Chapter 16
Web-Based Interactive Walkability Measurement Using Remote Sensing and Geographical Information Systems*

Ko Ko Lwin and Yuji Murayama

16.1 Introduction

The concept of walkability conveys how conducive the built environment is to walking. It has been adopted in many parts of the world to predict people's physical activity and mode of transportation (Frank and Engelke 2005; Owen et al. 2004; Sallis et al. 2004). Walkability captures the proximity between functionally complementary land uses (live, work, and play) and the directness of a route or the connectivity between destinations (Forsyth and Southworth 2008; Moudon et al. 2006). A walk score is an indicator of how "friendly" an area is for walking. This score is related to the benefits to society in terms of energy savings and improvements in health that a particular environment offers to its residents. For example, a recently developed walk score web site uses Google Maps, specifically Google's local search application programming interface (API), to find stores, restaurants, bars, parks, and other amenities within walking distance of any address entered. The walk score currently includes addresses in the United States, Canada, and the United Kingdom. The algorithm behind this score indicates the walkability of a given route based on the fixed distance from one's home to nearby amenities. The number of amenities found nearby is the leading predictor of whether people will walk rather than take another travel mode. However, evaluating walkability is challenging because it requires the consideration of many subjective factors (Reid 2008). Moreover, all technical disciplines related to walkability have their own terminology and jargon (Abley 2005).

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Neighborhood environmental quality is an important factor affecting human health. Fortunately, neighborhood environmental quality can be improved by proper urban management. Thus, epidemiological studies have explored the relationship between access to nature and health. For example, a study in Sweden by Grahn and Stigsdotter (2003) demonstrated that the more often one visits green areas, the less often one reports stress-related illness. An epidemiological study performed in The Netherlands (Maas et al. 2006) showed that residents of neighborhoods with abundant green spaces tended, on average, to enjoy better general health. Another possible mechanism relating nature to health occurs during social interactions and social cohesion. Several studies conducted in Chicago suggest that green spaces, especially trees, may facilitate positive social interactions between neighborhood residents (Kweon et al. 1998).

Therefore, in many parts of the world, current urban planning activities are shifting toward a focus on "green" living. Many cities around the world are now developing integrated solutions to major environmental challenges, and are transforming themselves into more sustainable and self-sufficient communities (Dizdaroglu et al. 2009). Among the environmental benefits achieved by such green interventions are the following: reduced cooling and heating demand, improved air quality, reduced storm-water runoff, the enrichment of urban biodiversity and urban agriculture, a reduced urban heat-island effect, a contribution to carbon-neutral architecture, an aesthetic improvement to the skylines of cities, and the economic impact of the green spaces (Roehr and Laurenz 2008).

Given the great interest in walking activities and other urban sustainability measures, the purpose of this chapter is to develop an integrated methodology [using remote sensing, geographical information systems (GIS), and spatial web technology] to model urban green space walkability, which enables local residents to make informed decisions that will improve their living conditions and physical health. The proposed methodology uses advanced land observing satellite (ALOS) data to identify the green spaces, which are then integrated with other GIS data sets, such as road networks, public facility locations, and building footprints, to calculate an eco-friendly walk score to enable residents to make decisions using an interactive web-based GIS. We use Tsukuba City, Japan, as a case study.

This chapter is organized into three sections. Following the introduction, the conceptual framework is presented. This is followed by a discussion of the case study, including a list of data used, data processing steps, and a description of the implementation of the system. We proceed to explain the GIS analytical functions of our eco-friendly walk score calculator and its potential applications. The results of a qualitative usability study are presented in Sect. 16.5, while our conclusions are discussed in Sect. 16.6.

16.2 Conceptual Framework

Recently, GIS studies of urban green space areas have been increasing in number. For example, Mahon and Miller (2003) used GIS to identify green space areas with high ecological, recreational, and aesthetic values to protect certain green space

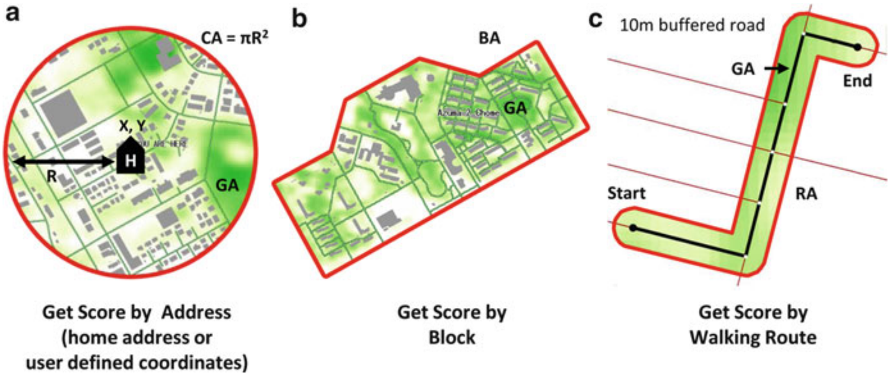


Fig. 16.1 Conceptual view of different greenness score measurements

areas from development. Randall et al. (2003) presented a GIS-based decision support tool to model planning scenarios related to the creation of new green space areas as part of neighborhood greening strategies. Zhang and Wang (2006) presented a study that used landscape metrics to quantify the spatial configurations of green spaces, and performed GIS-based network analyzes to assess the accessibility of many proposed enhancements of green spaces. Ghaemi et al. (2009) implemented a web-based platform "interactive park analysis tool," which is part of the "Green Visions Plan for 21st Century Southern California" project (Wolch et al. 2005). The quality of eco-friendly living places can be measured by an indicator of walkability index or score. Although most walk score calculations are based on distances between home and public facilities, an eco-friendly walk score calculation is based on green spaces (i.e., the location of home or a walking route with green spaces). The higher the score, the better the environmental quality (i.e., eco-friendly) for living or taking green exercise. We propose to measure the greenness score of urban locations through the three modalities illustrated in Fig. 16.1. In the first modality, greenness is measured for the spatial neighborhood around a certain address by user-defined distance (get score by address); in the second modality, greenness is measured for each block of the urban region (get score by block), while the third modality computes the greenness score for walking routes (get score by walking route).

