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Investigating the urban heat island effect of transit oriented development in Brisbane

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A B S T R A C T

Transit oriented development (TOD) has been identified as a key planning tool to limit sprawl development and thereby to tackle a range of undesirable outcomes of cities. Generally, research findings are supportive of TOD policies over sprawl development in many aspects such as reducing car-dependency, congestion, and emissions. Although sprawl development has been identified as a key factor of the urban heat island (UHI) effect, a phenomenon when an urban area experiences a higher temperature compared to its surrounding non-urban areas, existing empirical studies, however, lack to answer whether TODs are likely to reduce the UHI effect. Using Brisbane as a case, this research answers this question by: a) identifying TOD neighbourhoods based on a cluster analysis of six built environment factors (residential density, employment density, land use diversity, intersection and cul-de-sac densities, public transport accessibility levels); b) validating the selection of TOD neighbourhoods based on travel behaviour analysis of residents living between TOD and non-TOD areas; c) examining patterns of UHI effects between the areas and their changes over the period of 2004–2013 based on Landsat remote sensing data; and d) identifying the factors contributing to the UHI effects in TODs. Results show that TODs experienced a higher level of UHI effect compared to non-TOD areas. Although both areas experienced an increase in the UHI effect between the periods, the rate of increase was found to be significantly higher in TOD areas. Land use diversity, percentage of porous land vis-à-vis density significantly contributed to the UHI effect. The findings suggest that a compromise between natural and built-up areas is essential to reduce the UHI effect while contributing to the ultimate goal of TODs – i.e. to create settings which prompt people to drive less and ride public transit more.

1. Introduction

This research aims to assess the urban heat island (UHI) effect of transit oriented developments (TODs). TOD is a relatively new neighbourhood planning concept, developed as a part of the smart growth movement, to limit sprawl development (Rohe, 2009). Urban sprawl is defined as low density outward expansion of cities and is associated with a range of urban problems such as car-dependency, long commute trips, congestion, greenhouse gas emissions, high infrastructure cost, and the loss of community (Pacione, 2009). TODs, on the other hand, are conceptualised as moderate-high density, diverse land use patterns, well connected street networks (as oppose to cul-de-sacs), and centred on high frequency transit nodes (Bertolini et al., 2009; Cervero and Kockelman, 1997; Renne, 2009a; Rohe, 2009). High density generates enough people to support the viability of frequent public transport services in a TOD (Cervero and Kockelman, 1997; Oakes et al., 2007). Land use diversity promotes walking and cycling because of the availability of various destination types (Duncan et al., 2010; Kamruzzaman et al., 2014a). Street connectivity makes walking comfortable to destinations and transit nodes, and therefore, increases transit ridership (Lin and Gau, 2006; Oakes et al., 2007). High frequency public transport services increase its utility to travel over competitive modes (car) (Curtis et al., 2009).

Research studies have investigated various impacts of TODs such as satisfaction with living (Lund, 2006), health benefits (Brown and Werner, 2008), accessibility benefits in terms of finding a job (Cervero and Day, 2008), social sustainability (Kamruzzaman et al., 2014b), property value gain (Bowes and Ihlanfeldt, 2001; Kay et al., 2014), parking demand (Broaddus, 2010), changes in transit ridership, car use/ownership, and active transport uses (Broaddus, 2010; Crowley et al., 2009; Dill, 2008; Faghri and Venigalla, 2013; Kamruzzaman et al., 2015; Lee et al., 2010; Nasri and Zhang, 2014; Pan et al., 2011; Renne, 2009a). Generally, the findings from these studies are supportive of TOD policy. However, very little is known about the UHI effects of TOD neighbourhoods, whereas many studies have shown that sprawl development reduces vegetation cover and thus contributes to the UHI

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intensity (Al Kuwari et al., 2016; Lemonsu et al., 2015). While studies have shown that many of the individual attributes of a TOD (e.g. high density and public transport services) can affect the UHI effect (Deilami et al., 2016; Elsayed, 2012; Lemonsu et al., 2015), there has been little research about the aggregated impacts of these individual attributes which together form a TOD.

