comm_1.0												0.482	−0.560	0.407
Per_Renter_Occ													−0.739	0.798
Per_Single_Fam														−0.723
Per_Apt ⩾ 5														

Table 4. Spearman's rho for the normalized difference vegetation index and urban form variables in neighborhoods dominated by residential development built between 1946–70 in the Greater Toronto Area, Ontario. All values are significant at the $p = 0.001$ level.

	Parcel_Size	Pop_Density	Roads_0.1	Road_Density	Land_Diversity	Park_0.1	Park_1.0	Green_0.1	Green_1.0	Ind-Comm_0.1	Ind-Comm_1.0	Per_Renter_Occ	Per_Single_Fam	Per_Apt ⩾ 5
Parcel_Size		−0.164	−0.024	−0.226	−0.117	−0.053	−0.034	0.143	0.101	0.034	−0.072	0.048	0.014	0.070
Pop_Density			0.037	0.058	0.116	0.052	0.105	0.001	−0.034	0.034	0.108	0.175	−0.202	0.130
Roads_0.1				0.042	0.023	0.016	0.031	0.014	0.019	−0.002	−0.005	0.006	−0.055	0.026
Road_Density					0.101	−0.214	−0.273	−0.190	−0.434	0.053	0.132	−0.010	0.059	0.009
Land_Diversity						−0.005	0.321	−0.029	0.002	0.109	0.469	0.212	−0.229	0.211
Park_0.1							0.197	0.774	0.208	−0.064	−0.032	0.010	−0.056	0.035
Park_1.0								0.197	0.577	−0.059	−0.093	−0.023	−0.072	0.022
Green_0.1									0.341	−0.058	−0.081	0.003	−0.044	0.033
Green_1.0										−0.079	0.203	−0.041	−0.028	−0.016
Ind-Comm_0.1											0.293	0.178	−0.152	0.184
Ind-Comm_1.0												0.292	−0.278	0.275
Per_Renter_Occ													−0.736	0.704
Per_Single_Fam														−0.692
Per_Apt ⩾ 5														

Table 5. Spearman's correlations between the normalized difference vegetation index and urban form variables. All values are significant at $p = 0.001$ level.

Variable name	Prior to 1946	1946–70
Parcel_Size	0.395	0.251
Pop_Density	−0.142	−0.179
Roads_0.1	−0.062	−0.032
Road_Density	−0.374	−0.119
Land_Diversity	−0.117	−0.136
Park_0.1	0.092	−0.075
Park_1.0	0.074	0.001
Green_0.1	0.179	0.100
Green_1.0	0.308	0.079
Ind-Comm_0.1	−0.372	−0.203
Ind-Comm_1.0	−0.394	−0.185
Per_Renter_Occ	−0.303	−0.214
Per_Single_Fam	0.434	0.262
Apt $\geqslant$ 5	−0.210	−0.171

Road density and the percentage of neighborhood industrial or commercial land use is negatively correlated. Weaker correlations also exist for four other variables: the percentage of neighborhood green space is positively correlated and the percentage of neighborhood industrial or commercial land use, industrial or commercial view, and the percentage of renters are negatively correlated.

When housing type is controlled for the relationship between industrial or commercial view and NDVI stays moderate (-0.313, $p < 0.001$), while only a weak relationship exists for the percentage of neighborhood industrial or commercial land use (-0.206, $p < 0.001$). Furthermore, when the percentage of single-family homes is controlled for, there is no significant relationship between NDVI and the percentage of renter-occupied homes. The same is true for NDVI and the percentage of neighborhood green space when controlling for road density.

The primary difference between the two time periods is that weaker relationships exist for the 1946–70 residential areas, perhaps because the younger age of some of the residential areas leads to less mature vegetation.