The following equations are used to calculate the greenness score for each of the three modalities (Fig. 16.1a–c).

$$\text{(A) Get score by address} = \left(\frac{\text{GA}}{\text{CA}}\right) \times 100 \tag{16.1}$$

$$\text{(B) Get score by block} = \left(\frac{\text{GA}}{\text{BA}}\right) \times 100 \tag{16.2}$$

$$\text{(C) Get score by walking route} = \left(\frac{\text{GA}}{\text{RA}}\right) \times 100 \quad (16.3)$$

where GA = green area, BA = block area, CA = circle area, RA = 10 m buffered route area, and R = circle radius (user-defined walking distance).

The calculation of a get-score-by-walking route is based on (16.3). This measurement is ideal for informing people who want to make outdoor recreation or exercise activities part of their daily or weekend routines. Outdoor recreation or exercise has become an important element of healthy living, and a remedy against the deficiencies of a modern lifestyle that involves separation from nature. People with special needs, such as the elderly or those with disabilities, often gain therapeutic benefits from activities conducted in a natural environment. Mental well-being is also supported through playing, because play helps establish personal and community identity for children and young people (Bell et al. 2007). A study by Sugiyama et al. (2008) shows that perceived neighborhood greenness was more strongly associated with mental health than with physical health. Moreover, Pretty et al. (2007) summarized the effects on 260 participants of 10 green-exercise case studies (including walking, cycling, horse-riding, fishing, canal boating, and conservation activities) in 4 regions of the United Kingdom. It was determined that green exercise (i.e., exercise in a green area) led to significant improvements in self-esteem and in total mood. The effects were not found to be affected by the type, intensity, or duration of the green exercise.

Furthermore, we can also find the available facilities within a user-defined distance or circle radius based on the accessibility concept. The circle is a spatial analysis boundary whose radius is defined by the user. This radius indicates how far the user is willing to walk to reach the facilities. We also assume that the effectiveness of greenness has a circular pattern known as the distance decay effect. Accessibility is a measure of the spatial distribution of activities around a point location, adjusted for the ability and desire of people to overcome spatial separation (Handy and Niermeier 1997). Several studies describe accessibility, review various accessibility measures, provide case studies, and present novel methods (Bhat et al. 2002; Levinson and Krizek 2005; Thill 2009; Thill and Kim 2005; Handy and Niermeier 1997; Pirie 1979). In short, accessibility describes the ease of travel between a source and a target. For example, having retail stores close to where people live and providing connecting streets increases the likelihood that a person will incorporate walking into their daily routines (Frank and Engelke 2005; Moudon et al. 2007). Furthermore, spatial syntax has been proposed as a new computational language to describe the patterns of modern cities (Hillier 1996; Hillier and Hanson 1984). Typical applications of spatial syntax include pedestrian modeling, crime mapping, and way-finding processes in complex built environments (Hillier 1996; Jiang 1999; Peponis et al. 1990). The axial line-based representation of an urban structure is the earliest approach to spatial syntax (Hillier and Hanson 1984). Recent developments in spatial information science have much to offer for the identification of land-use types, street connectivity, and access to services, in order to determine the factors

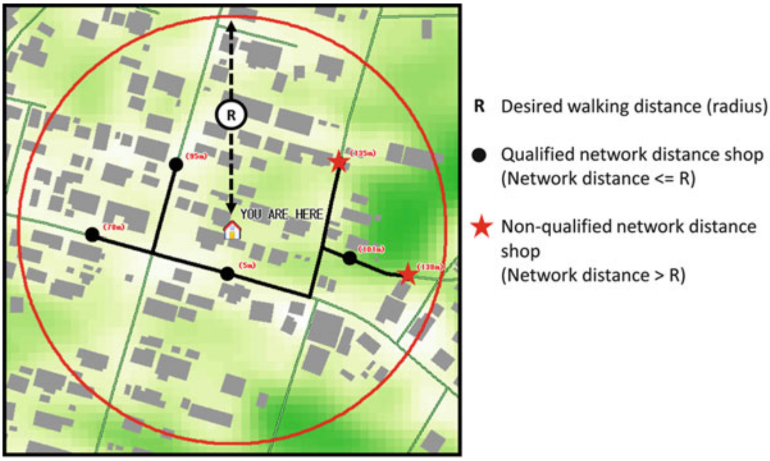


Fig. 16.2 Conceptual view of cumulative opportunity measurements

that might increase or decrease the probability of people being physically active according to selected spatial units of interest (Leslie et al. 2007).

In our urban green space walkability model, users are allowed to choose their desired travel distances and desired types of facility. The desired distance indicates how far people are willing to travel to reach their desired facilities. For example, some may want to reach their desired facilities by walking or cycling, which might mean that they are concerned about the environment, and want to reduce gasoline use and cut carbon dioxide emissions. In contrast, some people are willing to use a car to reach their desired destinations. Moreover, different people may require different facilities. We counted the available facilities based on user choices (i.e., their desired walking distance and desired facility types). The calculation was then based on the "cumulative opportunity," which provides a measure of the number of available facilities within a certain distance or travel time (Fig. 16.2). Examples of cumulative opportunity measures are found in various publications (O'Sullivan et al. 2000; Sherman et al. 1974; Wachs and Kumagi 1973). Cumulative opportunity can be expressed by the following equation:

$$A_i = \sum j(B_j a_j) \tag{16.4}$$

where A_i is the accessibility measured at point i to potential activities in zone j, a_j is the opportunities in zone j, and B_j is a binary or threshold value (i.e., 1 if network distance ≤ search radius, and 0 if network distance > search radius).

