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Street network accessibility-based methodology for appraisal of land use master plans: An empirical case study of Wuhan, China

Yang Xiao[a], Chinmoy Sarkar[b], Chris Webster[c,*], Alain Chiaradia[d], Yi Lu[e]

[a] Department of Urban Planning, Tongji University, 1239 Siping Road, Shanghai, 200092, China
[b] Faculty of Architecture, The University of Hong Kong, Knowles Building, Pokfulam Road, Hong Kong
[c] Faculty of Architecture, The University of Hong Kong, Knowles Building, Pokfulam Road, Hong Kong
[d] Faculty of Architecture, The University of Hong Kong, Knowles Building, Pokfulam Road, Hong Kong
[e] Department of Architecture and Civil Engineering, City University of Hong Kong, Hong Kong

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ABSTRACT

In rapidly developing countries where master plans quickly lead to new cities, planning professionals still lack a robust methodology for the appraisal of land use at the proposal stage. This research proposes a novel approach to master-plan appraisal based on examining whether the relationship between the planned land use pattern and the proposed street layout follows a systematic spatial logic, with land use allocation correlated to accessibility characteristics of a location. Each land use zone is given a score that reflects the degree to which it is connected to every other land use zone in the master plan. The scores are derived from topological analysis of the urban street grid using sDNA (spatial domain network analysis) methodology.[1] Our analysis supports the hypothesis of a systematic link between connectivity and land use class in general and also reveals certain specific features of land use decision-making in the city. This includes a tendency for public uses to be located on small sites and in the periphery. This is consistent with profit-maximizing behaviors of local government. The potential for application of this methodology for evaluating urban-scale master plans is discussed.

1. Introduction

Accessibility is a key concept underlying academic and practical applications of transportation, real estate valuation and land use planning (Geurs and Van Wee, 2004). Many studies have highlighted the role of different types of accessibility in driving land use change (Verburg et al., 2004; Stanilov, 2003; Davidson, 1977, Borzacchiello et al., 2010). Various mathematical and algorithmic measures of accessibility have been used to assess land use plans, projects, and scenarios, and to support decision-making for policy (Talen, 1996; Borzacchiello et al., 2009; Geurs et al., 2006; Borzacchiello et al., 2010; Geurs and Van Eck, 2003; Davidson, 1977). The logic behind such studies is that a prescribed land use pattern should reflect the underlying accessibility characteristics of the plan and should resonate with established behavior in respect to travel and the valuation of land for different types of activities.

During the previous 30 years of intense city building in China, there has been very little behavioral evaluation or calibration of urban development plans by planning professionals. Like early city plans in the West, the vast majority of China's plans are purely physical growth strategies, and are increasingly criticized for ignoring socioeconomic and neighborhood-level factors (Tian and Shen, 2011). Evidence from decades of research and policy in advanced industrial countries suggests that robust land use planning can efficiently reduce travel, improve air quality, reduce traffic congestion, and improve livability, health and economic performance (Badoe and Miller, 2000; Van Wee, 2002). Physical plans that are often little more than grand visions by growth-maximizing officials have little chance of optimizing urban performance in any meaningful way, other than maximizing municipal revenues, perhaps. The performance criterion that is currently poised to replace outright expansion and growth at the top of the Chinese planners' list of priorities is environmental performance. In recent years, the Chinese government has placed significant impetus on reducing carbon dioxide emissions and, more generally, improving the quality of the built environment via more efficient land use and infrastructure configuration. Designing walkable neighborhoods is an important part of this, as is linking such neighborhoods together in ways that reduce home–work distances. Design-trained planners in China are increasingly looking for more formal methodologies to assist with the production of more evidence-based plans (Webster, 2011). Most existing

* Corresponding author.
E-mail addresses: yxiao@tongji.edu.cn (Y. Xiao), csarkar@hku.hk (C. Sarkar), cwebster@hku.hk (C. Webster), alainjfc@hku.hk (A. Chiaradia), yilu24@cityu.edu.hk (Y. Lu).
[1] http://en.wikipedia.org/wiki/Spatial_network_analysis_software.

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methods of measuring accessibility in order to evaluate land use suitability are implemented at the aggregated macro scale (Geurs and Van Wee, 2004). These methods are unable to capture the micro-level patterns that are so important in the multi-scalar dynamics of a city and are of little use in master plan design decisions.

As an alternative to aggregate accessibility analysis, urban street layouts provide an information base that can be used for easily computed models of urban connectivity for use in land use and transportation planning. An urban road grid creates and reflects an intrinsic accessibility pattern that is, in essence, a manifestation of agglomeration effects of many different activities operating at different scales and following the laws of locational economics, also known as "centrality" (Batty, 2009; Weibull, 1980; Webster, 2010). Since a street layout partially determines the cost of making the multiple transactions that make a city work (Jones and Macdonald, 2004) it can be understood as the fundamental geometry and topology that shapes demand and supply, profit and loss, bid rent land price, and land use competition. There are many empirical studies that confirm that centrality within a street layout is statistically associated with different types of economic activity (retail, residential, etc.) (Davidson, 1977; Porta et al., 2012; Porta et al., 2009; Wang et al., 2014; Xiao et al., 2016a).

