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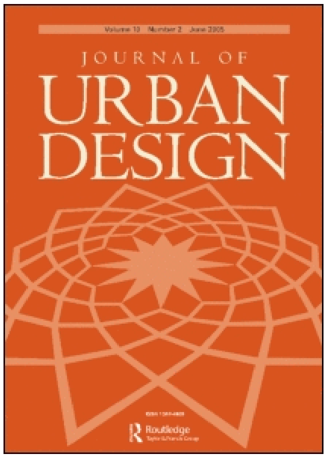

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Space Syntax and Walking in a New Urbanist and Suburban Neighbourhoods

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ABSTRACT *Prevailing measures of street design have largely ignored the relational properties between local and global street design as correlates of walking behaviour. This study contributes to understanding relationships between the syntactical properties of street design and walking behaviour by examining whether space syntax measures in New Urbanist and conventional suburban neighbourhoods are associated with the walking patterns of residents in these communities. Relying on geographic information systems, survey data and travel diaries, the study relates control, local integration and global integration to walking behaviour, while adjusting for the effect of individual- and household-level characteristics. It finds significant relationships between the number of leisure trips and all three syntactical measures. It also finds a consistent positive relationship between total utilitarian walking and two of the space syntax variables, control and global integration. By explaining individuals' walking behaviour using relational measures of street design, urban designers and planners are encouraged to expand their consideration of how street design may influence walking beyond the local purview.*

Introduction

The burgeoning literature on the built environment and travel behaviour has focused on disaggregate measures of urban form that emphasize particular dimensions of the built environment. Density, street design, access to commercial land uses and proximity between jobs and houses are examples of dimensions for which particular measures have been developed and tested (e.g. Cervero & Kockelman, 1997; Cervero & Wu, 1997; Boarnet & Greenwald, 2000; Frank *et al*., 2005; Giles-Corti *et al*., 2005; Forsyth, 2006; Mudon *et al*., 2006; Shay *et al*., 2006). However, relational properties among urban form attributes that may be particularly relevant for characterizing street design and layout have received less attention. Prevalent measures of street design such as percent of streets in a grid, number of intersections, percent of three- and four-way intersections within a

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buffer, and block size are limited to local area characteristics and ignore the area's connection with the broader environment. Notwithstanding the availability of methodological tools, such as space syntax, the relational properties between local and global street design have not been examined as possible correlates of walking behaviour.

Rooted in graph theory and the idea of urban morphology, space syntax theory describes and measures quantitatively the configurational properties of urban space (Hillier & Hanson, 1984). Space syntax aims at describing the relational properties of urban space and through those relationships convey meaning to individuals using the space. The theory posits that the built environment, viewed as a system, affords or carries movement from every space to every other space within the system. Environments that are most directly linked to other environments, for example through better physical connections and longer lines of sight, will tend to attract higher densities of movement. A testable implication of space syntax theory is that movement is a function of the syntactical properties of the space (Peponis & Wineman, 2002). To date, the emphasis of prior research has been on explaining the presence of individuals in space, and its relationship to spatial cognition and crime occurrence. Empirical research has widely supported this view by showing that areas with high syntactical accessibility have a higher number of pedestrians and car users. Despite this early work, space syntax theory has not been used to explain some fundamental behavioural aspects of individuals, such as the number of trips they make or the preferred travel modes they use.

This study contributes to understanding and disseminating space syntax theory applied to walking behaviour by calculating space syntax measures of New Urbanist and conventional suburban neighbourhoods and associating them with the walking patterns of residents in these communities using statistical methods.

The focus on a New Urbanist neighbourhood is the result of New Urbanism's emergence as a defining element in urban design and planning in the last two decades (Garde, 2006). New Urbanist neighbourhood designs are distinguished by their mixed land uses, higher land-use density than most conventional suburban developments, alternative means of transportation, and an emphasis on enhancing the sense of place and community. It is through these characteristics that New Urbanist communities are seen as havens for alternative modes of transportation (Bookout, 1992).

Indeed, a growing body of literature has explored various aspects of New Urbanist communities. Among others, studies have examined the relationship between New Urbanism and sense of place (Brown & Cropper, 2001; Kim, J. 2001), interaction among residents (Lund, 2003), the environment (Berke *et al*., 2003), physical activity (Rodríguez *et al*., 2006), and travel patterns (Lee & Ahn, 2003; Khattak & Rodríguez, 2005). Similar to the broader literature on urban form and walking behaviour, research on New Urbanism has not examined its syntactical properties relative to conventional suburban neighbourhoods and associated them to individual walking patterns.

This study examines the relationship between three quantitative measurements of syntactical properties of space as defined by space syntax theory and leisure and utilitarian walking behaviour while controlling for individual- and household-level attributes in a large New Urbanist community and a conventional suburban neighbourhood. For leisure walking, the study finds that

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higher control values and higher global integration are related to a higher number of leisure walking trips, whereas, higher local integration is related to fewer leisure trips. These results suggest that residents of streets that provide (1) high control on the permeability of their neighbouring streets, (2) higher global accessibility, and (3) lower local accessibility exhibit more leisure walking. The study also finds a consistent positive relationship between total utilitarian walking and two of the space syntax variables, control and global integration. The results point out that street segments that are (1) globally more accessible and (2) exhibit higher control on the permeability of their neighbouring streets are related to a higher number of utilitarian walking trips. Together, the findings suggest that different space syntax properties are associated with leisure vs. utilitarian walking in one's neighbourhood.

The remainder of the paper is organized as follows. First, there is an overview of the empirical findings linking neighbourhood design and walking behaviour. Second, the space syntax theory and methodology is introduced. Third, the research design and methods utilized in this study are presented. Fourth, the study results are presented and discussed. The final section presents conclusions and implications for urban designers.

Neighbourhood Design and Walking Behaviour

A rapidly increasing body of literature majority relating neighbourhood design and walking behaviour has emerged over the last two decades. Various characteristics of travel patterns such as trip-making frequency, distance and time travelled have been positively related to attributes of space such as land-use patterns, street networks and streetscape design features. Of the land-use patterns related to utilitarian/travel walking behaviours, proximity to commercial and retail land uses (Cervero & Kockelman, 1997; Giles-Corti & Donovan, 2002; Humpel *et al*., 2002; Huston *et al*., 2003; Frank *et al*., 2005; Giles-Corti *et al*., 2005; Lee & Moudon, 2006; Moudon *et al*., 2006; Rodriguez *et al*., 2006; Shay *et al*., 2006), and higher employment and population density (Frank & Pivo, 1994; Cervero, 1996; Messenger & Ewing, 1996; Cervero & Wu, 1997; Frank *et al*., 2005; Moudon *et al*., 2006) surface as fairly consistent attributes in recent research. After reviewing the literature, Heath *et al*. (2006) conclude that development-related policies appear to be effective interventions to increase physical activity through walking.

