Assessing Walkability in the City of Buffalo: Application of Agent-Based Simulation

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Abstract: Significant research has been conducted on how environmental attributes influence people's decisions to walk. In much of this research, however, environmental attributes are averaged for neighborhoods or census geographies for sampled populations. Moreover, the effect of an agent's walking choices on other actors is not adequately represented by either objective or perceived measures in the literature. Macro-level patterns of walkability arise from interactions across actors and urban environments. The agent-based approach allows for modeling individual uses of the environment by treating the populations as objects that can interact with the environment and other people. This study builds on previous research on pedestrian movement and geographic information system (GIS) measures of the built environment using the agent-based approach to explore the dynamics of the built environment and people's decision-making processes concerning walking. The results show that models that take individual perspective into account and include social interaction can better capture characteristics of the built and social environment that influence people's walking choices. This method lays out a new framework for assessing macro-level patterns of walkability across a city using micro-level data. **DOI:** 10.1061/(ASCE)UP.1943-5444.0000147. *© 2013 American Society of Civil Engineers.*

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Introduction

The direct and indirect costs of health issues related to overweight and lack of physical activity are measured in billions of dollars every year in the US (CDC 2004; Finkelstein et al. 2003). In recent years, we have seen a significant increase in research on how walking contributes to the health and quality of life of cities and residents (Forsyth et al. 2008; Warburton et al. 2006; Lin and Chang 2010; Southworth 2005). Many studies have revealed a correlation between characteristics of the built environment, including all human-made physical structures and infrastructure, and the increasing health problems linked to an inactive lifestyle due to automobile dependency (Frank and Engelke 2002; Doyle et al. 2006). Studies have suggested that enticing people to walk may be the best way to reduce obesity and associated health risks and to help improve health (Sallis et al. 2004; Williamson 1999). These studies help urban planners, urban designers, and decision makers to rethink the planning and design of the physical environment at the local, regional, and state levels to provide pedestrian and bicycle access and to increase physical activity (Southworth 2005; Owens 1993; Al-Azzawi and Raeside 2007; Ben-Joseph and Warner 2011). Building walkable and livable communities to provide a pedestrian-friendly and pedestrian-safe environment that encourages people to engage in physical activities has become an increasingly important goal for many federal and local governments (Southworth 2005; Rahaman et al. 2012).

Many built environment variables have been examined concerning their influences on people's decisions to walk. The amount and intensity of pedestrian physical activity in a neighborhood is found to be positively associated with the physical design of the neighborhood where people live (Moudon et al. 1997; Shriver 1997; Roemmich et al. 2006, 2007; Frank et al. 2006; Rodriguez et al. 2006; Ewing et al. 2011; Handy et al. 2009; Aultman-Hall et al. 1997; Randall and Baetz 2001; Samimi and Mohammadian 2010; Southworth 2005). Environmental attributes such as accessibility, opportunity for activity, safety, and aesthetics are linked to physical activity behavior (Humpel et al. 2002; Southworth 2005; Albert et al. 2011). A host of studies have linked population density, land-use mix, proximity of services, street connectivity, presence of footpath, connectivity, traffic volume, and speed to transportation mode choices of walking or driving (Cervero and Kockelman 1997; Sallis et al. 2004; Saelens et al. 2003; Frank and Engelke 2001; Ewing 2005; Kitamura et al. 1997; Landis et al. 1999; Cervero and Radisch 1995).

Perceived and objective measures are the two types of environmental characteristics measures currently used. Perceived measures are often collected through self-reported surveys, and objective measures are often made using GIS (Frank et al. 2004, 2006; Ewing et al. 2011; Lotfi and Koohsari 2011; Amistad 2010). The spatial analysis capability of GIS in recent years has helped to explore and measure physical factors objectively such as residential population density, street connectivity, ratio of retail, and proximity of services to test the influences of such variables on encouraging and stimulating physical activity (Frank and Engelke 2001; Saelens et al. 2003; Roemmich et al. 2006, 2007; Southworth 2005).

Despite increased understanding and interest in making US cities more walkable, planners and policymakers still have limited resources and tools to use to assess walkability across a whole city

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combing objective and subjective measures. Many recent studies measured the built environment based on neighborhoods for sampled population such as, for example, 0.8-km (half-mile) radius around residences, 1.6-km (1-mile) radius, 5-min walking areas, 10-min walking areas, and census tracts (Krizek and Johnson 2006; Raja et al. 2010; Frank et al. 2006; Cervero and Duncan 2003; Roemmich et al. 2006, 2007). Individual behaviors are averaged across these neighborhoods and measured for pieces of the studied cities for the sampled population. Moreover, how one person's walking choices affect other people's choices is not adequately represented in either objective or perceived measures currently used. Literature from the 1980s suggests that people feel more comfortable or are more willing to walk if they see other people walking in the area (Whyte 1988; Appleyard et al. 1981). William H. Whyte wrote in his book *City: Rediscovering the Center* that "what attracts people most, it would appear, is other people" (Whyte 1988). The macro-level patterns of walkability in a city are a result of the dynamic interactions between people and their built environment and between people who are using the environment.

The physical design of neighborhoods may be more appropriately interpreted and measured from the perspective of individuals who use neighborhood spaces. Various technologies have been used to develop virtual environments that help test how humans respond to the landscape and actions of other people (Lewin 1951; Al-Azzawi and Raeside 2007; Zacharias et al. 2005). Many models and measures have been developed with respect to pedestrian movement and flow and group dynamics including agent-based models of pedestrian movement and space syntax measures (Lewin 1951; Hillier and Hanson 1984; Al-Azzawi and Raeside 2007). These studies, however, are focused on modeling individual pedestrians' movement experiences or pedestrian flow rather than a large-scale assessment of walkability related to walking and public health.

