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The use of a virtual city model for assessing equity in access to views

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ABSTRACT

The development of virtual city models has provided novel possibilities for analyses that require consideration of building heights in urban areas. The study was undertaken to explore these possibilities by using the virtual Kyoto model to examine equity in access to views in the Japanese city. A sample of just over 5000 residences was selected by stratifying for population age and affluence. A series of viewsheds were computed to quantify the visibility of a range of environmental amenities (greenspaces, water bodies, historical buildings, mountains) and disamenities (factories and roads). Evidence of inequity in visual amenity was identified, whereby homes in areas with many old people were much less likely to have views of greenspaces and water bodies, although they were also less likely to see factories and roads and were more likely to view mountains. Homes in more affluent areas had better views of greenspaces, historical buildings, and mountains, and were less likely to see factories and water bodies. We discuss the potential of virtual city models for furthering analyses of the urban environment and raise some caveats regarding their use.

1. Introduction

The widespread adoption of Geographic Information Systems (GIS) in the past two decades has had a significant impact on research related to the fields of urban planning and design (e.g. Bateman, Jones, Lovett, Lake, & Day, 2002; Higgs, 2004; Murayama & Shibasaki, 2008). One of the most significant advances is the development of virtual city models, which show particular promise for new directions in urban planning (Evans, Hudson-Smith, & Batty, 2005; Nakaya et al., 2010; Shiode, 2001).

A virtual city model is a three-dimensional urban representation which is produced and stored in a GIS or similar Computer Aided Design (CAD) package. Virtual city models often use virtual reality techniques to depict realistic buildings and supply various services, functions, and information contexts (Dodge, Smith, & Doyle, 1997). A particular advantage of the use of these models is that they provide information on vertical variations in building heights (Kurakula & Kuffer, 2008), and many of their current applications are based on this attribute. For example, Kolbe, Gröger, and Plümer (2005) introduced several potential uses of the models for hazard management, including examining effects of floods on building storeys under a range of scenarios. Kurakula and Kuffer (2008) also demonstrate noise modelling in an urban model which allows estimates of noise exposure at the population level to be computed considering the elevation of buildings and the presence of noise barriers. Using a case study of a university campus, Thill, Dao, and Zhou (2011) demonstrated the feasibility of using three dimensional urban models for novel forms of route planning which consider vertical movements of individuals within buildings as well as between them, as well as the optimal placement of facilities within the buildings.

One area within which, to our knowledge, virtual city models have not yet been applied is in the assessment of equity of access to scenic amenity, which we define as views of landscape elements which are positively valued by society, or attractive views, amongst urban residents. We believe they possess considerable potential for this type of work. Attractive views are valued as they have been repeatedly shown to provide high levels of visual amenity, as well as more generally enhancing quality of life and the living environment (Thompson, Aspinall, & Bell, 2010; Tyrväinen & Miettinen, 2000). Being able to view nature from windows has been shown to be a determinant of good general health and well-being (Hartig, Evans, Jamner, Davis, & Gärling, 2003; Kaplan, 1993, 2001; Ulrich, 1984). Cavailhès et al. (2009) have also shown that having direct views of different land types is more influential on property prices than those types that actually surround a property but cannot be seen.

There are several methods that have previously been employed to quantify the characteristics of the views that people experience of their surrounding landscapes. Most simply, metrics may be

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calculated based on the distance between an observer and some object or objects of interest (e.g. Garrod & Willis, 1992a). Under such analyses, close objects are assumed to be more visible whilst those more distant are classed as less so. However the technique lacks precision since unconsidered landscape elements, such as buildings or other topological features, might stand between the observer and a feature being considered. Alternatively, site visits can be made in order to take photographs or videos which can subsequently be used to rate the quality of views (e.g. Anderson & Cordell, 1988; Luttik, 2000). These methods facilitate the capture of detailed landscape elements such as roadside trees, but collecting a sufficient number of samples for analyses can be labour intensive (Paterson & Boyle, 2002; Yu, Han, & Chai, 2007). It has also been noted that these methods may not provide a consistent categorisation of views across observers due to their subjective interpretation (Paterson & Boyle, 2002; Yu et al., 2007).

Most recently, viewshed analysis techniques have been developed using GIS. A viewshed is a spatial layer which identifies inter-visibility between specific locations in a landscape, and can encompass digital land surface models, data on the heights of buildings and other notable obstacles, as well as maps of land use (Sander & Manson, 2007; Lake, Lovett, Bateman, & Langford, 1998). Viewshed based methodologies allow a range of metrics associated with the characteristics and quality of views to be derived. For example, Lake, Lovett, Bateman, and Day (2000) and Cavailhès et al. (2009) determined how the visibility of certain landscape elements, such as greenspaces, water and components of built environments affect property prices. Although the computation time strongly depends on model parameters and the computing power available, such methods hold the potential to reduce study costs and subjective categorisation of views compared to other methods such as undertaking on-site visits (Paterson & Boyle, 2002; Yu et al., 2007).