For street design, the most popular characteristic examined has been street connectivity, defined as "the directness and availability of alternative routes from one point to another within a street network" (Transportation Research Board/Institute of Medicine, 2005, p. 104). Despite the broad definition of connectivity, prevalent measures of connectivity have been limited to local and discrete characteristics, such as percent of grided streets in a buffer of a person's home (Boarnet & Sarmiento, 1998; Boarnet & Greenwald, 2000), number of intersections per square kilometre (Frank *et al*., 2005), percent T-intersections and 4-way intersections (Handy, 1996), average block area (Krizek, 2003), median block area (Forsyth, 2006) or number of entrance and exit links (McNally & Ryan, 1993). Using these local measures, prior research has related higher local street connectivity (Greenwald & Boarnet, 2000; Boarnet & Crane, 2001; Frank *et al*., 2005) and smaller blocks (Moudon *et al*., 2006) to more walking.

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Unlike utilitarian walking, recreational/leisure walking behaviours have been mainly studied with regard to streetscape design features such as sidewalk continuity, sidewalk width, crosswalk and presence of cycling and walking paths. The evidence from the leisure walking literature does not suggest consistent relationships between leisure walking and the built environment. While some studies have shown relevant positive associations between the presence of sidewalks (Giles-Corti & Donovan, 2002; Reed *et al*., 2006), the presence of footpaths (Corti *et al*., 1996), accessibility to opportunity for activity (Huston *et al*., 2003; Giles-Corti *et al*., 2005) and hilliness of the terrain (Troped *et al*., 2001) others have failed to show such relationships (Sallis *et al*., 1997; Wilcox *et al*., 2000).

Other research has relied on comparisons of neighbourhoods that differ in one or more design characteristic (such as street connectivity, walking facilities, land-use mixes and residential density). To the extent that the neighbourhoods embody key differences in the built environment, this research design provides the advantage of providing a whole comparison across neighbourhoods. However, because of lack of controlled 'treatment' these study designs could only ascribe cause in a provisional way (Groat & Wang, 2002). These comparative studies have demonstrated that the share of all trips that are walking and the raw number of these trips is higher in walkable neighbourhoods than those in not walkable neighbourhoods (Cervero & Gorham, 1995; Cervero & Radisch, 1995; Handy & Clifton, 2001; Dill, 2004; Khattak & Rodríguez, 2005). Saelens *et al*. (2003) review suggests that most of this difference is due to walking to destinations, as opposed to walking for leisure and recreation.

A commonality among many of the studies reviewed is the emphasis on local and, more importantly, discrete characteristics of the built environment, from land use to streetscape and road design. This is not to say that variables related to a broader context have not been included in the study of walking behaviour. For example, contextual variables relating an individuals' location relative to regional opportunities have been used when examining walking to work (Ewing, 1995; Cervero & Kockelman, 1997; Kasturi *et al*., 1998; Ewing & Cervero, 2001), or non-work travel (Handy, 1992, 1993). However, what is absent from prior studies of walking behaviour is relating discrete measures of the built environment, such as local street connectivity, to the function they provide: connectivity to where? These relational properties of street designs link the design of local street attributes with their functional aspects. Relational properties summarize how spaces are related to each other within the urban system, thereby facilitating or impeding activities. This study responds to the paucity of research on the relational aspects of urban form by utilizing a space syntax approach to relate the syntactical properties of street design in a New Urbanist and conventional neighbourhoods with walking behaviour. The next section introduces space syntax concepts used in this study.

Space Syntax Theory and Methodology

Space syntax theory describes and measures quantitatively the relational properties of urban space (for a review see Hillier & Hanson, 1984; Hillier, 1996). Such relational properties rest on assumptions that longer lines of sight, fewer turns, higher connectivity and a high ability to reach points from every other point in space are desirable. The evidence, reviewed below in detail, has

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shown a positive relationship between the occurrence of activity and spaces that exhibit these desirable properties.

In developing the quantitative syntactical measures, street layouts are first transcribed into appropriate representations of their spatial structure called 'axial maps'. The axial map is a network of intersecting lines that consists of the longest sets of lines of sight that pass through all the open spaces in a study area (Kim & Penn, 2004). Intuitively, two individuals standing at each end of an axial line will be able to see each other. The underlying intent of measuring axial lines is that changes in direction and the presence of intervening streets are more likely to affect individual's sense of orientation within a complex plan than sheer length of streets (Hillier & Hanson, 1984). Second, the axial lines are used to calculate a set of measurements of syntactical properties of space (Hillier & Hanson, 1984). Each measure is assigned to each axial line on the map. Commonly calculated syntactical measures include connectivity, control and integration, which are defined next.

The connectivity of a line (roadway, alley or trail) is the number of lines that are directly connected to it. A modification of connectivity is control, which measures the degree to which a line controls access to its immediate neighbours taking into account the number of alternative connections that each of these neighbours has (Klarqvist, 1993). Simply, control value represents the degree to which a line is important for accessing neighbouring lines. A high control value indicates that the line is an important, almost necessary, link for neighbouring lines. To better understand this concept, consider a straight street segment that is connected to three different dead-end streets and another street segment that is connected to three other non-dead-end streets. The former street segment has higher control value, as access to any of the three dead-end streets is possible only through the segment. The later street segment has lower control, as there are alternative streets to access the three non-dead-end streets. In addition, a street segment that has more connections potentially will have a higher control than a street segment that has fewer connections, as shown in Figure 1. Therefore, this study uses control as a measure of local connectivity, expecting that residents of streets with higher control lines will be more likely to walk than residents of streets with lower control.