Simulation is useful for modeling systems where there are nonlinear and complex interactions among variables (Parker et al. 2003; Benenson et al. 2002; Torrens et al. 2011; Yin 2009, 2010; Yin and Muller 2007). The agent-based simulations can provide insight into complex and unexpected interactions among variables or agents in the real world (Axtell 2003). Individual usage of the urban environment can be simulated by treating the populations involved as objects that can interact with the environment and other agents to generate macro-level patterns of walkability across a city. This study builds on previous research on agent-based pedestrian models (Torrens et al. 2011) and GIS measures of the built environment using the agent-based approach to explore the dynamics of the built environment characteristics and social environment in people's decision-making processes concerning walking and to provide a framework for assessing macro-level walkability patterns across a city using micro-level data. We use the city of Buffalo as our case study area and aim to represent walkability patterns similar to that found in Buffalo using the agent-based approach that can help model the interaction between the walking preferences and the heterogeneity of the landscape and model how other agents' walking choices would feed back into walking decisions.

Trips and Built Environment Measures for Walking

Walking trips usually have an origin-destination component and a path component. A trip has an origin and one or a few destinations. Every trip passes through spaces on the way from origin to destination. Street connectivity and integration are two variables that focus on the path component to measure how the built environment affects levels of walking activity (Sallis et al. 2004; Hillier and Hanson 1984). The literature also suggests that pedestrian movement is influenced by the number of turns made (Hillier and Hanson 1984; Hillier et al. 1983; Ueno et al. 2009). Streets from which other streets can be reached with fewer turns, therefore, attract more people. These variables help measure how easy and close it is to walk from one place to other places (Hillier and Hanson 1984; Hillier and Iida 2005).

The predominant method of measuring street connectivity in the planning and public health literature is to use GIS to calculate the number of street intersections or the number of blocks per unit area. When the study area is a city, the measure of street connectivity is usually the number of street intersections per mile of street length network in a census boundary such as census block or block group. Such measurement aggregated and averaged information to the census blocks or census block groups. There are few studies that have included the influences of street integration or number of turns one has to make on the way to destinations.

Space syntax represents space as a network of visual lines of movement and attempts to study human behaviors from a spatial configuration point of view. It provides a spatial configuration description of an urban environment by a connectivity graph representation for the computation of spatial properties, such as how each node in the network links to other nodes. Connectivity and integration are two space syntax measures that calculate the level of accessibility of a line segment from other line segments in a spatial environment. Connectivity is calculated as the number of lines that are connected to a specific line, and therefore, is an indicator of how well a line is intersected by others or how well interconnected the lines are in a neighborhood.

Integration measures the degree of ease to which a line can be reached from other lines in a system. A more integrated space can be reached easily from other spaces and a more segregated or a less integrated space would require traveling through many spaces. A more integrated space also has a better visual field and movement potentials. Integration is found to be correlated well with the number of pedestrians walking along the street lines (Hillier et al. 1983; Jiang et al. 2000). Studies also showed that people are safer in more integrated spaces (Hillier and Shu 2000). These space syntax measures help to describe the accessibility of an urban place as well as how easy a place is for people's navigation and exploration when walking, and understand the propensity of paths to be chosen on the way from origins to destinations (Hillier et al. 1987; Hillier and Iida 2005).

Another factor that is related to the path component of a walking trip is safety. Safety has been a focus of much of the literature as a major barrier to walking (Zweig et al. 2002; Knoblauch et al. 1995; Campbell et al. 1998). The consideration of safety includes how the street design help to control automobile speed, whether streets are shaded by trees to protect pedestrians, and other physical factors. Moreover, the crime rates also influence people's perceptions of safety of walking in the area.

Street patterns not only influence pedestrian movements, they also attract shops and over time shape land use patterns, which are related to the origin-destination component in a walking trip. Some land uses such as retail attract pedestrians. Literature also suggested that food stores can seed a place with activities (Whyte 1988; Raja et al. 2010). Parks, schools, libraries and public spaces provide places for the public to gather, walk, and play. Multiple points of interest and diverse activities in a neighborhood provide choices of things to do to help attract people to walk in the area. Many studies measured the origin-destination component at a macro-level using GIS. There are a few studies that measured built environment variables in a half-mile-radius neighborhoods or 5-min walking areas of a limited number of subjects studied (Roemmich et al. 2006, 2007; Raja et al. 2010).

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This study considered the factors on both the origin-destination component and path component of a walking trip to examine whether an area's physical environment was supportive or unsupportive of walking behaviors from the individual resident's perspective around the individual's residence. This study used space syntax to help measure how easy it is to travel from one place to another. In addition to measuring both types of components objectively, one additional path component factor in people-attract-people was also introduced and was identified in the urban design literature but rarely used in studies that examine the association between the built environment and health (Whyte 1988; Appleyard et al. 1981). The use of the agent-based approach makes it possible to add this subjective measure to how people's walking choices are influenced by other people's preferences and choices. By examining attributes that impact walking, this study will help elucidate what features constitute a pedestrian-friendly environment that encourages walking.

A range of physical and social environmental characteristics that were identified in the health and planning literature as influencing transportation choices and promoting walking was used and applied to the city of Buffalo, New York. The results of the study can help assess walkability in large-scale areas and understand the design elements of the built environment that are pedestrian-friendly and inform decisions about zoning, transportation, and land use that influence the distances people travel and whether or not they choose to walk.