5 Discussion

The analysis indicates that a few of the design principles associated with New Urbanism are related to variations in NDVI. One of the factors most strongly correlated with NDVI is neighborhood road patterns, where higher road densities are associated with lower levels of vegetation on residential property. Higher road density is a key component of New Urbanism, as it is seen as a way to meet social goals through increased connectivity. On the basis of this analysis, the adoption of a highly connected road pattern, like a grid, may actually increase negative environmental impacts. Gordon and Tamminga (2002) acknowledge the clear conflict between higher built connectivity (that is, a grid road pattern) and natural ecosystem connectivity, and suggest that a cul-de-sac design may actually better minimize that conflict. Alternatively, a modified grid pattern, using pedestrian pathways not roads to maintain high levels of built connectivity (CMHC, 2002; Southworth and Ben-Joseph, 2004) could be a compromise solution.

The positive correlation between NDVI and parcel size indicates another dilemma that arises through the design principles of New Urbanism. On the one hand, larger building lots can support more vegetation, and the positive ecological services (microclimate regulation, pollution filtration, and habitat) associated with that vegetation. On the other hand, larger parcels mean that less land is available for other uses, including the protection of ecological features.

The very weak correlation between population density and NDVI may point to an alternative to this problem. While New Urbanism is usually associated with higher-density building lots, most of the homes are still single-family structures (detached, semidetached, or townhouses). Replacement of single-family homes with multifamily medium-rise or high-rise buildings could potentially allow for a larger percentage of land to be kept in a vegetated state. However, this type of approach, which includes the modernist design of the 'high-rise in the park', has been criticized by advocates of New Urbanism because it is not seen as aesthetically pleasing or supportive of social interaction (Calthorpe, 1993; Grant, 2006). However, medium-rise or high-rise buildings may be a more efficient use of space that still allows for abundant vegetation.

The results do suggest that housing structure and occupant type are related to NDVI. Neighborhoods with a larger percentage of single-family dwellings are associated with higher vegetation levels, even when controlling for parcel size. This is one example where a common feature of New Urbanism is associated with a positive environmental situation. Of course this is also a dominant feature of conventional suburbs. Interestingly, larger apartment buildings (more than five storeys) are not associated with less (or more) vegetation, again suggesting that the 'high-rise in the park' style of development many supporters of New Urbanism scorn may have some environmental benefits over New Urbanism. However, the negative relationship between the percentage of renter-occupied dwellings and vegetation abundance appears to be due primarily to the influence of fewer single-family homes. Thus, while high levels of vegetation abundance may be possible with apartment buildings, these conditions are more likely to occur in areas with high concentrations of single-family homes.

The relationship between vegetation and views of industrial or commercial land suggests that the influence of these types of land use extends beyond the site they occupy, with industrial or commercial land and surrounding residential parcels tending to have low levels of vegetation. One possible explanation may be that fewer single-family homes and more rental units tend to occur in neighborhoods with higher levels of industrial and commercial use, thus housing type may be influencing the relationship. However, the partial correlations suggest that this is not the case for residential properties with a view of industrial or commercial land. Alternatively, the positive effects of neighboring green space seem to be merely an artefact of lower road densities in those neighborhoods.

Interestingly, while specific neighborhood land-use types are related to residential vegetation, the total number of land uses in a neighborhood is not. Thus, a mixed-use design, which is promoted by New Urbanism, in and of itself, may not lead to lower levels of vegetation, but certain land uses (industrial or commercial) and/or the type of dwellings that usually occur near these land uses do.

5.1 Urban environmental impacts

There is growing evidence that New Urban communities do not necessarily support healthier natural systems or reduced local environmental impacts as compared to conventional suburban design. In addition, the relatively small scale of New Urbanism within a metropolitan context, and the tendency for such development to be located on the urban fringe, has the potential for most New Urban communities not only to be associated with more intensive local environmental impacts, but also to not necessarily encompass the benefits of compact forms, cheaper infrastructure, and reduced travel distances. Thus, New Urbanism, in practice, may represent no more than the process of converting greenfields along the urban edge to high-density sprawl (Grant, 2006).

To date, New Urbanists have focused on creating the illusion that there are no negative environmental effects, but actually draw on a very narrow understanding of ecology in their design principles (Zimmerman, 2001). In particular, New Urbanism glosses over the inherent conflict between built and natural systems. Calthorpe (1993, page 44) notes that "environmentally sound communities need parks, regional greenbelts, and high-quality open spaces, but they also need density and street-life" yet the principles associated with New Urbanism do not provide a clear pathway to reconcile these needs.