Integration is an indicator of how easily one can reach a specific line of the axial map. Mathematically, integration is an algebraic function of the number of axial lines that must be traversed if one were to move from every line (street) to every other line (street) in the axial map. The higher the integration value of a line, the lower the number of axial lines needed to reach that line. For a given line, integration can be computed in terms of access from all other lines (called global integration) or in terms of those lines that are accessible up to a given number of lines away (called local integration). In syntactical analysis this is called the radii. If we limit the analysis to radius of 3, it means that the integration measure for a line will be calculated by considering only lines that are up to three turns away. Therefore, local integration can be a measure of local syntactical accessibility if the radius is small (Hillier, 1998) and global integration can be a measure of general syntactic accessibility if the radius considers all lines in the axial map (Peponis & Wineman, 2002). The axial line with the highest degree of global integration would be the one that could be accessed with the least number of turns from all other axial lines. By contrast, an axial line that requires many turns to get to it from all other lines in the system is considered to have low syntactical accessibility and

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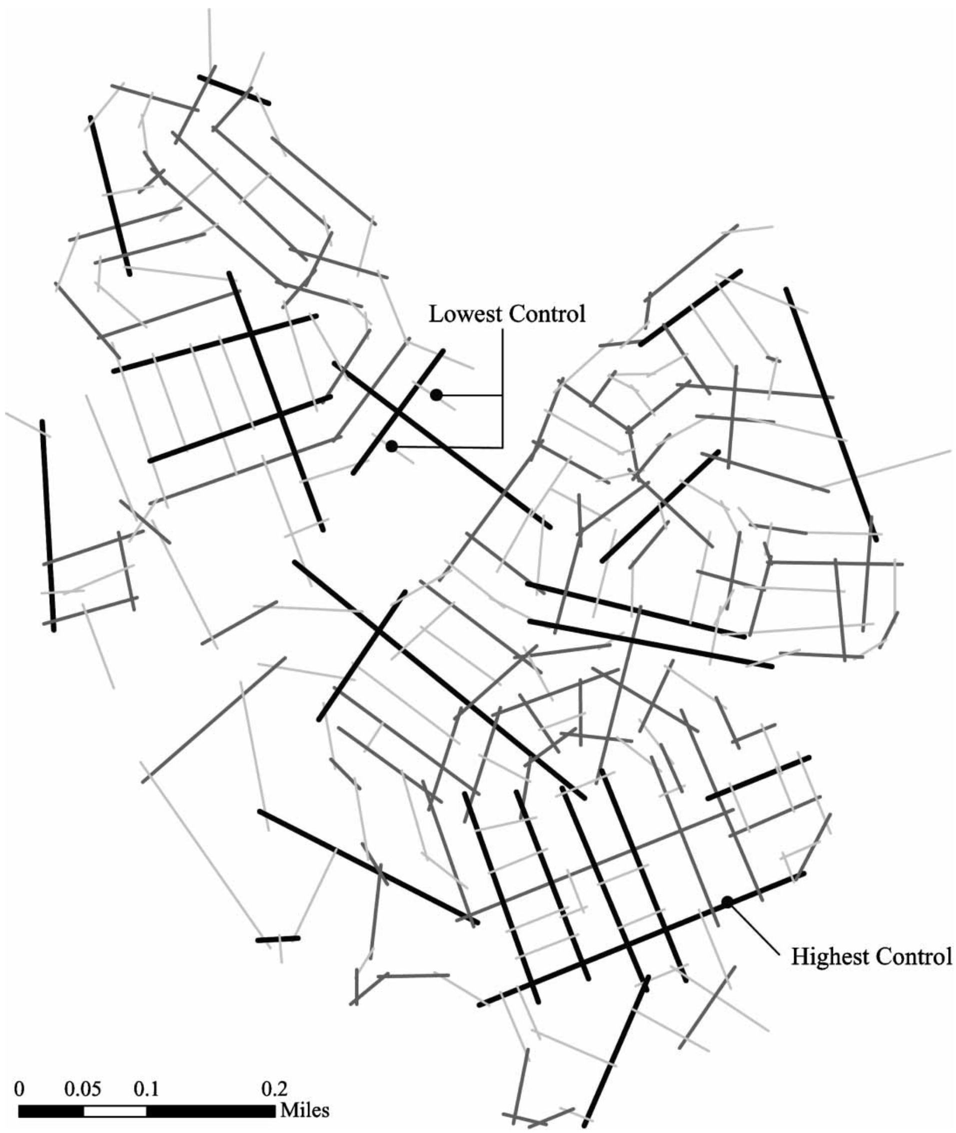

Figure 1. Axial map of the pedestrian network for the New Urbanist neighbourhood; the 10% highest control lines shown in heavy black and the 50% lowest control lines shown in light grey.

will have a low global integration value. Similarly, an axial line with the highest local integration value is a line that is accessible with the least number of connections from all other lines in its surrounding (Figure 2). This study uses a measure of local integration (radius 3) and global integration.

The ability of space syntax to describe global configuration properties of street design as well as relationships of part-to-whole quantitatively provides an important advantage over the existing methods of measuring street connectivity and syntactical accessibility. By attaching configurational measurements to each street segment in a study area, relationships between individual behaviours and those measurements can be examined. The evidence to date has focused mainly

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Figure 2. Axial map of the pedestrian network for the New Urbanist neighbourhood; the 10% local integration core shown in heavy black and the 50% locally most segregated lines shown in light grey.

on the presence of activity on a street, finding that high integration streets have a higher number of pedestrians and car movements (Hillier & Hanson, 1984; Peponis *et al*., 1989; Hillier *et al*., 1993; Hillier, 1996; Penn *et al*., 1998; Read, 1999; Hillier, 2001; Raford & Ragland, 2006). In addition, the syntactical properties of space have been used in explaining crime occurrence (Reis *et al*., 2003; Shu & Huang, 2003; Hillier & Sahbaz, 2005; Nubani & Wineman, 2005; Baran *et al*., 2006; Long & Baran, 2006a), pedestrian safety (Raford & Ragland, 2003), and spatial cognition (Kim, Y., 2001; Kim & Penn, 2004; Long & Baran, 2006b). Overall, it is expected that people who live on well-integrated streets, locally and globally, will show greater propensity to walk.

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Despite the usefulness of space syntax as a framework for describing and measuring local and global properties of street configurations, to the authors' knowledge no research has related the walking behaviours of individuals residing on axial lines with varying syntactical properties. This study contributes to understanding relationships between the syntactical properties of street design and walking behaviour. Formally, positive relationships are expected between the three syntactical measures and both utilitarian and leisure trips.

Research Design and Methods

The approach in this study is to integrate walking behaviour and demographic data collected through mail surveys and travel diaries with a set of objective measurements of the configurational properties of space calculated using the space syntax methodology in carefully selected neighbourhoods. A quasi-experimental research design is utilized (Shadish *et al*., 2002) matching a large New Urbanist neighbourhood with a set of conventional suburban neighbourhoods in close proximity to each other, located in the Chapel Hill-Carrboro area in North Carolina's Research Triangle region. The New Urbanist neighbourhood was built in the late 1990s and at the time of the study, some of the commercial space was occupied and so were most of the residences. The conventional neighbourhoods were chosen to match age of development, proximity to regional employment sites, average assessed value of single-family homes in the neighbourhood, school system and transit provider of the New Urbanist neighbourhood.