Method

Study Area

The study area was the city of Buffalo, New York (Fig. 1); it is approximately 135 km^2 with Main St., Delaware Ave., Elmwood Ave., and Bailey Ave. serving as north-south arterials. A metro rail runs beneath Main St. connecting the inner suburbs to the heart of downtown. Elmwood Village was recently ranked the third best neighborhood by American Planning Association's Great Places in America Program (American Planning Association 2007). Elmwood Strip in the village features a string of boutiques, cafes, boutiques, galleries, and restaurants; sidewalk patios attract customers during the summer months. This is one of the few thriving areas that bring vibrancy to Buffalo's economy. Another important business strip is on Hertel Ave. in North Buffalo. Running east to west, the avenue contains many restaurants and popular nightspots, as well as many ethnic grocery stores and shops.

Buffalo has an abundance of green space. Three-quarters of city park land is part of the Olmsted Park and Parkway System designed by Frederick Law Olmsted, a landscape architect who designed many well-known urban parks including Central Park in New York City. The park system includes six major parks and eight connecting parkways scattered around the city. They provide places for diverse recreation and scenic enjoyment for Buffalo's residents and opportunities for economic development. The largest park of the park system is Delaware Park located between Main St. and Elmwood Ave. and south of Hertel Ave. Another major park is Cazenovia Park in South Buffalo. Sidewalks in the city run along all of the streets, and trees are planted between the traffic and the sidewalks for most of the streets. Parks and trees along the streets provide important incentives for walking in the city. In certain areas of the city, however, the crime rates are relatively high and few people are seen walking in the neighborhood.

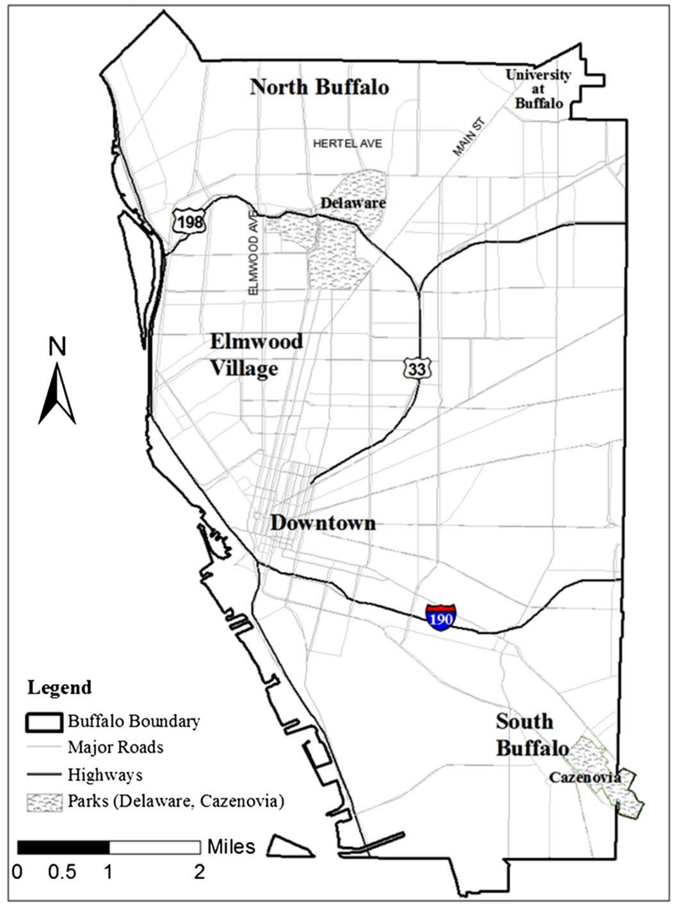

Fig. 1. Study area

Data Collection

Data on streets, parcels, crime rates, locations of restaurants and other eateries, grocery stores, bus stops, hospitals, libraries, parks, bike paths, city maintained trees, and vacant parcels were collected from Niagara Frontier Transportation Authority, Greater Buffalo-Niagara Regional Transportation Council, ReferenceUSA, New York State Dept. of Health, New York State GIS Clearinghouse, and the City of Buffalo (Table 1). Tabular data on locations of restaurants, grocery stores, hospitals, and libraries were geocoded in *ArcGIS* (ESRI, Redlands, CA) into shapefiles.

Pedestrian count data were also collected and geocoded for model validation. One pedestrian count data set was collected from Greater Buffalo-Niagara Regional Transportation Council. This data set, however, only pertains to major streets such as Main St., Elmwood Ave., and Niagara St.. To obtain citywide information, a grid was created to partition the city into 20 zones and data were collected in those zones in the fall and spring of 2006–2010. These data yielded enough information to capture consistent patterns of walkability in the city over the years. Approximately 1,500 points on streets in the city were selected to count pedestrians during peak and nonpeak hours in 10- to 15-min intervals. These data collected from the field were tabulated and geocoded. To validate the pedestrian count data, photos were taken when collecting counts and compared with the counts later in the lab.

Models

This section describes how micro-level models were constructed based on measures identified in the literature to explain observed

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Table 1. Data Source

Data	Source
Parcels	City of Buffalo, New York State GIS Clearinghouse
Streets and roads	Tele Atlas
Restaurants and other eateries	ReferenceUSA
Groceries	ReferenceUSA
Bus stops	Niagara Frontier Transportation Authority
Parks and parkways	City of Buffalo
Bike paths	Greater Buffalo-Niagara Regional Transportation Council
Libraries	New York State GIS Clearinghouse
Schools	Dept. of Education
Hospitals	New York State Dept. of Health
Census blocks	US Census
Trees	City of Buffalo
Crime rates	City of Buffalo
Pedestrian counts (a)	Geocoded
Pedestrian count (a) validation	Photograph
Pedestrian counts (b)	Greater Buffalo-Niagara Regional Transportation Council

patterns of pedestrian density. Three models were built in three phases. At the first stage, a suitability model/Model 1 was built to assess areas in the city in terms of their suitability for walking. The second and the third phases involved building agent-based models from individual residents' perspectives to explore the patterns of walkability arising from micro-level interactions between people and their built environment across the city. Interaction among people was added in the third model to capture suggestions from the literature that people are more willing to walk in places with other people (Whyte 1988; Appleyard et al. 1981).