We identify all available facilities inside the circle (Fig. 16.2), and then separate them into two groups; one group is composed of a qualified network of facilities for which the travel distance would be less than or equal to the search radius (marked as •), and the other group is the non-qualified network of facilities for

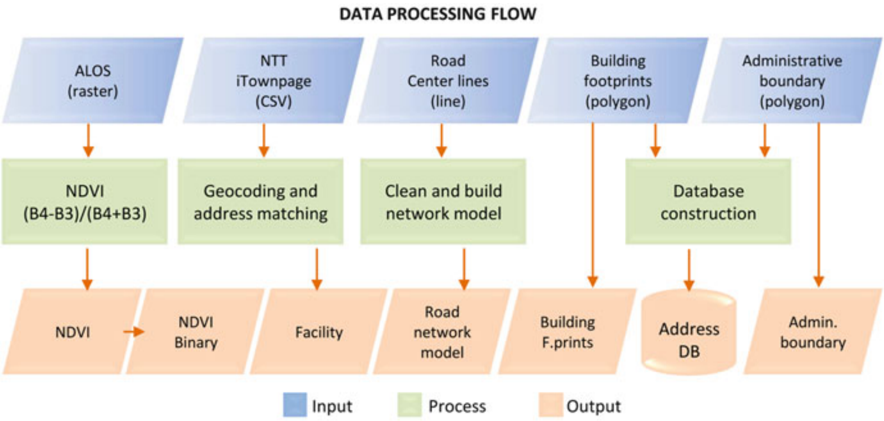


Fig. 16.3 Workflow for data processing and output of data to be used in the eco-friendly walk score calculator

which the travel distance would be greater than the search radius but would still fall within the area of the circle. Moreover, some points, such as shopping malls and supermarkets, include more than one shop. In this model, all measurements between the home and the available facilities are calculated as the actual shortest network distances. Okabe and Okunuki (2001) discussed the advantages of network distances over straight-line distances in the case of a retail market analysis in urban areas. The most traditional analytical tools are based on the assumption that market areas are homogeneous planes, and that the distances can be measured in terms of Euclidean distances. In a small area, however, irregular street layouts produce a heterogeneous plane, and consumers can access stores only through a network of streets. This suggests that there would be great potential demand for analytical tools for micro-spatial analysis of a network in which distance is measured in terms of the shortest route (Fig. 16.3).

16.3 Case Study

16.3.1 Study Area and Data

Our study area was Tsukuba City, a city that was planned for academic and scientific purposes and the home of the University of Tsukuba and the Japan Aerospace Exploration Agency (JAXA). As of 2008, the city had an estimated population of 207,394, and a population density of 730 people per km^2. Its total area is 284.07 km^2. Located approximately 50 km northeast of Tokyo, Tsukuba is sometimes considered part of the Greater Tokyo metropolitan area. Table 16.1 lists the various data used in this study, and their respective uses and sources.

Table 16.1 Data, descriptions, and applications of their use

Data and source	Description	Purpose
ALOS AVNIR-2 (Japan Aerospace Exploration Agency, JAXA)	• Band 3 (red: 0.61–0.69 μm) • Band 4 (infrared: 0.76–0.89 μm) • 10 m spatial resolution at nadir raster in GeoTIFF format	• To delineate green spaces • To convert binary green images • To compute the greenness score
Building footprints (Zmap-TOWNII product from ZENRIN Company)	Building footprints including building name, parcel number, and number of floors Polygon in an ESRI Shape file	• To integrate with administrative boundary data and construct a database of residential addresses • To create masks on vegetated areas
Administrative boundary (Zmap-TOWNII product from ZENRIN Company)	• Administrative boundary including name Polygon in an ESRI Shape file	• To integrate with building footprints and create a database of residential addresses • To calculate the greenness score by administration zone
Road center lines (Geospatial Information Authority of Japan, previously known as the Geographical Survey Institute)	• Road center lines with major road names Line in an ESRI Shape file	• To build a road network model • To measure network distances between a user-defined point and locations of facilities • To compute a greenness score for each road segment • To perform an analysis of the shortest or greenest route
Facility locations (iTownpage from NTT, Nippon Telegraph and Telephone Corp.)	• Business name, address, category, sub-category, business contents, phone number, URL, etc. Comma-separated value (CSV) format	• To convert a point layer for facilities • To find desirable and available facilities by a user-defined search distance

16.3.2 Data Processing

16.3.2.1 Data Processing Workflow

16.3.2.2 Creation of a Binary Green Image from ALOS Satellite Data

ALOS includes an optical sensor known as the advanced visible and near infrared radiometer type 2 (AVNIR-2) with high spatial resolution (10 m at nadir) composed of four multi-spectral bands (i.e., three bands in the visible range and one band in the near infrared region). The normalized difference vegetation index (NDVI; $NDVI = (NIR - RED)/(NIR + RED)$) is computed using a visible red band (RED, Band 3: 0.61–0.69 μm) and a near-infrared band (NIR, Band 4: 0.76–0.89 μm) acquired from vegetation growing seasons. This NDVI (Fig. 16.4) shows the degree of vegetation (intensity) represented as pixel values between 0 and 255, which are stretched from their original values of between −1 and 1.