Despite their shared characteristics, the two neighbourhoods have key differences that make each group of neighbourhoods prototypical of conventional and New Urbanist developments. These differences include the following: lot sizes (single family homes in lot sizes of 0.16 acres for the New Urbanist neighbourhood versus 0.4 acre lots for the conventional neighbourhood), presence of commercial land uses in the neighbourhood (the New Urbanist neighbourhood has approximately 18 580 square metres of commercial space while the conventional neighbourhood has no commercial space), net density (2.4 times higher in the New Urbanist neighbourhood), type of residences (New Urbanist has single family, rowhouses and multifamily units, whereas the conventional neighbourhood has single family units only), presence of sidewalks (one side versus both sides of the street), presence of bicycle and walking trails, and street pattern (the New Urbanist neighbourhood has shorter, more connected streets than the conventional neighbourhood) and street density. The syntactical properties of the neighbourhoods are described in detail below.

Between March and May 2003 a mail-in mail-back survey instrument was distributed to all households in both neighbourhoods. The survey also included an activity/travel diary. A total of 920 household surveys and diaries were distributed in the New Urbanist community and 891 household surveys in the conventional neighbourhood. To increase response rates, a postcard was first mailed to each household alerting the residents about the forthcoming survey. A $10 certificate for a local grocery store was used as incentive for completing the survey. One postcard reminder was sent to non-responders and up to two follow-up telephone calls were made to ensure a high response rate.

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The survey was composed of two sections. The first section, to be filled out by the head of household, focused on the respondent's household attributes, attitudes and preferences for the built environment and demographic characteristics. Section two of the survey consisted of an activity/travel diary with detailed instructions for completion. The diary design and majority of questions were developed based on the 2001 National Household Transportation Survey (NHTS). The NHTS defines a trip as travel from one address to another. Because this excludes leisure walking trips in which no destination address would be available, this definition was expanded to include travel "from one place to another" involving "movement of more than 300 feet. These include walking for exercise, walking dogs, bike rides, etc". The diary was directed toward obtaining detailed data on trips and miles by travel mode and trip purpose, with a special emphasis on walking behaviour. In order to link survey data with the street level measurements of syntactical properties, the survey data was geocoded using the respondents' home address information.

Outcome Variables

The outcome measures for this study were obtained from travel diary responses by heads of household. Walking trips were identified as either leisure or utilitarian based on responses to the travel purpose column. Trips for exercise and leisure, and trips that began and ended at home were identified as leisure trips. Other trips were identified as utilitarian and they include trips that are derived from the desire to access a destination, such as purchasing groceries, dropping off a relative somewhere or visiting a friend.

Independent Variables

Socio-demographic and household variables. Socio-demographic and household variables were obtained from the responses to the first section of the survey. These included age, gender, household size, vehicles per household and respondent's occupational status. Age was measured in years as a continuous variable; gender was coded as dichotomous variable (male = 1); vehicles per household and household size were coded as counts; respondents' occupational status included two indicators, being a student and being employed outside of home place, which were coded as dichotomous variables (student = 1; employed outside of home = 1).

Space syntax variables. Axial maps for the neighbourhoods were constructed using the street and parcel layers in ArcGIS 9 software. To test for differences between pedestrian and vehicular networks in explaining walking behaviour, an axial map for the pedestrian network and an axial map for vehicular network were developed, representing the spatial configuration of the two neighbourhoods. The pedestrian network includes all trails, alleys and pedestrian-only paths in addition to the vehicle network. The axial maps were then subject to syntactical analysis in Ovation software and the three variables of interest were calculated as defined by Hillier & Hanson (1984).

The global integration values for the pedestrian axial maps of the New Urbanist and conventional neighbourhoods are shown in Figures 3 and 4, respectively. The more globally integrated streets, shown with the darkest lines,

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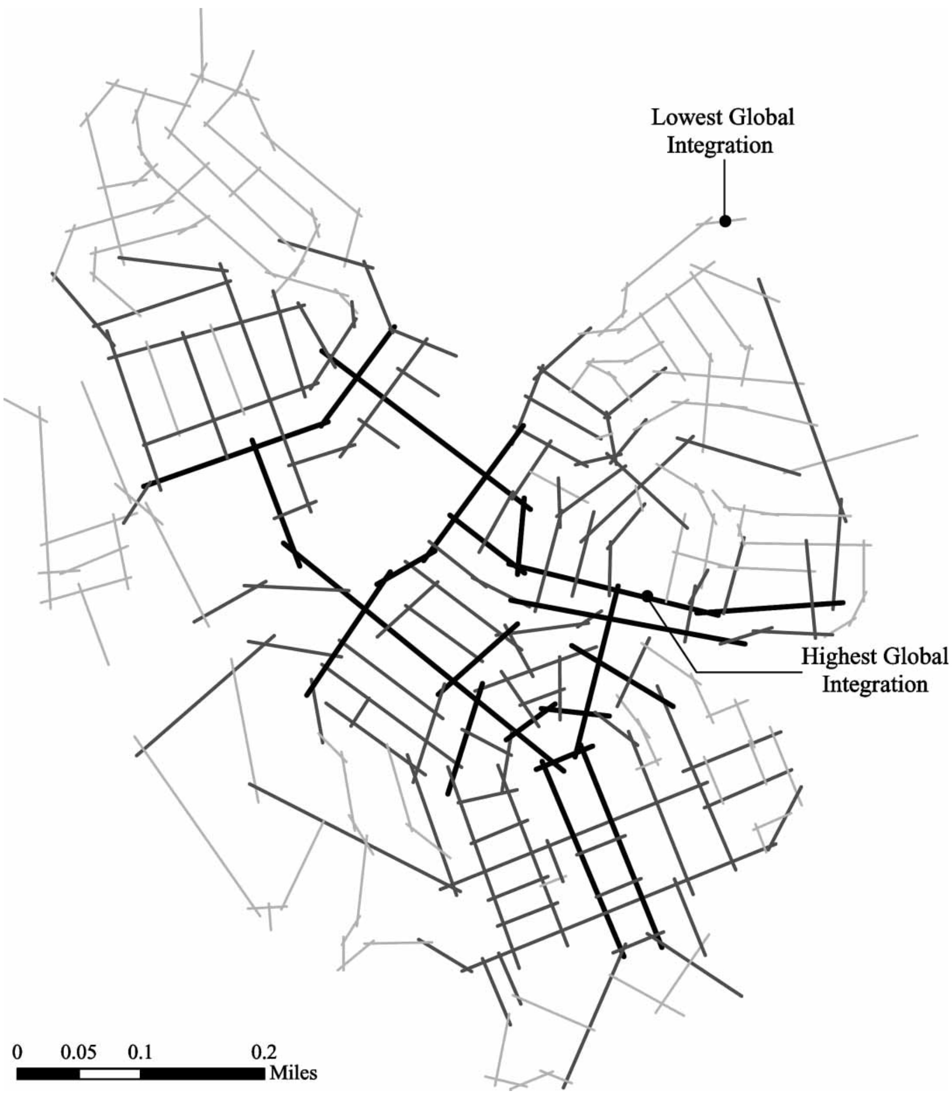