Walkability was modeled with respect to built and social environment characteristics with two major components. They are origin-destination components and path components under four subcategories: (1) activities available in the neighborhood, (2) street network configuration in the neighborhood or accessibility, (3) pedestrian safety, and (4) street attractiveness and popularity among residents. These four categories reflect how people interact with the physical environmental and social characteristics of a neighborhood (Frank et al. 2006; Roemmich et al. 2006; Morland et al. 2006; Day 2006) (Fig. 2). Walkability was examined in this study for the entire city, which includes people with different income levels and socioeconomic statuses who may have different preferences among the various components. It was assumed in this study that nonweighted components or variables represented an average set of measures across the entire city. Table 2 provides a general framework on the variables used to represent the four major components.

Table 2. Physical Environment Characteristics and Variables

Attributes	Variables
Activities and uses (A)	Restaurants and other eateries, grocery stores, retail stores, parks, parkways, schools, libraries, bike paths, hospitals, tree-lined streets
Accessibility (N)	Connectivity, integration, street intersections, area within 10-min walk
Image and safety (S)	Crime statistics, vacant parcels
Sociability (C)	Number of people using place

Specific measures of the variables differ from model to model and are discussed in detail in each model section.

Suitability Model/Model 1

Suitability models are usually used to answer questions of where the best and worst locations are for a certain purpose. Such models weigh locations relative to each other on how suitable they are for a particular use based on given criteria. This study built a suitability model to rank the study area with respect to walkability using variables suggested in the literature and measured similarly to the method widely used in the recent literature [Eq. (1)]. The unit of analysis is 9×9 m$(30 \times 30$ ft$)$ cells covering the entire city. The result of the model is a map showing the relative suitability for walking and helps locate the most walkable areas in the city:

$$W = A + N - S \qquad (1)$$

where W = walkability score; A = density of (restaurants and other eateries + grocery stores + bus stops + parks + parkways + schools + libraries + bike paths + hospitals + trees along streets + housing units); N = density (of street intersections); and S = density (of homicide incidents + robbery incidents + vacant parcels).

Locations of restaurants, grocery stores, bus stops, schools, libraries, hospitals, housing units, street junctions, homicides, robberies, and trees were points. Parks and vacant parcels were polygons. Parkways and bike paths were lines. Kernel densities were created using GIS based on point and line data. Park and vacant-parcel polygons were converted into points, and a park density map was created using the information on the size of each park. A total of 16 density raster data sets were generated with cell sizes of 9×9 m$(30 \times 30$ ft$)$. Each raster data set was then reclassified to have a score range of 1–10, with 10 being the most walkable. Finally, these raster data sets were overlaid and the total value of each raster cell was added up as the walkability score for each 9×9 m$(30 \times 30$ ft$)$ cell in the city.

Agent-Based Models

The second and the third stages involved using the agent-based approach to build Models 2 and 3. These two models included all

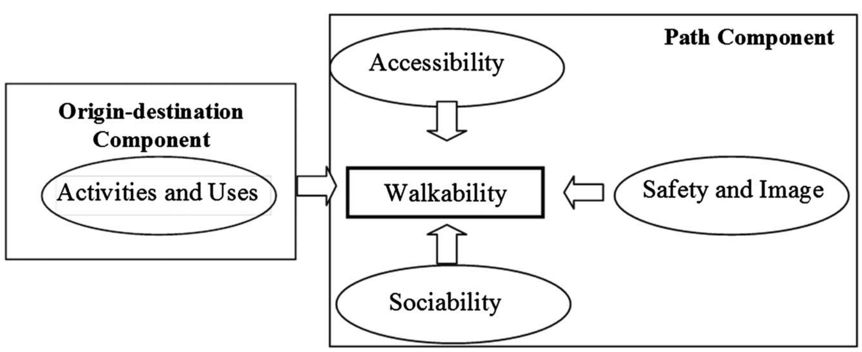

Fig. 2. What makes a place walkable?

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existing residential lots in the city and simulated dynamically where people would walk within a 10-min walking area around their houses based on a literature review (Raja et al. 2010; Frank et al. 2006; Cervero and Duncan 2003; Krizek and Johnson 2006). Each agent represents a resident living on a residential lot in the city assuming one resident on each lot. The assumption is based on a quick survey of housing density patterns in the city. More than 95% of all housing units are either single-family housing or duplexes; they are evenly distributed in the study area. Residents evaluate the environment in the area around their residence to decide where they will be walking. Using the agent-based approach, a large-scale space was modeled as a set of micro-scale, disaggregated, and heterogeneous spaces from individual residents' point of view. Moreover, this approach made it possible to include agent-environment and agent-agent interaction dynamically, which in turn allowed for integrating into the model the effect of one person's walking choices on other people's choices (Yin 2009; Parker et al. 2003; Yin and Muller 2007; Benenson et al. 2002; Torrens et al. 2011). The agent-based models were implemented using *ArcObjects* (Burke, 2002). An *ArcGIS* extension network analyst was used to calculate a 10-min walking area around each residential lot in the city.

Model design. Pedestrian behavior rules were designed based on suitability measures identified in the literature. For each agent, a 10-min walking area was created as neighborhoods, and then the 16 GIS layers on activities and uses (A), accessibility (N), and image and safety (S) were clipped out for the 10-min walking area. While walking speed is different for different age groups (Knoblauch et al. 1996; Milazzo et al. 1999), this study assumed an average walking speed of approximately 4.8 km/h as suggested by the literature. The resulting walking area for each lot was placed in a spatial database to be overlaid with other layers of information. All layers on activities and uses were polygons and were converted into a raster data set with 9×9 m(30×30 ft) resolution. The total number of raster cells for restaurants, grocery stores, bus stops, parks, parkways, schools, libraries, bike paths, hospitals, trees, and housing units in an agent's neighborhood was counted for each agent to represent the activities and uses category(A); the higher the count, the more activities and uses available in the 10-min walking area.