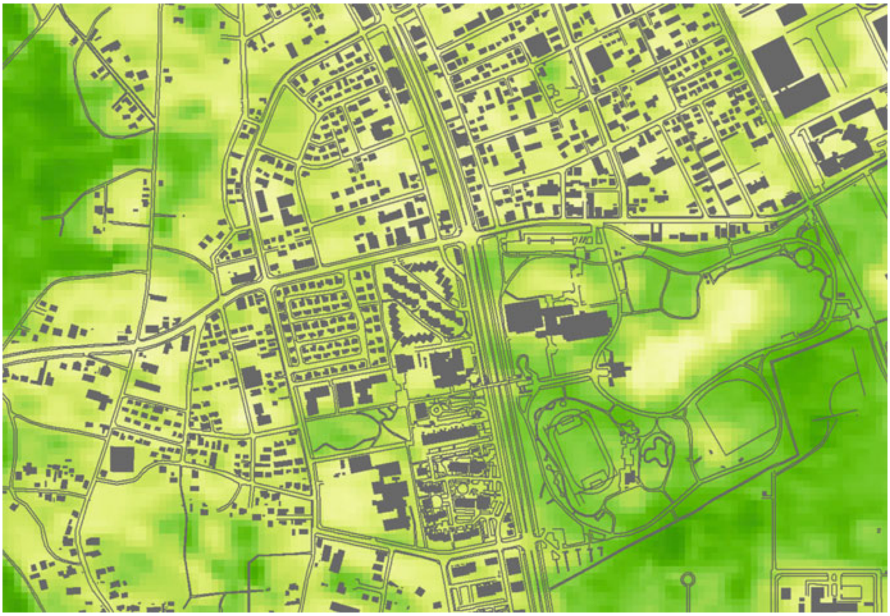


Fig. 16.4 NDVI image (*green intensity*) from an ALOS AVNIR-2 sensor masked with building footprint polygons

After stretching, this NDVI image was re-sampled to a 5 m spatial resolution with the Spline interpolation method using the ArcGIS Spatial Analyst extension (i.e., we converted the 10 m raster to a 10 m point, and the 10 m point to a 5 m raster again, by setting the output raster resolution at 5 m). The purpose of this re-sampling was to reduce the errors between raster and vector analysis (Fig. 16.5) because the analysis is made between the 10 m road-buffer line and the center point of each raster. Another way to convert low resolution to high resolution is called "pan-sharpening." However, this process requires an additional high-resolution panchromatic band. The use of pan-sharpened images in the analysis of vegetation is very rare because the original spectral values are transformed during the pan-sharpening process. Pan-sharpened images are commonly used for visualization purposes. We use original spectral properties to calculate the NDVI and interpolate the middle one. Interpolation of the image is a technique in which the spatial resolution of an image is increased from its original size to a higher resolution to improve the image quality.

To separate vegetated and non-vegetated spaces, we set the threshold at 113 of the NDVI pixel values by comparing two images (i.e., one from the 67 cm RGB-321 true color ortho-image and one from the 5 m re-sampled ALOS NDVI images) using the view > link/unlink viewers > geographical function in the commercial remote sensing software ERDAS Imagine (Fig. 16.6). After this step, the intensity image is converted into a binary green image (1 for vegetated

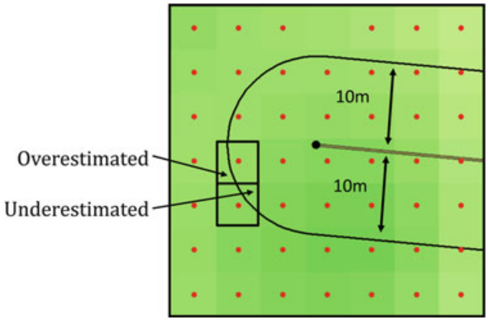


Fig. 16.5 Errors between raster cells and vector line analysis, depending on cell size

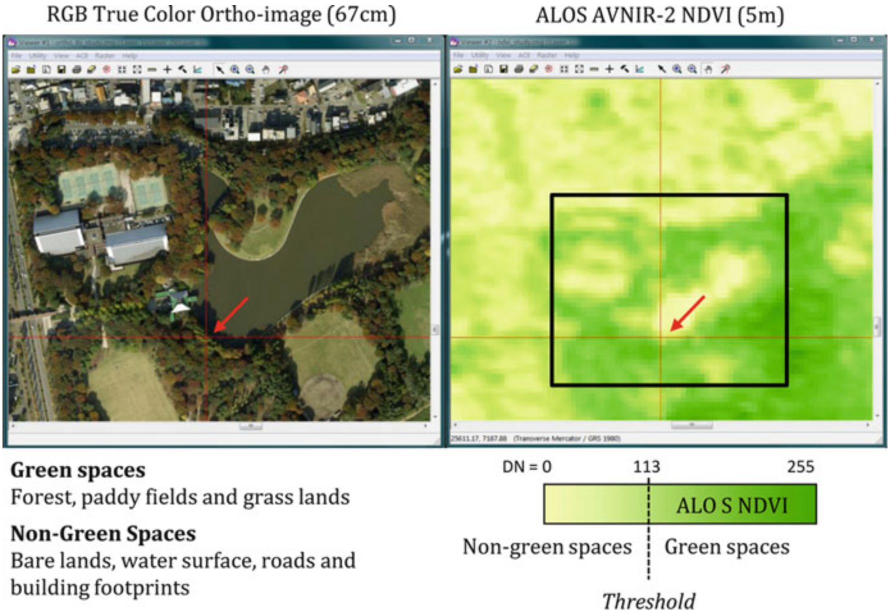


Fig. 16.6 Identification of the threshold value by linking the 67-cm ortho-image and the 5 m re-sampled ALOS NDVI image (viewing the actual landscape features from the high-resolution ortho-image *left view*, and obtaining the NDVI pixel values from the *right view* while moving the cross-hairs by using ERDAS commercial remote-sensing software)

area, and 0 for non-vegetated area). The main purpose of this conversion is to identify the vegetated areas rather than the vegetation intensities, which vary from season to season. The binary green image also reduces the data size and the required computational time. This procedure is especially suitable for web-based GIS in which the network and computational resources are limited. Vegetated areas included trees, bush land, grass land, and paddy fields. Non-vegetated areas include buildings, parking lots, bare land, rivers, and lakes.

