Computers, Environment and Urban Systems 64 (2017) 288–296

Contents lists available at ScienceDirect

Computers, Environment and Urban Systems

journal homepage: www.elsevier.com/locate/ceus

Street level urban design qualities for walkability: Combining 2D and 3D GIS measures

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A R T I C L E I N F O

Article history:
Received 8 June 2016
Received in revised form 31 March 2017
Accepted 1 April 2017
Available online xxxx

Keywords:
Walkability
Streetscape features
3D GIS
Line of sight

A B S T R A C T

Much of the physical activity and built environment literature has focused on composite walkability indices based on the D variables– *design*, *density*, *diversity*, *destination accessibility*, and *distance to transit*. This literature, however, has largely ignored the microscale streetscape features that affect the pedestrian experience. Five street level urban design qualities were recently identified and defined for quantitative measures although these measures are mostly through subjective field observation. View related features such as long sight line and proportion of sky have not yet been objectively measured due to the limitation of data and method. This study uses both 2D and 3D GIS to objectively measure street level urban design qualities in Buffalo, New York and tests their correlation with observed pedestrian counts and Walk Scores. Our results showed that 3D GIS helped to generate objective measures on view related features. These objective measures can help us better understand the influence of street level urban design features on walkability for designing and planning healthy cities.

1. Introduction

The increasing interest in building walkable and healthy cities and communities has produced in recent years many studies that measure built environment characteristics subjectively and objectively on their roles in influencing physical activity and pedestrian behavior (Ewing & Handy, 2009). Much of the work has focused on composite walkability indices (Christian et al., 2011) based on the Ds – *design*, *density*, *diversity*, *destination accessibility*, and *distance to transit* (Saelens et al, 2003; Frank, Sallis, Conway, & Chapman, 2006; Frank, Schmid, Sallis, Chapman, & Saelens, 2005; Ewing & Handy, 2009; Christian et al., 2011). Majority of studies referred to *design* as street grid design represented mostly by street connectivity and measured objectively using GIS (Ewing, Hajrasouliha, Neckerman, Purciel-Hill, & Greene, 2016; Purciel et al., 2009). The street connectivity measures, however, "do not capture people's overall perceptions of the street environment" (Ewing & Handy, 2009, p66). There are few studies or tools focusing on street level urban design qualities, termed "streetscape features" by Ewing et al. (2016), which reflect experience walking down a street, as discussed in classic urban design works like Lynch (1960).

Ewing & Handy (2009) and Purciel & Marrone (2006) defined the streetscape features qualitatively, and developed a comprehensive manual to guide field observation for quantitative measures of these features. These measures, however, were based on observational tools that require trained observers. The estimated measures through observations are subjective and can be inconsistent across the raters. Recent studies found that objective measures of the built environment had stronger associations with walking than subjective measures and suggested future studies to include objective measures (Lin & Moudon, 2010; Yin, 2014).

Purciel et al. (2009) translated some of the urban design variables into objective GIS measures for New York City. Yet, a number of features were listed either as "no data source available" or "not measured with the GIS". These features remain difficult to be measured by 2D GIS partly because of the limitation of 2D GIS and partly because of the GIS data availability. They include view related variables such as proportion of sky ahead of or across the street, and line of sight (Ewing, Handy, Brownson, Clemente, & Winston, 2006). These features contribute to two important urban design qualities associated with walking experience: *enclosure* and *human scale*. Literature in environmental psychology showed evidence of a preference for a sense of enclosure (Nasar, 1987). One way to achieve enclosure is when lines of sight are decisively blocked so that it feels that outdoor spaces have fixed boundaries or distinct and definite shapes for a room-like environment (Alexander, Ishikawa, & Silverstein, 1977, Jacobs, 1993). Line of sight is also associated with human scale. For example, street trees and branches can block the line of sight, and therefore moderate the scale of buildings and wide streets that intimidate pedestrians (Arnold, 1993). With the aid of 3D GIS models and tools, these streetscape features can be measured more consistently and objectively.

This study builds on Ewing & Handy (2009), Purciel et al. (2009), and Ewing et al. (2016) using both 2D and 3D GIS to objectively measure street level urban design qualities in Buffalo, New York and tests their

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http://dx.doi.org/10.1016/j.compenvurbsys.2017.04.001
0198-9715/

correlation with observed pedestrian counts and Walk Scores. The methodological contribution of this article lies in the development of systematic objective measures of view related features combing 2D and 3D GIS. This article also extends the current studies on the investigation of these streetscape features empirically in a city other than New York City. Findings from this study can help us better understand the influence of street level urban design features on walkability and help us design more walkable and healthy streets and cities.

2. Measuring streetscape features for walkability

Engaging physical activity has significant health, environmental, and social benefits, such as lower obesity rate, less congestion and greenhouse gas emission, and improved livability. Walking or bicycling for transport, recreation, shopping, or other purposes helps to incorporate physical activity with a moderate intensity into daily activities (Tudor-Locke, Bittman, & Merom, 2005). Many studies and tools have been developed to help communities audit and study the built environment and measure walkability of the built environment using the D variables. *Density* is often represented by population or housing density. *Diversity* refers to the mix of land uses. *Destination accessibility* examines the availability of activities or destinations in a neighborhood (Frank et al., 2006, 2005; Yin, 2013). *Design* usually refers to the layout of the street grid and has been measured mostly by street intersection density or block size (Hajrasouliha & Yin, 2015). However, as stated by Ewing et al. (2016), *design* should also incorporate micro features of the street environment that has an impact on the pedestrian experience. Unfortunately, "both the travel and physical activity literatures largely ignore the streetscape features deemed so important by urban designers" (Ewing et al., 2016; p6).