Figure 3. Axial map of the pedestrian network for the New Urbanist neighbourhood; the 10% global integration core shown in heavy black and the 50% globally most segregated lines shown in light grey.

are the most accessible streets from all other streets within the network, whereas the more globally segregated streets, shown with the lightest lines, are the least accessible streets. All street level syntactical properties data were linked to survey data using 'spatial join' procedure in ArcGIS 9. This procedure made it possible to assign all three street level syntactical measurements to each respondent based on the location of respondent's home in the street network.

Statistical Modelling

To examine the relationship between syntactical properties of space and walking behaviour while controlling for individual and household-level attributes, models were estimated in which number of walking trips by trip purpose (leisure or

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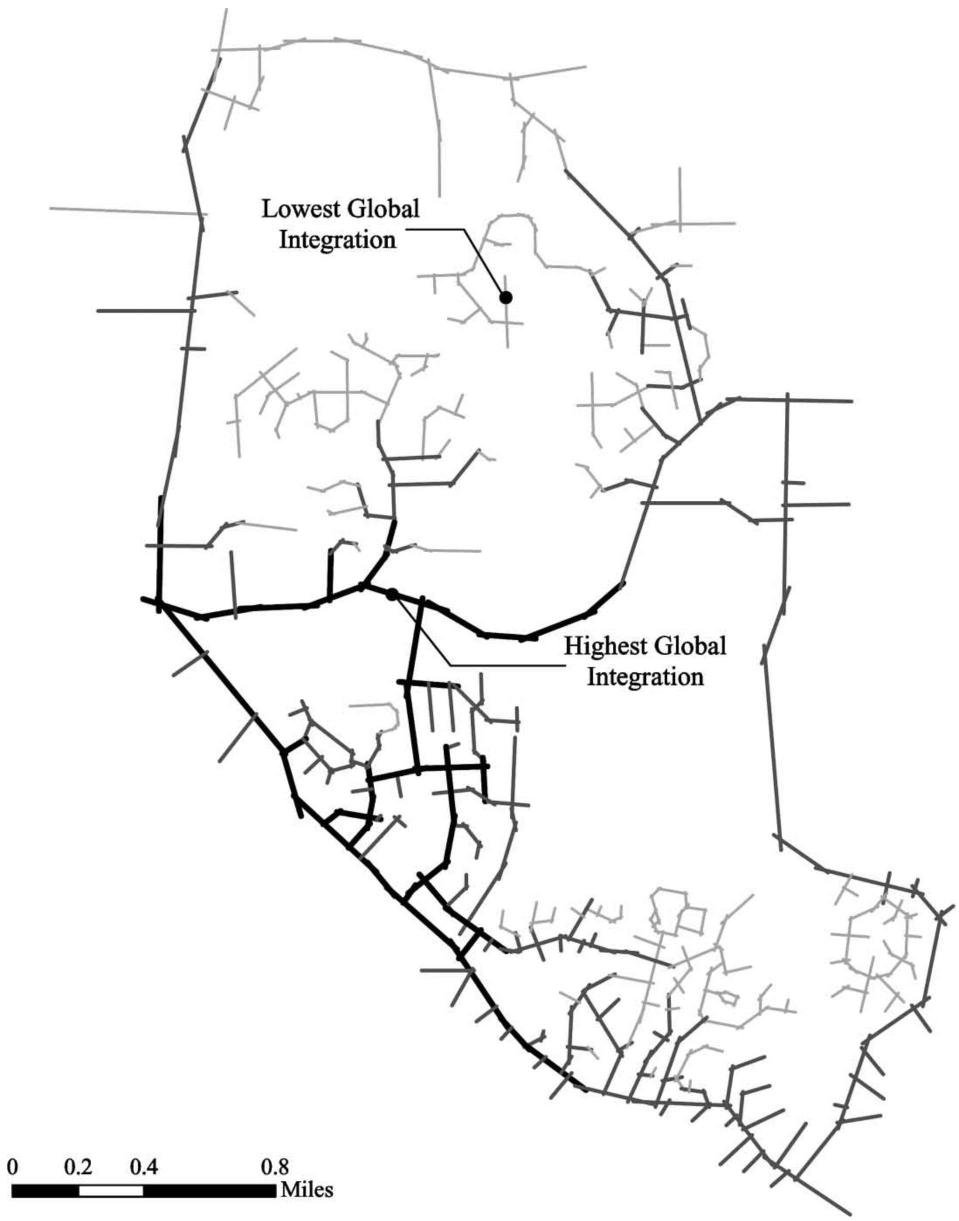

Figure 4. Axial map of the pedestrian network for the conventional neighbourhood; the 10% global integration core shown in heavy black and the 50% globally most segregated lines shown in light grey.

utilitarian) were the dependent variables, and demographic and syntactical variables were the independent variables. Count regression models were applied, such as Poisson and negative binomial models, which are the most appropriate modelling techniques for count data (Cameron & Trivedi, 1998). The Poisson model imposes a restrictive assumption of mean-variance equality, which is relaxed in a negative binomial model. Important summary statistics are if the model is statistically significant overall and the goodness of fit. Based on theory and statistical properties, the approach thus was to select the best fit among

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a number of count regression models. Once a preferred model was selected, the independent contribution of syntactical variables to the observed behaviours and their statistical significance were evaluated.

Descriptive Statistics

Sample Characteristics

Response rates of 26.4% ($n = 243$) and 23.6% ($n = 210$) were achieved for the New Urbanist and conventional neighbourhoods, respectively, which are comparable to similar studies. Clearly the length of the survey and filling out a travel diary by adult members of the household reduced the response rate. Although potential exists for non-response bias in such surveys, the responding individuals compared well in terms of demographic characteristics with the US Census Bureau information for this block group and a transportation survey conducted for the metropolitan planning organization in the mid-1990s. A total of 393 valid household head survey responses and 370 valid household head travel diaries were received. Of those, six addresses were not geocoded successfully and therefore the respondents were dropped from the analysis for a final diary sample size of 364.