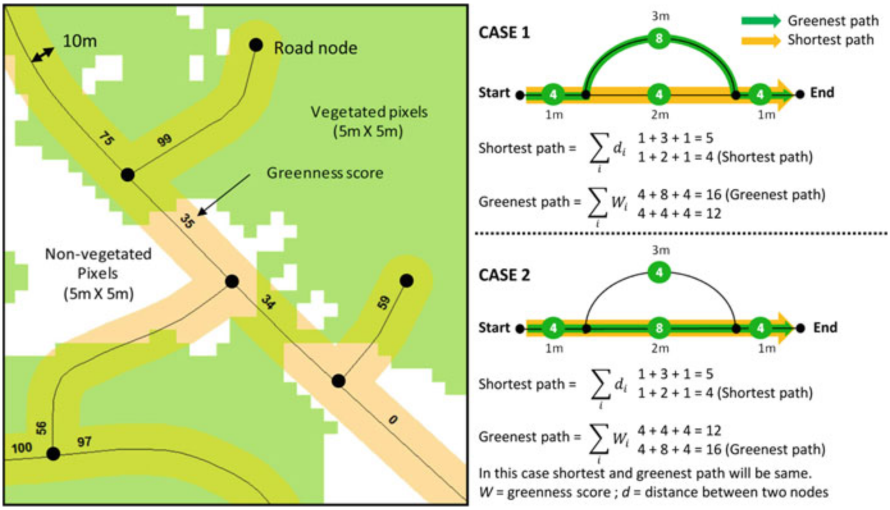


Fig. 16.7 Calculation of the greenness score for each road segment based on the binary green image, and an example of the shortest and greenest path calculations using greenness score as the weighted factor

16.3.2.3 Computation of the Greenness Score and the Road Network Model

Road center-line data were acquired from the Geospatial Information Authority of Japan. However, this data set does not cover all the small streets in the city. Therefore, small streets that were missing were digitized based on Zmap-TOWNII data. Following this, we added a 10 m buffer to both sides of the road, and computed the greenness score based on the binary green image (Fig. 16.7) for each road segment using (16.3). Next, we built a topological road network model using VDS road network builder provided by VDS technologies. In this process, we set up the greenness score attribute field as a weight factor in order to compute the shortest or greenest route between two points. The shortest route was computed based on road distance, while the greenest route was computed based on road distance and the greenness score, whose value ranges from 0 to 100.

16.3.2.4 Construction of a Residential Address Database

For this case study, a database of residential addresses was created from a combination of administrative boundary and building footprint data sets. Building footprint data sets are useful for estimating building populations (Lwin and Murayama 2009) because such data contain rich attributes including building number, number of floors, and building name. Unlike other countries, most Japanese addresses are based on a block-by-block system. The address does not contain a street or road name; instead, it is expressed by a sequence of blocks (prefecture block, city block, ward block, ownership block, etc.). For this study, we constructed the address database by performing an intersection function between these block layers. We separated the addresses into two parts: the main block and the sub-block. The main block represented the smallest administrative unit, and the sub-block represented the smallest land unit. For example, in the case of Kasuga 3–15-23, Kasuga 3 was constructed from an administrative boundary block, and 15-23 was constructed from the smallest land unit. The purpose of the address database is to locate the place in a user-friendly way, and to avoid problems with mis-typing when performing an address search. Although this approach is not appropriate for large land blocks (e.g., factories, schools, and hotels), users can still locate their position and the distance of the desired destination by using the interactive map circle tool.

16.3.2.5 Conversion of Public Facility Data

Our model also uses the count of available facilities classified by a user-defined search area and specified facility types. This is useful for potential home-buyers and current residents to calculate the distances between home and available facilities on the network. We use iTownpage data, which were downloaded from the Nippon Telegraph and Telephone Corp. (NTT) website. These data include the business name, type, category, content, address, telephone number, and other information in a comma-separated value (CSV) format. The iTownpage website supports the everyday life and business activities of visitors and expatriates in Japan, as well as people living overseas, by enabling users to search for information about stores and businesses via the Internet. These CSV data were converted into ESRI point features (Fig. 16.8) using commercial geo-coding software with an accuracy at the building level. These NTT iTownpage data can be used to separate the residential and non-residential buildings, and to carry out other retail market analysis. For example, Lwin and Murayama (2010) used NTT iTownpage data to separate the building-use types and integrate those with a digital volume model (DVM) that was derived from light detection and ranging (LiDAR) data to produce a fine-scale dasymetric map for Tsukuba City.

16.3.3 Implementation of the Eco-Friendly Walk Score Calculator

We have implemented a system called the “eco-friendly walk score calculator” based on our urban green space walkability model. The overall system is built on Microsoft ASP.NET with an AJAX extension and VDS technologies (web mapping components for ASP.NET). ASP.NET is a web application framework marketed by Microsoft that programmers can use to build dynamic websites, web applications, and XML web services. AJAX (shorthand for asynchronous JavaScript and XML)

Fig. 16.8 Conversion of an iTownpage comma-separated value (CSV) file to ESRI point features (one point may contain many shops, such as a shopping mall and supermarkets)

is a group of interrelated web development techniques used on the client side to create interactive web applications. With AJAX, web applications can retrieve data from the server asynchronously in the background without interfering with the display and behavior of the existing page. The use of AJAX techniques has led to an increase in interactive and dynamic interfaces on web pages. AspMap for .NET from VDS technologies is a set of high-performance web-mapping components and controls for embedding maps in ASP.NET applications (web forms). Figure 16.9 shows the overall system design and potential users.