Virtual city models have particular potential for the enhancement of GIS-based visibility analyses, including viewshed techniques, because they provide a digital representation of the landscape of a real city in three dimensions with high detail levels (Evans et al., 2005). Some publications have recently begun to explore their potential. Yano, Nakaya, and Isoda (2007), for instance, used a virtual city model to undertake viewshed calculations to create a visibility map of cultural objects in the city of Kyoto, Japan. Yu et al. (2007) and He (2007) employed three-dimensional building models to evaluate effect of views on property prices. Using viewshed analysis, the former research also conducted a simulation exercise of a redevelopment project to maximize sea views and assist with the identification of associated premiums on property prices. Yang, Putra, and Li (2007) extended the concept of viewsheds by showing how virtual city models can be used to implement viewsphere techniques. These better encompass the inclusion of three dimensions in the estimation of visibility. However, to our knowledge, the potential of the models to assess how population exposure to views may be socio-demographically patterned has not been explored, and this forms the focus of our case study which uses the Kyoto virtual city model.

Jones, Brainard, Bateman, and Lovett (2009) defined equity of access to amenities as equal opportunity to use among different socio-demographic groups, and in this work equity of access to views is thus defined as the equal distribution of a view from properties regardless of the socio-demographic characteristics of their residents. For our case study, we employed the two measures of access to views from properties that were suggested by Bateman, Day, Lake, and Lovett (2001). Firstly, the expansiveness of the view from properties (i.e. total area of visible land regardless of landscape elements) was investigated. Secondly, we examined equity in access to views of different types of land uses: four scenic amenities (greenspaces, historical buildings, bodies of water, and sacred mountain sites) and two landscape disamenities (factories and roads).

Greenspaces and bodies of water are probably the landscape elements that have been shown to possess the highest visual amenity, with urban greenspaces such as parks (e.g. Luttik, 2000), natural vegetation such as trees (e.g. Anderson & Cordell, 1988), and bodies of water (e.g. Luttik, 2000) consistently found to be positively valued components. We also focused on visibility of valued mountain sites since this is a positive component of Kyoto's landscape (Kyoto City Council, 2007). To evaluate this, locations of Gozan–Okuribi were chosen as visual objects. Gozan–Okuribi are six large bonfires which are lit on the hillsides of five mountains in an ancient ritual to send Buddhist spirits back to the realm of the dead after their annual visit to the world of the living (Yano et al., 2007). This is a famous summer event in Kyoto, and several new apartment buildings are advertised with views of Gozan–Okuribi as one of the advantages (ibid). Compared to more natural settings, relatively few projects have examined how components of constructed environments may be valued, although historical buildings are known to possess positive qualities (e.g. Sasaki, Ogasawara, Akatani, Ando, & Minami, 2003). In this research, we thus consider four types of historical buildings: shrines, temples and castles and early modern architectural structures, which are buildings which were designed and built incorporating Western techniques in the 19th century and which are culturally valued in Japan (Yano et al., 2007). For disamenities, industrial areas (e.g. Bateman et al., 2001) and roads (e.g. Cavailhès et al., 2009; Bateman et al., 2001) have been shown to be negatively valued in settings outside Japan, and are therefore focused upon here.

Using the case-study of Kyoto, Japan, this research was undertaken to examine the utility of virtual urban models for the assessment of visual amenity, and to evaluate how access to visual amenity may vary across different populations within the urban environment. The work builds on the existing literature by using a cutting-edge dataset (the "Virtual Kyoto" model) which provides a more complete representation of the complexity of the urban form. It also develops new methodologies to assign measures of visual amenity to large population samples, and by applying these methodologies, it provides new insights into how equitably views may be distributed across different population subgroups. In this paper we firstly describe the study area and the "Virtual Kyoto" model employed before discussing the generation of datasets required for the assessment of views. We then use a sample of 2% of residential properties to present a method for linking view quality scores to population census data. We present an analysis based on this linkage which shows the equity of access to views in Kyoto before concluding with a discussion of the benefits and caveats associated with our approach, as well as the potential policy implications of our findings.

2. Data and research design

2.1. Study area

The case study is set in the city of Kyoto, which is situated in the Kyoto prefecture of Japan. The study area boundaries were defined based on the spatial extent of the virtual city model we used (Fig. 1). The northeastern ward of Kyoto (called Sakyo ward) was not included in the study area since land use data was not available for this area. Kyoto is a city with the seventh largest population in Japan, and is known as one of the most popular tourist attractions (see Kyoto City Council, 2007). Compared to other Japanese cities, a great number of historical buildings still remain, and in 1994 seventeen locations in the city were classified as world heritage sites by UNESCO. The local authority also has been attempting to