Two space syntax measures—connectivity and integration—were used to reflect how interconnected the lines were in a neighborhood and how easy a neighborhood was for walking. A centerline street file was used to construct a pedestrian route network for the entire city and imported into *Depthmap* (Hillier et al. 1983), an application developed by University College London to perform visibility analyses of spatial environments. *Depthmap* was used to generate an axial map and to perform axial map analyses and segment analyses to obtain connectivity and integration measures for the accessibility category (N). These two measures were converted into two grids so that each street cell carried values on connectivity and integration. Another measure of accessibility was the size of the 10-min walking area for each agent. This measure reflected the extent to which a street network was connected in an agent's neighborhood. The larger the area, the more interconnected the streets are and the greater the possibilities for accessing more activities in the area. In other words, in an area with good street connectivity, people can walk further away from home in 10 min and can potentially access more activities.

Three variables were included for the image and safety category (S). Homicide incidents and robbery incidents were point data; vacant parcels were polygons. They were converted into a raster data set using a cell size of 9×9 m(30×30 ft). The total number of cells for homicide incidents, robbery incidents, and vacant parcels was counted and then divided by the city average for an area of the size of the 10-min walking neighborhood of each agent. In other words, these four variables were standardized based on the city average. The higher the count, the less desirable an area is for walking.

There were more than 60,000 residential lots in the study area. Since the computing time for the scripts to run for each residential lot was 1 min, the time needed to run scripts for the entire process would be several weeks. One lot, therefore, was selected from every two lots to be included in the model and several machines were used for the calculation to shorten the model running time.

Model 2. The second phase involved building a model for residents in each residential lot in the city to evaluate and explore how easy it was in their neighborhood to walk to grocery stores, schools, health care facilities, and other locations. The unit of analysis was a residential lot. The result of the model was a walkability score map for residential lot cells in the city based on three sets of variables [Eq. (2)]. Unlike Model 1, the walkability assessed in this model represented walkability in the neighborhood around each lot cell:

$$W_i = A_{i,n} + N_{i,n} - S_{i,n} \tag{2}$$

where n = 10-min walking area around agent i; W = walkability score for each agent i's residential lot and neighborhood around the lot; A = number of cells for restaurants and other eateries + grocery stores + bus stops + parks + parkways + schools + libraries + bike paths + hospitals + trees along streets + housing units within agent i's neighborhood n; N = connectivity + integration + size of 10-min walking area within agent i's neighborhood n; S = standardized number of cells for homicide incidents + robbery incidents + vacant parcels within agent i's neighborhood n.

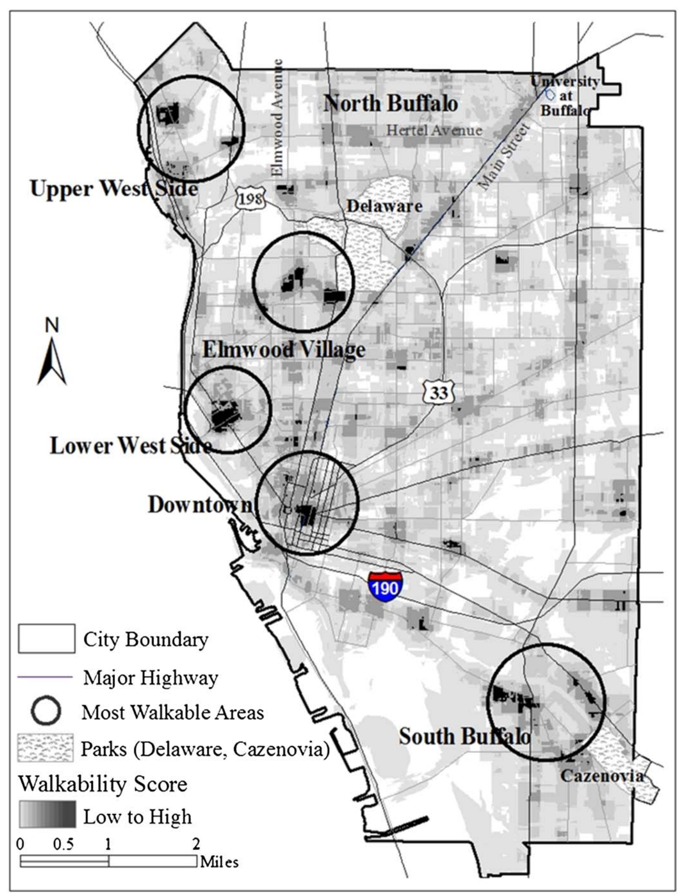

Fig. 3. Results from suitability model

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Model 3. In the third model, a sociability factor was incorporated to explore how people walking on the street attract other people to walk there [Eq. (3)]. A random number generator was used to select residents living in areas with characteristics that promote walking, in other words, areas with high walkability scores from A, N, and S. These residents then looked for the safest street segments or cells in their neighborhood with high connectivity and integration values. Residents also tried to determine whether or not people were walking there before they made decisions on where to walk in their neighborhood. The unit of analysis for this model was a street cell. The result of the model was a map showing the walkability level for street cells in the city:

$$Wj = A_{i,n} + N_{i,n} - S_{i,n} + C_{i,n} \quad (3)$$

where n = 10-min walking area around each residential lot i; j = one street cell in the city; W = walkability score for each street cell i; A = number of restaurants and other eateries + grocery stores + bus stops + parks + parkways + schools + libraries + bike paths + hospitals + trees along streets + housing units within agent i's neighborhood n; N = connectivity + integration + size of 10-min walking area within agent i's neighborhood n; S = standardized number of cells for homicide incidents + robbery incidents + vacant parcels within agent i's neighborhood n; C = number of people walking in a cell or the neighborhood of the cell.