16.4 Model Outcomes

Figure 16.10 shows the graphical user interface (GUI) of the eco-friendly walk score calculator. We measured the greenness score via the three modalities called "get score by address," "get score by block," and "interactive score." The first measurement mode of our program is the "get score by address" function (Fig. 16.11). This is ideal for current residents to evaluate the environmental quality of their neighborhood by entering their home address and search radius (the default search radius is 250 m). This tool also finds the available facilities within the user-defined search radius based on the concept of accessibility. The second measurement mode of our program is the "get score by block" (Fig. 16.12) function, which is ideal for

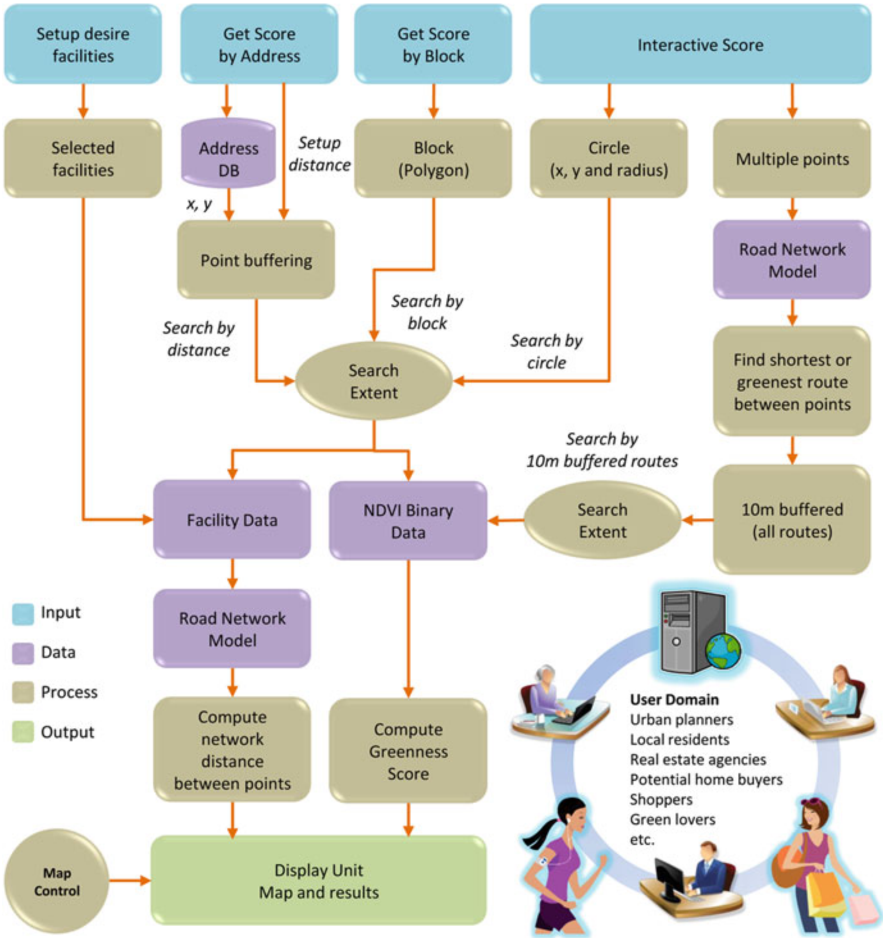


Fig. 16.9 System design of the eco-friendly walk score calculator

urban planners to evaluate the greenness of spaces according to planning zone (i.e., administrative block). The third measurement mode of "interactive score" is ideal for potential home-buyers who are planning to live in Tsukuba City, or for local residents who want to walk along the greenest or shortest route between locations. As for potential home-buyers, users can locate their location and desired walking distance by drawing a circle on a map (Fig. 16.13).

The calculation of the greenness score is the same as for the get score by address mode. In interactive score mode, users can also find either the shortest or the greenest walking route (Fig. 16.14) by specifying their start and end points. The shortest route is ideal for shopping activities, and the greenest route is ideal for recreational

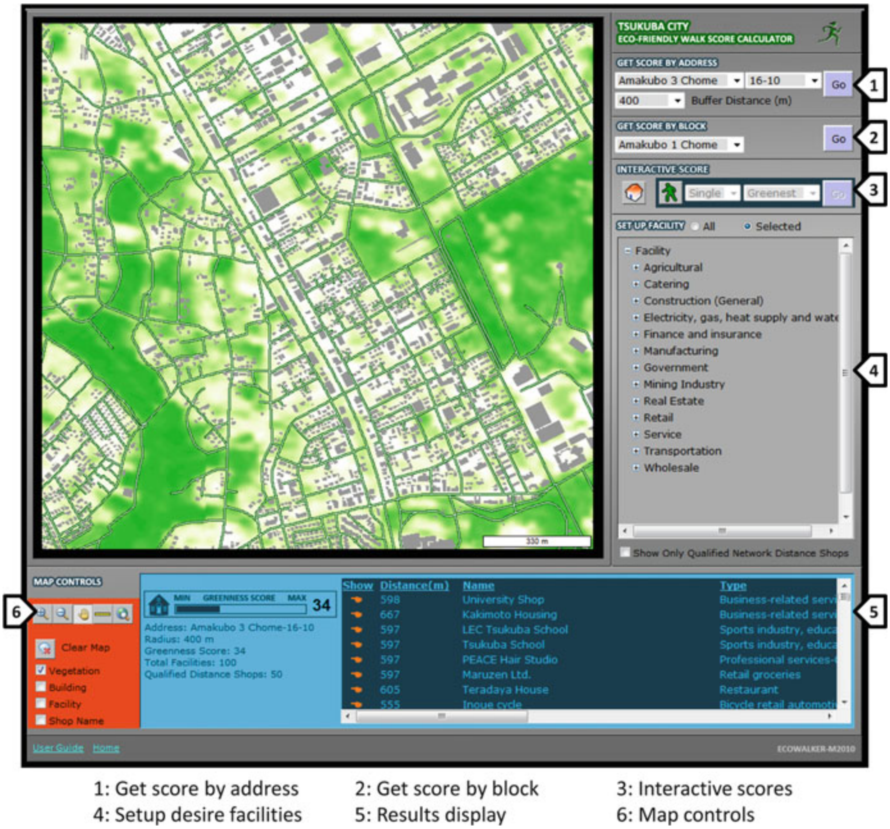


Fig. 16.10 Graphical user interface of the eco-friendly walk score calculator (URL: http://land.geo.tsukuba.ac.jp/ecowalkscore)

walking activities. Finally, users can also compute the walking score for multi-stop trips. To this end, the user specifies multiple activity sites. For example, one could start from home, go to the library, continue on to a shopping center, and then return home (Fig. 16.15).