Table 1 reports average values for socio-demographic and travel behaviour characteristics of household heads in each neighbourhood. Residents of conventional and New Urbanist neighbourhoods share similar characteristics in terms of employment outside of the home. Demographics are slightly different, with New Urbanist heads of household being slightly younger, less likely to be male, having a smaller household size and fewer cars and being more likely to be students than heads of household of the conventional suburban neighbourhoods. Household heads in the New Urbanist neighbourhood make 1.5 times more leisure trips (0.33/0.22) and 3.9 times more utilitarian trips (0.66/0.17) than household heads in the conventional suburban neighbourhoods. This large difference in utilitarian walking trips between the two study sites is expected, since the New Urbanist neighbourhood has a town centre accessible within a

Table 1. Average values for socio-demographic and walking behaviour characteristics of household heads by neighbourhood type

	Overall sample $n = 364$	Conventional neighbourhoods $n = 172$	New Urbanist neighbourhood $n = 192$	Sig.
Explanatory variables				
Age (years)	44.4	46.9	42.2	***
Male (%)	53.8	63.4	45.3	***
Vehicles per household	1.9	2.1	1.7	***
Household size	2.8	3.3	2.3	***
Employed outside the home (%)	73.1	76.7	69.8	
Student (%)	6.9	1.7	11.5	***
Dependent variables				
Leisure walking trips per day	0.28	0.22	0.33	*
Utilitarian walking trips per day	0.43	0.17	0.66	***

Notes: *** and * denote significance at 99% and 90% level of confidence respectively.

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quarter-mile for most residents, whereas the conventional neighbourhood lacks such town centre amenities.

Syntactical Properties of New Urbanist and Conventional Neighbourhoods

Syntactical characteristics of the study neighbourhoods for pedestrian and vehicular street networks are shown in Table 2. Comparisons between the conventional and New Urbanist neighbourhoods confirm the very distinct morphology of each. The New Urbanist neighbourhood is composed of shorter and fewer axial lines than the conventional neighbourhood. It is worth noticing that the vehicular and pedestrian networks in the conventional neighbourhood are almost identical in terms of the number of axial lines, pointing to the fact that there are no paths designed for pedestrian use only. By contrast, the number of axial lines for the pedestrian network in the New Urbanist neighbourhood is more than twice the axial lines for the vehicular network.

Comparison between the communities points also to substantial differences in their global and local integration properties. Higher global integration values indicate that the New Urbanist community has a grid with less depth and much less segregated streets than the conventional neighbourhood. This confirms that the street design pattern of the New Urbanist neighbourhood is more permeable and provides easier syntactic accessibility between streets than that of the conventional neighbourhood. The more globally integrated streets, shown with the darkest lines in Figures 3 and 4, are the 10% most globally accessible streets and the more segregated streets, shown in light grey, represent 50% most segregated streets in the neighbourhood street networks.

Mean global integration for the 10% integration core of both vehicular and pedestrian networks in the New Urbanist neighbourhood is 2.3 times higher than that of the conventional neighbourhoods: 1.26 and 1.24 versus 0.56 and 0.54, respectively. The structure of the 10% integration core also points to differences between the neighbourhoods. The integration core of the New Urbanist neighbourhood is centrally located with streets penetrating towards the outside boundary (Figure 3). This structure provides easy access to the commercial areas located within the integrated core from the surrounding residential areas. However, the integration core in the conventional neighbourhoods is localized in the southwest part of the tract (Figure 4), segregating most of the residential areas from each other.

Remarkably, significant variation within each neighbourhood was also found for local integration and control values, and less so for global integration. The range of control values for the pedestrian network in the New Urbanist neighbourhood is 0.2 and 3.84, while the range for the same variable in the conventional neighbourhood is 0.13 and 5.22.

Finally, for descriptive purposes the intelligibility of each of the four networks was calculated. Intelligibility is defined as the correlation between the connectivity and global integration values of a line in an axial map (Hillier, 1996). An intelligible design is one that is understandable by gleaning the structure of the global system on the basis of the structure of the local area (Peponis & Wineman, 2002). The intelligibility values of both vehicular and pedestrian networks of the New Urbanist neighbourhood are higher than that of the networks of the conventional neighbourhood; 0.50 and 0.53 versus 0.31 and 0.32, respectively. These results also point to differences in the spatial structure of the two neighbourhoods.

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Table 2. Descriptive statistics for syntactical parameters of New Urbanist and conventional neighbourhoods

		Pedestrian network			Vehicular network		
		New Urbanist neighbourhood	Conventional neighbourhood	Sig.	New Urbanist neighbourhood	Conventional neighbourhood	Sig.
Total number of axial lines		243	408		104	407	
Global Integration[a] (Rad = n)	Mean	0.91	0.42	***	0.84	0.42	***
	St.Dev.	0.18	0.08		0.18	0.07	
	Maximum	1.39	0.60		1.24	0.59	
	Minimum	0.53	0.22		0.53	0.21	
Local Integration[b] (Rad = 3)	Mean	1.86	1.30	***	1.74	1.29	***
	St.Dev.	0.68	0.66		0.55	0.66	
	Maximum	4.20	3.67		3.50	3.67	
	Minimum	0.21	0.21		0.50	0.21	
Control[c]	Mean	1.00	1.00		1.00	1.00	
	St.Dev.	0.57	0.68		0.47	0.68	
	Maximum	3.84	5.22		3.15	5.22	
	Minimum	0.20	0.13		0.13	0.13	
Axial line length (metres)	Mean	119.94	193.61	***	163.53	193.68	**
	St.Dev.	75.15	152.98		97.98	152.96	
	Maximum	471.04	1173.36		645.90	1173.36	
	Minimum	15.80	20.98		33.83	20.98	

Notes: *** and ** denote significance at a 99% and 95% level of confidence respectively.
[a] Degree of global syntactical accessibility.
[b] Degree of local syntactical accessibility.
[c] Degree to which a line controls access to its immediate neighbours.

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Results and Discussion

Separate regression models were estimated for each of the three space syntax measures (control, local integration, global integration) with each of the two walking outcome measures (leisure and utilitarian walking trips), yielding a total of six regression models. All space syntax measures were also entered into a regression with each dependent variable. In the end eight regression equations were estimated. Overall, the equations have low explanatory power. In this type of modelling the explanatory power of a model depends on many factors. One factor is the complexity of the phenomena being studied. If the phenomena are complex, as is in the case of walking behaviour, it is harder to explain it with available variables. This suggests that there can be a host of other variables at the personal, household and community levels that are not included in the current model but that may contribute to understanding walking behaviour.