Model Validation

Model validation is one of the key challenges in the development of agent-based models (Crooks et al. 2008). Pedestrian count data were used to compare and test which model gave a better description of real-world walkability. Based on points with information on pedestrian counts, a density map was created to show clusters of high pedestrian densities. In the first phase, these pedestrian clusters were compared visually with clusters with high walkability scores identified by the suitability model, Model 2, and Model 3. In the second phase, the standard deviation method was used to classify areas with different walkability scores and then *Map Comparison Kit* (MCK, Power et al. 2001), a software tool to help compare raster maps developed by RIKS BV, was used to compare three sets of maps. The three sets included suitability model results, Model 2 results, and Model 3 results versus observed pedestrian counts.

MCK can generate a set of statistics including fuzzy global similarity statistics that help assess the overall areal agreement between two maps. Power et al. (2001) suggested that the global matching statistics in their study "outperformed a number of commonly used overall similarity statistics." In the present research, fuzzy global similarity statistics were created using MCK for the three sets of maps and the results were compared.

Results and Discussions

The results of the models show the areas in the city with respect to walkability (Figs. 3–5). The darker the color, the higher the walkability score of the area. To highlight the areas that are most walkable in the city, they were circled with thick dark lines. Fig. 3 shows the result from the suitability model. Five clusters of areas with the highest suitability scores were identified. They are downtown Buffalo, the lower West Side, South Buffalo, the upper West Side, and the area directly north of Elmwood Village. Fig. 4 shows the

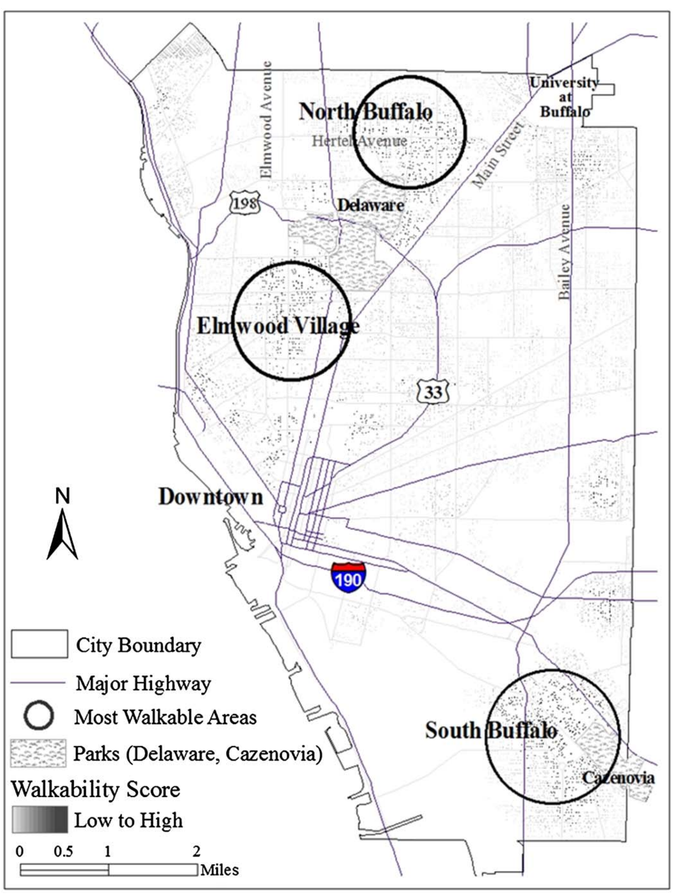

Fig. 4. Results from Model 2

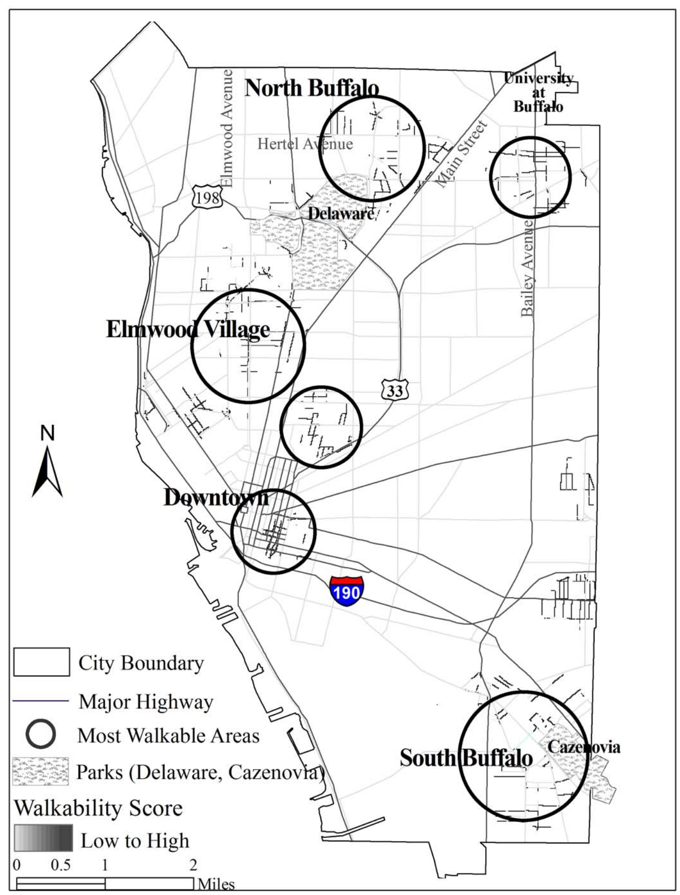

Fig. 5. Results from Model 3

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result from Model 2. Three large clusters that received the highest scores are Elmwood Strip/Village, North Buffalo around Hertel Ave., and South Buffalo. Among the three clusters shown in Fig. 4, Elmwood Village and North Buffalo were not identified as the clusters with the highest scores in Fig. 3, although both of them are among a few thriving places in the city where one would expect to see many pedestrians (American Planning Association 2007). Although the lower West Side was identified as a highly walkable cluster in Fig. 3, few people walk there, especially at night. Fig. 5 shows the streets that were identified by residents as the most walkable areas. Three major clusters were highlighted; they are similar to those in Fig. 4. In addition to the three large clusters, a few smaller clusters are downtown, areas around the University at Buffalo's south campus along Bailey Ave., north of downtown near medical campus, and the lower West Side near D'Youville College.