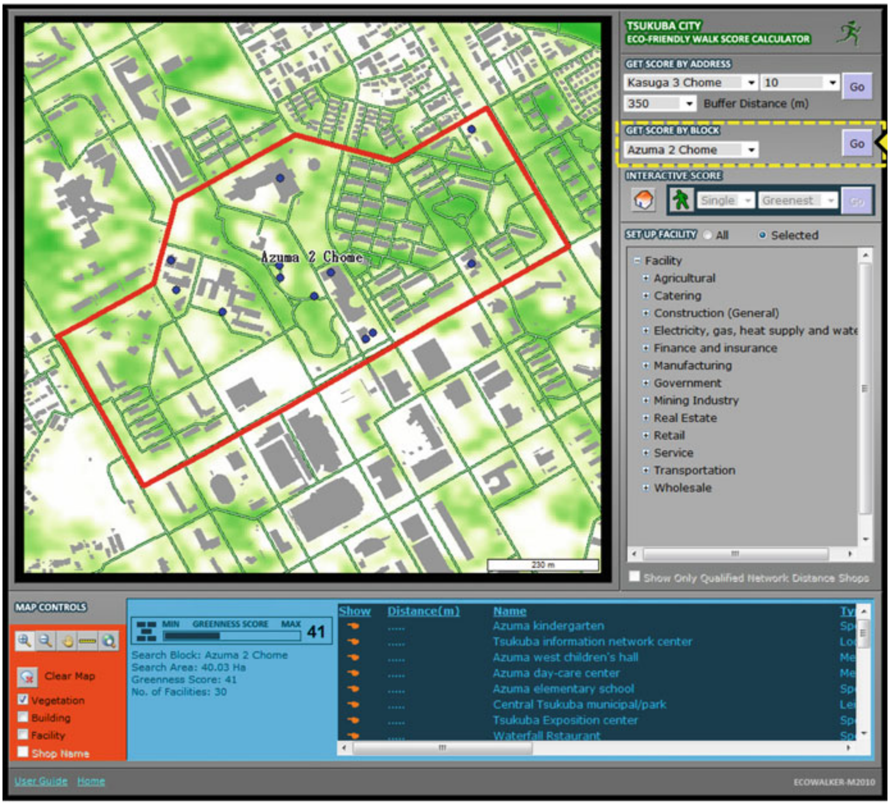
16.5 Qualitative Usability Study

In order to evaluate our web-based GIS eco-friendly walk score calculator in Tsukuba City, we conducted a number of face-to-face interviews and telephone conversations with university students, researchers, private companies, non-profit organizations (NPOs), local residents, real-estate agencies, and city planners. Of the groups of users that were part of this study, real-estate agents found the ability to

Fig. 16.11 Get score by user-defined address and default search radius of 250 m (*Note*: one point may contain more than one shop)

show the neighborhood environmental quality and surrounding public facilities to potential home buyers a highly valuable resource, while local residents tended to favor the get score by address function. Students, on the other hand expressed a preference towards the get score by route analysis capabilities.

In order to provide an avenue for system improvement, researchers proposed incorporating the ability to integrate additional scores or indices to the system, including accessibility and connectivity indicators such as the alpha or beta index, average block length, or average block size based on a GIS network data model (Thill 2000). City planners in our usability study suggested that in addition to the get score by administrative block function, scores could also be calculated by irregular boundaries such as a user-defined polygon, given that land-use planning is often performed according to land-use type or within specific properties. For example, computing the greenness score for a university would help to improve campus environmental quality.



Search Block: Azuma 2 Chome ; Search Area: 40.03 Ha ; Greenness Score: 41 ;
No. of Facilities: 30

Fig. 16.12 Getting a score by administrative block

NPOs found the system to be moderately useful, since their primary purpose is to locate open spaces for humanitarian assistance and other social or cultural activities. Although we did not find any significant difficulties with the graphical user interface, a handful of students commented on the size of the GUI panel, suggesting that the eco-friendly walk score calculator would be handy to have as an application on their smart phones or Netbook computers in order to find the greenest route while they walk or exercise. They also suggested making separate route analysis web-GIS pages for mobile Internet users. Overall, the system was evaluated favorably by real-estate agencies, researchers, and students.