The results of the first four models for total leisure walking trips are shown in Table 3. The models shown were estimated with the pedestrian network. Results of all leisure walking models indicate that Poisson regression is appropriate, providing a reasonable fit. The first three models indicate that only one of the syntactical measures, control value, has a positive (and statistically significant) relationship with total leisure trips made. However, the results of the fourth model that included all space syntax measures show statistically significant relationships for all three syntactical measures. The space syntax variables being significant when all three are included in the model is explained by the fact that the model is properly specified and that there is some colinearity that required the presence of the other variables for proper specification.

The overall results indicate that higher control values and higher global integration are related to a higher number of leisure walking trips, whereas higher local integration is related to fewer leisure trips. Consistent across all four models, the only demographic variables related to leisure walking trips are household size and being employed outside of the home, with both exhibiting a negative relationship. That is, fewer walking leisure trips occur as household size increases and as individuals are employed outside of the home, everything else held equal.

These findings confirm the a priori hypothesis that the number of leisure trips will increase with increased control value. To better understand the meaning of control, consider a street segment connected to five different dead-end streets. The street segment has high control, as access to any of the five dead-end streets requires traversing the segment. The dead-end streets have low control. It is not surprising, therefore, that some axial lines in the conventional neighbourhoods have very high control, whereas there is less variation in control values in the New Urbanist neighbourhood because of better overall connectivity. The results for control suggest that residents of streets that provide high control on the permeability of their neighbouring streets exhibited more leisure walking. Although it is not known with certainty what higher control axial lines afford for walkers, it is surmised that they provide good local connectivity. Indeed, control and connectivity are highly correlated in the study data (correlation coefficient = 0.71).

By contrast, local integration is negatively related to leisure walking, rejecting the initial hypothesis. This means that the more locally segregated the line on which a residence is located (i.e. the more the number of connections needed to reach it within its surrounding), the higher the leisure walking activity.

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Table 3. Poisson regression models of leisure walking trips ($n = 364$)

	Control			Local integration			Global integration			All variables		
	Coef.		Std Err.	Coef.		Std. Err.	Coef.		Std. Err.	Coef.		Std. Err.
Age (years)	−0.004		0.008	−0.003		0.008	−0.003		0.008	−0.003		0.008
Cars per household	0.220		0.174	0.260		0.173	0.288	*	0.174	0.276		0.177
Household size	−0.224	**	0.102	−0.212	**	0.104	−0.212	**	0.103	−0.217	**	0.103
Employed (yes = 1)	−0.325		0.215	−0.294		0.216	−0.294		0.215	−0.358	*	0.216
Control	0.297	**	0.130							0.718	***	0.245
Local integration				0.184		0.132				−0.681	**	0.318
Global integration							0.503		0.337	1.586	**	0.622
Constant	−1.122	**	0.506	−1.266	**	0.636	−1.324	**	0.641	−1.651	**	0.655
Model p-value	0.048			0.044			0.015			0.004		
Pseudo R-squared	0.023			0.027			0.029			0.043		

Notes: ***, ** and * denote significance at a 99%, 95% and 90% level of confidence respectively.

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One possible explanation is that residents may choose to walk more for leisure in areas that have less vehicular traffic. These results indicate that streets that are locally less accessible are related to more leisure walking. This is consistent with hypotheses suggesting that environments that support leisure walking may not support utilitarian walking, and vice versa (Pikora *et al*., 2003). Together with the results for control, the results of this study for local integration provide a more nuanced view of suggestions that the local environment may be less important for leisure trips than for utilitarian walking trips (Handy, 1992, 1996; Saelens *et al*., 2003; Rodríguez *et al*., 2006). The local street environment does seem to matter for leisure walking, but in different ways. Gateway or high control streets favour leisure walking, whereas high local integration seems to disfavour leisure walking.

Confirming the third hypothesis, the results indicate that global integration is positively related to leisure walking trips. The difference between the least globally integrated (0.22) and the most globally integrated axial lines (1.39) translates into 0.5 more leisure walking trips per head of household, holding everything else constant.

Table 4 summarizes the results of the four models for total utilitarian walking trips using the pedestrian network. Negative binomial models were found to be statistically superior to Poisson regression models in explaining utilitarian walking behaviour. The models are statistically significant and fit reasonably well. Results of the three independent regression models indicate that local integration and global integration have positive significant relationships with total utilitarian trips made. However, results of the fourth model that included all three measures revealed significant positive relationships for control and global integration, although the effect for control is marginally significant. Although local integration is significant in the model where it is entered by itself, it is not significant when all syntax variables are entered together. This could be explained by the moderate colinearity among the variables.

The overall results indicate that, for a given line, the lower the number of connections needed to reach it from all other lines (the higher the global integration), the higher the utilitarian walking activity of residents. These results support the expectations that utilitarian walking is related to higher control values and global integration. One explanation for the global integration results comes from research suggesting that routes with increasing numbers of turns are perceived as longer than routes with less angularity (Raghubir & Krishna, 1996; Jiang, 1998). Anecdotal evidence also suggested that utilitarian walkers may avoid too many crossings and intersections because they may pose greater safety hazards. Globally integrated streets provide direct accessibility and thus less angularity than streets that are not well integrated. Overall, neighbourhoods that offer highly accessible streets to their residents appear to offer more route choices and more direct routes between home and destinations. Others (e.g. Peponis & Wineman, 2002) have suggested that by attracting more pedestrians and car users globally integrated streets may create livelier streets, which also may play role in people's decision to walk to a destination (Handy, 1996; Zimring *et al*., 2005).