New Urbanism also ignores what Neuman (2005) calls the compact-city paradox: a compact city (that is, high density along the lines of New Urbanism) is not necessarily a more sustainable one as such cities are associated with their own set of environmental problems (that is, pollution, heat islands, little room for vegetation). In fact, minimizing these problems has historically been one of the push factors associated with the development of conventional suburbs (Neuman, 2005).

One way to overcome the environmental shortcomings of New Urbanism may be better integration of landscape ecology, which involves the study of ecological processes across settled landscapes (Turner et al, 2001), into urban-design principles. Gordon and Tamminga (2002) point out that there is a wide gap between landscape ecology and New Urbanism, but landscape ecologists have begun to develop a set of strategies to protect natural systems in urbanizing landscapes (McCraken and Bignal, 1998; Odell et al, 2003; Opdam et al, 2002). Joining landscape-ecology principles and a neighborhood-level urban-design approach, such as New Urbanism, may help elucidate a way to balance built and natural systems in an urban context, ensuring that the environmental promises of New Urbanism can be met.

5.2 Limitations and next steps

This study was an initial attempt to better understand the relationship between urban vegetation in residential neighborhoods on the basis of conventional suburban and New Urban design principles. A major limitation of the study is that the vegetation measure was limited to abundance, and does not take into account species composition. Native species are likely to require less water and other inputs, while more likely to provide habitats for other species. The benefits of planting native species may be even greater when such planting replaces conventionally managed lawn grass, due to a reduction in chemical inputs (Robbins et al, 2001). Site-level surveys of species composition in New Urban and conventional suburbs would begin to determine if developers of New Urbanism are more likely to incorporate native vegetation and alternatives to lawns, and if property owners retain or replace that vegetation over time.

A second limitation is that New Urban communities were not actually examined in this study due to the relatively recent creation of many of these developments. While analysis of locations that do and do not have some of the same design components as New Urbanism may begin to illuminate conditions associated with this form, this approach does not enable a study of the ways in which different design features work together to influence the local environment and residents' property management. A long-term study tracing conditions in New Urban communities would provide a more robust understanding of the environmental impacts of this type of urban form. However, the type of approach used in this study provides some basic insight into the impacts of New Urban design elements.

A study focusing on specific New Urban communities would also enable neighborhood boundaries to be tailored to each site. In this analysis, variables were summarized reflecting the use of either a standard distance to reflect a 'walkable' neighborhood or one defined by the census data (that is, dissemination areas), rather than functional neighborhoods. This was a result of data availability and the large size of the study area. If actual New Urban communities were studied, then functional neighborhoods specific to each site could be identified (for example, see Song and Knaap, 2004), better reflecting actual conditions.

Overall, the generally weak relationship between the urban-form variables and NDVI suggests that factors other than design elements included in this analysis are primarily driving urban vegetation conditions. For example, the socioeconomic status of households, cultural influences, and muncipal or regional urban forestry policy, which have already been shown to play some role in urban vegetation conditions (Conway and Urbani, 2007; Heynen and Lindsay, 2003; Heynen et al, 2006; Martin et al, 2004; Stone, 2004; Wilson et al, 2003), may play a greater role than urban form. Further research needs to address more thoroughly the relative influence of, and interactions between, each of these broader factors.

6 Conclusions

New Urbanism is often associated with a number of social, economic, and environmental goals. While the social and economic impacts of New Urbanism have been well studied, relatively little attention has been given to the environmental claims. As an initial attempt to better understand the environmental implications of New Urbanism, this study compared vegetation abundance on residential property in relation to urban-form variables that differ between conventional suburbs and New Urbanism. The results indicate that the design principles of New Urbanism are not necessarily associated with higher levels of vegetation, and may actually be associated with less. These results are in line with a growing discussion that New Urbanism is not necessarily an improvement over conventional suburbs in terms of local environmental conditions, and is far from an environmentally sustainable form of residential development.

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