The present study measures accessibility at all links on an urban road grid and tests whether this continuous measure of connectedness correlates to a master-planned land use pattern by employing a set of multinomial logistic regression models. The specific objectives of doing this are four-fold. The first objective is to see whether there is regularity in the prescribed land use pattern of Wuhan's master plan. Second, probing further, the different thresholds of each land-use type are explored in relation to accessibility. The third objective is to uncover what these patterns might tell us about the behavior of Wuhan's master-planning authorities. The fourth and final objective is to reflect on the potential for using accessibility metrics to evaluate master plans *ex-post* and *ex-anti*.

One possible evaluation approach is to assess the correlation between planned and achieved accessibility (Talen, 1996). This might mean first testing the relationship between existing land use pattern and accessibility, and then evaluating how well the prescribed (post-master plan) land uses follow the more highly-evolved planned pattern. However, such conformity tests tend to be carried out after plans are made, rather than at the proposal stage, which would be more useful for plan makers. Consequently, this paper attempts to extend the notion of "optimality *ex ante*" in the PPIP model developed by Alexander and Faludi (1989), to investigate the land use–accessibility relationship of the entire set of master plan prescriptions, examining the extent to which plan objectives and policies would be optimally achieved, irrespective of whether they are existing or new uses. This amounts to decoding the planners' locational calculations regarding accessibility in street layout.

The remainder of the paper is organized as follows: published evidence about the impacts of accessibility on land use is reviewed in Section 2. The methodology for our study of Wuhan is introduced in Section 3. The study area is described in Section 4. Section 5 presents an experiment to explore how three levels of accessibility shape seven types of land use. Section 6 concludes with a reflection on the significance of the findings for city planning in China and elsewhere more generally.

2. Literature review

2.1. The association between accessibility and land use pattern

The concept of accessibility has a long tradition in land use and transport interaction modeling and is often reflected in transportation and land use planning goals (Handy and Niemeier, 1997). The notion of urban accessibility can be defined as "the ability of individuals to travel and to participate in activities at different locations in an environment" (Des Rosiers et al., 1999). The concept of accessibility thereby represents an individual's desire to participate in specific activities (living, working, shopping and recreation) in specific places, while land-use means the allocation of land for specific activities, such as residential, commercial, industrial, and educational provision. It is reasonable to assume, *a priori*, and in keeping with a long history of spatial economic theory, that each category of land use is supported by thresholds of accessibility. For example, home-owners' preferences for different residential locations are a function of trade-offs between the local environment and distance from destinations associated with their lifestyles (Davidson, 1977; Van Wee, 2002; Losch, 1954). Movement-minimization, measured by travel cost, can therefore help explain the spatial structure of settlement (Stanilov, 2003).

There are many existing studies that provide empirical evidence of the association between accessibility, land use pattern and land use change (Verburg et al., 2004). For example, Hunt et al. (1994) found that proximity to the transport system influences the attractiveness of residential locations. Stanilov (2003) found a strong and consistent relationship between accessibility and patterns of land-use in the suburban areas of Greater Seattle over a period of 30 years. Borzacchiello et al. (2010) studied proximity to transportation facilities and urban attractiveness as accessibility indicators, and found that accessibility indicators have significant influence on the variance of land use patterns.

2.2. Assessing land use and transport plans using accessibility

Some researchers have employed accessibility as an evaluation criterion for assessing land use scenarios and understanding impacts across social-economic domains (Geurs and Van Eck, 2003; Geurs et al., 2006; Borzacchiello et al., 2010; Guti,rrez et al., 1998; Davidson, 1977). Such a notion stems from the assumption that accessibility and land use patterns are intrinsically linked, and hence provide a prescriptive way to understand where to locate a specific land use, based on people's preferences and activity patterns.

Geurs and Van Eck (2003), for example, attempted to evaluate land use scenarios on the basis of job accessibility by car between 1995 and 2020. They found that incorporation of job accessibility could improve estimates of accessibility impacts on land use and transport policy. In another study, Geurs et al. (2006) extended their appraisal framework, using "location-based" and "utility-based" accessibility measurements to examine accessibility impacts and related user benefits of land use and transport policy strategies.

Many types of accessibility measurement have been devised for assessing land use planning. Geurs and Van Wee (2004) summarize four: (a) Infrastructure-based measurements; (b) Location-based measurements; (c) Individual-based measurements; and (d) Utility-based measurements. They note, however, that it is difficult to implement most of these approaches to study the disaggregated and fine-grained variations in accessibility necessary to explain land use patterns at an intra-city level (Geurs et al., 2006). It is an understanding of this level of variation that would be necessary to render accessibility evaluation useful in the master planning process. We also note that these approaches present problems in the context of rapidly urbanizing countries, where accurate data are scarce.

2.3. Associations between centrality and land use patterns

Connectivity metrics describing an urban road grid provide an alternative way to measure accessibility; often expressed in this context as "centrality". Such metrics have been employed for land use planning evaluation (Davidson, 1977; Batty, 2009; Pirie, 1979). Street layouts reflect the friction associated with the various kinds of economic and social transactions that draw people to live in cities. They are the veins and arteries along which resources flow and an urban transport network's topology is a crude map of distance-related transaction costs in