Comparisons of the above leisure and utilitarian walking models with the models estimated using the vehicular network, suggest that the pedestrian network has slightly better explanatory power than the vehicular network. A statistical test developed by Clark (2003) shows that the difference in explanatory power is not large enough to be deemed statistically significant for leisure

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Table 4. Negative binomial regression model of utilitarian walking trips ($n = 364$)

	Control			Local integration			Global integration			All variables		
	Coef.		Std. Err.	Coef.		Std. Err.	Coef.		Std. Err.	Coef.		Std. Err.
Age (years)	−0.042	***	0.014	−0.037	***	0.014	−0.040	***	0.014	−0.041	***	0.014
Cars per household	−0.718	**	0.287	−0.675	**	0.282	−0.561	**	0.279	−0.648	**	0.287
Household size	0.142		0.150	0.202		0.150	0.220		0.146	0.260	*	0.149
Employed (yes = 1)	−0.374		0.380	−0.393		0.372	−0.359		0.361	−0.456		0.369
Control	0.249		0.227							0.646	*	0.363
Local integration				0.496	**	0.213				−0.587		0.446
Global integration							1.901	***	0.550	2.927	***	0.948
Constant	1.686	*	0.918	0.528		1.026	−0.151		0.997	−0.454		1.060
Log(alpha)	1.770		0.209	1.716		0.211	1.630		0.213	1.599		0.214
Model p-value	0.000			0.000			0.000			0.000		
Pseudo R-squared	0.031			0.039			0.051			0.057		

Notes: ***, ** and * denote significance at a 99%, 95% and 90% level of confidence respectively.

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walking, but for utilitarian walking trips the difference is significant ($p < 0.01$). This finding has two implications. First, changes in the syntactical properties of space introduced by paths and alleys in the New Urbanist neighbourhood help to explain utilitarian walking behaviour better than leisure walking. Second, designers, planners and researchers should be aware that in addition to providing access and egress convenience and visual appeal, pedestrian-only segments also help in the movement to and from destinations in the neighbourhoods studied. This confirms the role that these segments play in frequency of walking trips and defies the view and practice that transportation planners and operators should focus on prominent streets that carry most pedestrian and vehicular traffic.

One concern with the results presented thus far is that the syntactical measures may be measuring the difference between the New Urbanist and the conventional neighbourhoods, but that any syntactical variation within each neighbourhood is meaningless. To examine this, all models were re-estimated with an indicator variable for neighbourhood type (1 = New Urbanist neighbourhood, 0 otherwise). The indicator variable was not significant in any of the models, partly because of its high colinearity with the space syntax measures. However, the results of the space syntax measures in these new models were similar to the results of the models presented above.

A second concern, related to the study design, is that the relationships identified can be interpreted solely as associations. It is probable that individuals or households with preferences towards certain travel behaviours (such as utilitarian walking) will choose built environments that support those behaviours. Thus, with this research design any relationships between the built environment and physical activity may be the result of individual preferences for activity in such environments. To a limited extent those preferences were captured by including socio-economic variables in the models. Similarly, the study is limited in the ability to generalize to other neighbourhoods or regions. Additional research should examine the degree to which any relationships found with this design exist elsewhere.

In summary, the results support expectations that the relational properties of street design and layout explain walking behaviour. This contrasts with prior evidence suggesting that the street network pattern was not related to travel decisions (Crane & Crepeau, 1998). More specifically, both the quality of local relational properties and the quality of global relational properties of street design play a role in encouraging or discouraging walking trips. Other studies (e.g. Meyer & Dumbaugh, 2004) have suggested that straight lines of sight can create potentially dangerous environments for walkers and cyclists due to vehicular speeding. However, the findings here for residential neighbourhoods suggest that directness and accessibility are important for utilitarian walkers, holding everything else equal. Therefore, street designs that achieve directness should also be made safe for pedestrians, perhaps through measures such as traffic calming or design improvements.

Conclusions

This study examined how space syntax measures of New Urbanist and conventional suburban neighbourhoods are associated with walking patterns of residents in these communities. In particular, relying on geographic information systems, survey data and travel diaries, the study examined the relationship

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between three quantitative measurements of syntactical properties of space as defined by space syntax theory and walking behaviour, while controlling for individual- and household-level attributes in a large New Urbanist community and a conventional suburban neighbourhood. It was hypothesized that residents of streets with higher connectivity and control, greater local integration and greater global integration will exhibit more walking behaviour than individuals residing in other streets.

A descriptive comparison of the syntactical measures for the two neighbourhoods confirmed the authors' views with regard to the New Urbanist and the conventional neighbourhood designs: the New Urbanist neighbourhood has more globally accessible streets (higher mean global integration) while the conventional neighbourhood has more locally segregated streets (lower mean local integration) than the New Urbanist neighbourhood. Both have similar control values. However, this comparison also masked important variations in design characteristics throughout the two neighbourhoods, which were explored through statistical analysis.

The results of the statistical analysis suggest that both local and global relational properties of street design and layout explain walking behaviour. Namely, control and global integration values of a street segment are positively associated with both total leisure walking trips and total utilitarian walking trips, independent of the neighbourhood in which the person lived. The results suggest that residents of streets that provide high control on the permeability of their neighbouring streets and are globally more accessible exhibited more leisure walking and utilitarian walking, whereas residents of streets that are locally more accessible exhibited less leisure walking. Furthermore, it was found that paths and alleys in the New Urbanist neighbourhood do not add significantly to explaining leisure walking behaviour but do so to utilitarian walking behaviour. This result confirms the usefulness of paths and alleys beyond their aesthetic appeal and their functional capabilities of providing access and egress to and from home.

The findings of this study are relevant for planners and designers. For example, transportation planners interested in estimating development impacts have a fairly good idea of how demographic factors influence trips. However, they do not capture the relevance of the interaction between streets and land uses, or as shown here, the relational properties of street configuration. The analysis confirms the expectation that the demand for walking travel varies with the configurational properties of urban space. To yield more accurate travel impact assessments, this study has demonstrated that a finer-grained categorization of streets, using space syntax, can better explain walking behaviour.

To reinforce (or contradict) the findings, future research should examine the relationships between syntactical measures and walking behaviour in other regions. Additional research is needed to examine whether the relationships found are persistent in intelligible and unintelligible neighbourhood designs. Space syntax research has suggested that the association between space syntax measures and observed movement weakens in unintelligible environments (Hillier, 1996). Research has also suggested that the size of the buffer area around the study area used to develop the axial map plays a role in calculation of syntactical measures, which in turn may impact the relationships between syntactical measures and movement (Stahle *et al.*, 2005) and consequently the relationships between syntactical measures and walking behaviour. Additional research should consider neighbourhood design as part of the larger urban system.

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This study has shown that the quality of local relational properties and the quality of global relational properties of street design and layout play an important role in explaining walking behaviours. The results are not surprising since the relational descriptions developed by space syntax theory have a solid behavioural basis, i.e. visibility in respect of movement (Hillier, 2005; Stahle *et al*., 2005). Study findings suggest that urban designers and planners should expand their consideration of how street design influences activity beyond the local purview, to understand how these relate to other streets and destinations in the vicinity. A broader conception of street design, one that emphasizes fit within the neighbourhood and its activity magnets, seems supported for New Urbanist or conventional suburban developments.

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