Fig. 6 shows high-density clusters of pedestrians from the survey data. The darker an area is, the higher the density is in that area. The major clusters in Fig. 6 are downtown Buffalo and Elmwood Village. Other smaller clusters include areas around Hertel Ave. in North Buffalo and areas along Bailey Ave. near the University at Buffalo's south campus. Comparing Figs. 3–5 with Fig. 6, it is clear that the suitability model does not recognize the Elmwood Strip as a highly walkable neighborhood, whereas the less walkable areas within the lower and upper West Side are identified by the model as being highly walkable. The lower and upper West Side have many dilapidated store fronts and relatively high crime rates, which created a less walkable environment. The major clusters shown in Fig. 6, such as downtown and Elmwood Strip, were identified as the most walkable areas by Models 2 and 3, the agent-based models.

Fig. 7 reports the comparison results generated from MCK. The lighter the color is, the higher the agreement is between maps. The upper left map shows the result of comparison between the suitability model and observed pedestrian density patterns. This map shows that there is a high disagreement on Elmwood Strip; in other words, the suitability model did not identify Elmwood Strip as a highly walkable area, whereas the observed map does. Downtown is light gray, indicating that there is a middle to high level of agreement between the two compared maps. There is both high and low agreement in the upper West Side and North Buffalo. The fuzzy global matching index that was derived by the fuzzy summation of the local matching to represent the overall areal agreement between the two sets of maps is reported for all three comparisons