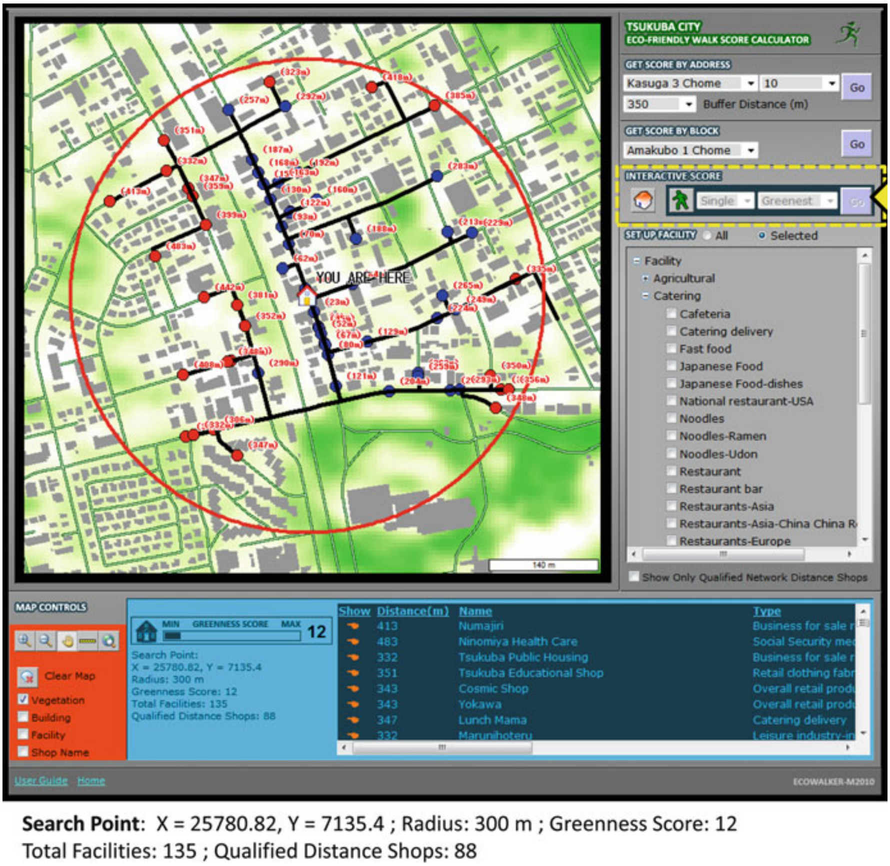


Fig. 16.13 Interactive score using the circle tool for potential home-buyers

16.6 Conclusion

The increasing popularity of the Internet and user-friendly web-based GIS applications such as Google Maps/Earth and the Microsoft Bing Maps platform have made GIS an integral part of life today for finding the nearest facilities, driving routes, and so on. However, choosing an eco-friendly place to live or a walking route is a big challenge for local residents because of the lack of GIS analytical functions and environmental data available online. Although the analysis of route paths has been widely used in GIS applications, the integration of green factors with the analysis of the route path is still lacking in the GIS arena. In this chapter, we have presented an integrated methodology for identifying an eco-friendly place to live or to walk by providing web-based GIS analytical functions using Tsukuba City in Japan as a case

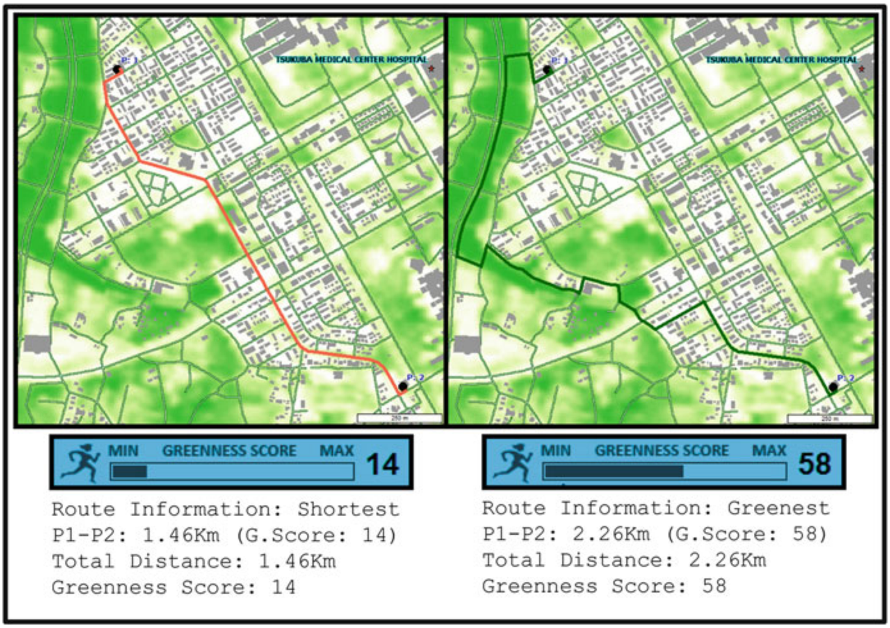


Fig. 16.14 Finding walking routes by either the shortest route or the greenest route

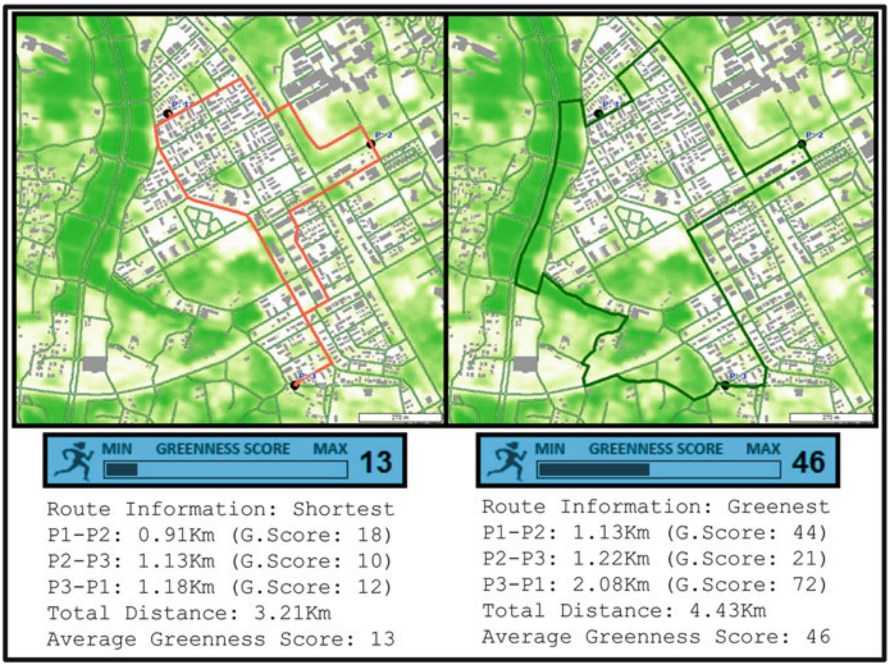


Fig. 16.15 Finding multiple places (points) with a walking route through use of the greenness score

study. This web-based, eco-friendly walk score calculator enables users to evaluate the environmental quality of a neighborhood, to find the nearest facilities which are accessible on foot, to choose an eco-friendly place to live for potential home-buyers, and to choose a route for green exercise. Although this web-based GIS represents a fairly localized prototype, we hope it will help local city planners and policy-makers to build sustainable eco-cities to improve the mental and physical health of their residents in various parts of the world.

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