These micro and street level features focus on the environmental psychological aspect of the built environment, and are referred to as perceptual qualities of the urban environment (Ewing et al., 2006) about how individuals perceive and interact with the elements of the street environment. They are generally assessed using observational and subjective measures through surveys. Some studies measured them subjectively as "attractive", "pleasant", or "interesting" (Pikora et al., 2002; Ewing et al., 2006). Others include "aesthetic" measures such as trees, street amenities, cleanliness, street maintenance, and architecture design (Pikora et al., 2006; Day, Boarnet, Alfonzo, & Forsyth, 2006). Previous Studies, however, have suggested that objective measures tend to perform better in association with physical activity or walking than their subjective counterparts based results from regression models (Lin & Moudon, 2010).

Five street level urban design qualities and their operational quantitative measures have been recently identified and defined to help study their influences on walking, including imageability, visual enclosure, human scale, transparency, and complexity (Ewing & Handy, 2009). Imageability describes how a place is recognizable and memorable. Variables include number of people, courtyards, buildings with non-rectangular silhouettes or with identifiers, presence of outdoor dining, proportion of historical buildings, and noise level. Enclosure describes how streets are visually defined by vertical elements such as buildings, walls, and trees. Variables include proportion of street wall, proportion of sky, and number of long sight lines. Human scale describes how the size and texture of physical elements match the size of human and how they correspond to people's walking speed. Variables include number of long sight lines, building height, number of small planter and street furniture, and proportion of first floor with windows. Transparency describes what people can see beyond the edge of a street block. Variables include proportion of first floor with windows, active use, and street wall. Complexity describes the visual richness of a street; in other words, the variety of the physical elements and human activities. Variables include number of buildings, outdoor dining, dominant and accent building colors, and number of people. Purciel et al. (2009) used GIS to measure objectively some of these variables to help study the street level experience for designing healthy built environment.

In attempting to replicate Ewing and Handy (2009) and Purciel et al. (2009), modifications are often needed due to availability of secondary data and resources available for collecting data by field observation. Limitations of the current methodology on measuring microscale urban design qualities have been embodied in the inconsistency and subjectivity of the observation rating system and the constraint of 2D GIS for measuring some of the urban design features. Although sufficient methodological detail was reported by Purciel & Marrone (2006) on data collection through observational survey, there may be various problems during the collection process because different people have different judgements using the measurement scale defined in the field manual. 2D GIS cannot handle variables and measures that require three dimensional information. The current method, based mainly on observational survey or 2D GIS, prevents a more detailed analysis and comparison between studies on these urban design features. There is also constraint on effective measurement in large geographic context. Therefore, many studies have called for more robust and objective measures of the street design features contributing to the study of the built environment that is supportive of physical activity, healthy and sustainable living (Ewing & Handy, 2009; Yin et al., 2015; Yin & Wang, 2016).

3. 3D GIS and virtual environment

While 2D GIS has been widely used in planning, it is limited in terms of visualizing and analyzing physical objects that need to be understood in their solid forms with sensory information such as texture, shape, and size or in vertical dimensions and spatial relations such as elevation, heights, volume, and space (Yin & Shiode, 2014). 3D GIS models are built on 2D GIS data and 3D models for buildings, trees, and other objects to create virtual environments. Such models can help make the complex spatial relationship within the urban fabric easier to understand to human by delivering information in an intuitively comprehensive form, and thus improve our ability to make decision as stakeholders, planners, and policy makers (Day, 1994; Shiode, 2001). 3D GIS enables interactive control of visual exploration and explanation of spatially referenced data by accessing accurately represented studied subjects and their properties as real world objects (Kwan & Lee, 2005). We can study and examine the 3D objects in great detail and manipulate them from any angle, point, or location in 3D GIS models. Such models have been used to support the design, development, and presentation of plans. They are especially important for planning and design activities with a focus on view assessment (Yin & Hastings, 2007; Yang, Putra, & Li, 2007).

Using a 3D GIS model, we can determine the line of sight between two points in the built environment. A line can be drawn between two points to find out whether a target is visible from an observation point on a street and what obstructs the view, if not visible, given observation point's position in 3D space relative to the target and the obstructions. Obstructions can be buildings, trees, etc. built on a surface with information of elevation, building heights, shapes and tree types. These functionalities have been recently used to conduct visibility analysis to help improve safety, assess zoning regulation, and estimate sky view factor for urban climate studies (Bassani, Grasso, & Piras, 2015; Yin & Hastings, 2007; Chen et al., 2012).

The development in gaming and military simulation industries and advances in computer technology in recent years have expanded availability of software programs that are increasingly more powerful and user-friendly to build large scale 3D GIS models for different disciplines. A variety of choices are available for building 3D GIS models for planners. There are simple models based on information stored in 2D GIS databases for extrusion, such as ArcScene models. There are also complex models with more accurate and realistic representation of the built environment using architectural models, photogrammetry and laser scanning, procedural modeling, etc. such as Autodesk and CityEngine