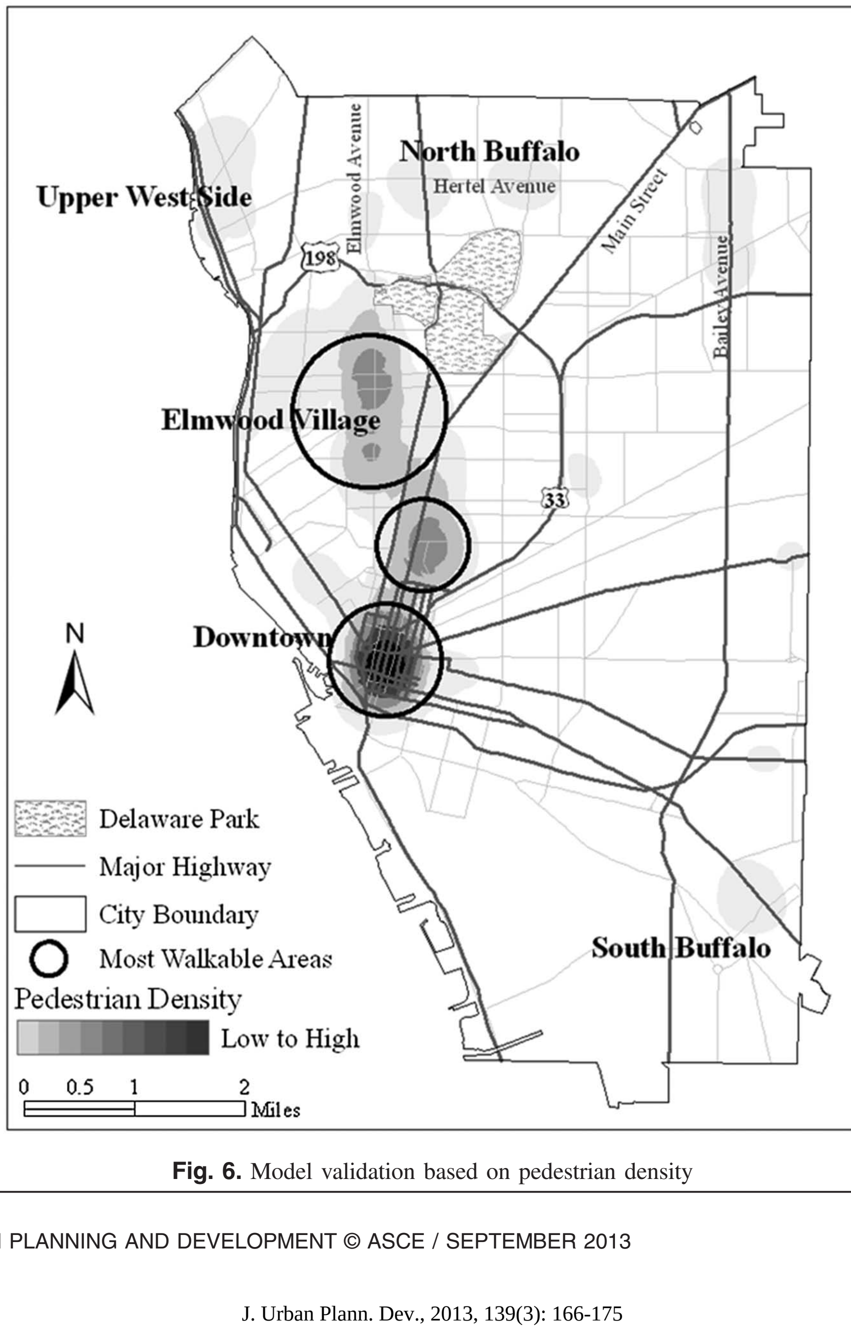

Fig. 6. Model validation based on pedestrian density

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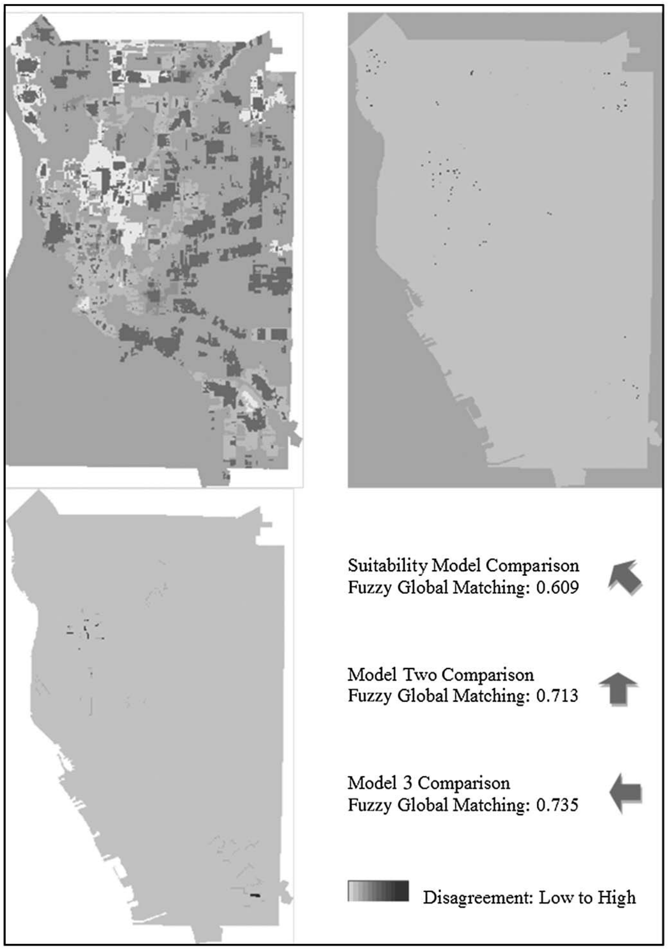

Fig. 7. Comparisons of model results against pedestrian density (Models 1 through 3)

(Power et al. 2001). The index value ranges between 0 for no similarity and 1 for identical (White 2006). The fuzzy global matching index is 0.609 for the first comparison and 0.713 for the comparison between Model 2 and the observed map displayed in the upper right map in Fig. 7 and indicates a higher level of agreement between these maps. The upper right map also shows that there is a relatively high disagreement in the area directly north of Elmwood Strip that results from an overestimate in Model 2. There are also spotty disagreements across the city. However, they are not major clusters. The lower left-hand map has a fuzzy global matching index of 0.735, higher than the other two models, indicating that the highest level of agreement is between Model 3 and the observed density patterns, demonstrating the importance of including the people-attract-people factor in the model. There are two clusters of highest disagreement. They are both small clusters including the one north of Elmwood Strip and south of Cazenovia Park in South Buffalo.

The result of a series of visual and statistical examinations, including site visits and data validation against pedestrian count data, shows that the agent-based models generated reasonable results and were able to better represent the patterns of walkability in the city. The use of a 10-min walking area around individual residences for a full population in Models 2 and 3 helped identify more reasonable areas that are used by individuals and produced more plausible results on walkability comparing with macro-level measures. The inclusion of the subjective people-attract-people phenomenon in Model 3 further helped the model to plausibly reflect the real situation in the city. The agent-based model can be used to combine objective and perceived measures, such as the people-attract-people variable used in Model 3.

Conclusion and Limitations

This paper built and compared three models to assess walkability across the city of Buffalo using micro-level data. The results show that, because an individual perspective was adopted and the people-attract-people phenomenon was included, the models presented here captured characteristics of the built and social environment with increasing accuracy. The agent-based approach helped to simulate the individual uses of the urban environment by (a) treating the populations involved as objects that can interact with the environment and other agents and (b) modeling a large-scale space as a set of micro-scale, disaggregated, and heterogeneous spaces from an individual resident's point of view to generate macro-level patterns of walkability across a city. The comparison of model types presented here suggests that the full agent-based approach (Model 3), which combines objective and perceived measures and incorporates the interaction between walking preferences and the heterogeneity of a landscape and the effect of an agent's walking choices on other actors, can provide a powerful tool for simulating patterns of walkability.

Creating a walkable community and identifying the characteristics of a walkable environment have become important tasks for local municipal governments responsible for the health and welfare of citizens. The agent-based approach helps model and identify the patterns of walkability arising from agent-environment and agent-agent interactions. The method used in this study laid out a new framework for systemically measuring and assessing macro-level walkability patterns across a city using micro-level data and combining objective and subjective measures, helping to understand the characteristics of a built environment that influence a person's willingness to walk. Areas identified with the lowest and highest walkability scores could be further studied with the aim of enhancing or improving the quality of living in such communities.

Many recent studies have developed databases for use by cities and towns to evaluate built environment characteristics and people's walking choices. Agent-based models can be constructed based on these databases to help transportation engineers and urban designers assess walkability so that standards and regulations can be revised to improve the quality of life of residents. In this study it was assumed that there was one resident in each lot based on the housing density and distribution of the study area. However, when similar studies are conducted in other cities, this assumption needs to be revised according to the local density to avoid distorted results. Moreover, a revised set of variables and localized measurements can better capture the influences of built environment characteristics and help design policy instruments for local communities.

This study used a 10-min walking neighborhood around individual residences. A better neighborhood definition might be defined when more studies and findings are available to suggest a more reasonable radius.

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