UHI effect is a phenomenon when urban areas experience a higher temperature compared to their surrounding non-urban areas (Ward et al., 2016). The adverse effect of UHI has been widely documented in the literature. For example, it increases temperature of cities; contributes to global warming (EPA, 2016); initiates storms/precipitation events (Bornstein and Lin, 2000; Dixon and Mote, 2003); increases energy demand of cities (Santamouris et al., 2015); and contributes to heat-related mortality (Hondula et al., 2014). As a result, an increasing emphasis is placed in the policy circle in terms of devising ways to mitigate the UHI effects in cities (Chow et al., 2012; Gago et al., 2013; Susca et al., 2011). In this regard, TOD policies could bring multiple co-benefits including the mitigation of UHI effect. Nevertheless, for example, if TODs are likely to increase the UHI effect (similar to sprawl development), then the policy benefit of reducing greenhouse gas emissions through modal shift in TODs will be compromised by the increasing use of electricity. However, a lack of empirical evidence about the UHI effects of TODs hinders the justification of their operationalisation as a key policy tool worldwide (Kamruzzaman et al., 2016). As a result, the findings from this research possess a significant policy implication.

Against this background, this study seeks to address the following research question: To what extent do TODs reduce the UHI effect over sprawl development? The question is investigated using Brisbane, Queensland, Australia as a case study. Brisbane's high level of policy emphasis on TOD planning and design (Kamruzzaman et al., 2014a), along with its subtropical climate, and vulnerability to the impacts of global warming (Braganza et al., 2003; Goonetilleke et al., 2014) makes it an interesting case study.

2. Data and methods

2.1. Data

Brisbane was chosen as a case for the empirical investigation of this research because Brisbane City Council (2014) has implemented a TOD planning approach over the past decade around high frequency public transport nodes. The city has adopted TOD strategies from a higher state level strategy. The Queensland Government (2008) wishes to minimise congestion and carbon emissions in order to make the state as a liveable place. In South East Queensland (SEQ), the government intends to: double the share of active transport trips to 20%; double the share of public transport to 14%, and reduce the car use from 83% to 66% (Queensland Government, 2010). A more specific policy guide has been framed in the SEQ Regional Plan 2009–2031 aimed to achieve the targets (Queensland Government, 2009). One of the highlighted strategies is to restrict urban expansion and to facilitate development in well-defined transport nodes to promote self-contained activities. The nodes are being developed following the principles of TOD and to be served by a single or a combination of public transport modes operational in Brisbane including train, bus rapid transit, and ferry (Sipe and Burke, 2011; Yang and Pojani, 2017). The key principles to be applied in these node are (Queensland Government, 2009, p.102): diverse land uses, high residential density, high employment intensities, well-connected street networks, and fast and frequent public transport services.

Table 1 outlines the data used from various sources for the case study to answer the research question which can be grouped under four categories: a) Satellite imageries including Landsat downloaded from the USGS website to monitor the UHI effects both within TOD neighbourhoods over the period of 2004-2013, and between TOD and non-TOD neighbourhoods; b) built environment (BE) data (e.g. land uses, road networks) downloaded from publicly available websites to derive different indicators used to identify TOD neighbourhoods; c) population and employment data obtained from the Australian Bureau of Statistics (ABS) to complement the derivation of different indicators; and d) travel behaviour data downloaded from the Queensland Government website to verify the validity of the identified TOD neighbourhoods.

2.1.1. Built environment data

This research used six BE indicators to identify TODs in Brisbane. The indicators were derived at the census collection district (CCD) level. Note that the CCDs were the lowest level of the administrative boundaries used to collect census data prior to 2011. However, this boundary structure has been revised and within the current structure, the Statistical Area Level 1 (SA1) category roughly corresponds with the CCD boundary. This research aims to monitor the UHI effects of TODs over time. As a result, it was required to match the boundary spatially between censuses in order to utilise various census datasets (e.g. population density). A correspondence file is available at the Australian Bureau of Statistics (ABS) website to match the geographic boundaries between the censuses and was used in this research (http://www.abs.gov.au/websitedbs/D3310114.nsf/home/Correspondences). However, this operation correctly matched 1661 out of 1740 CCDs in Brisbane. As a result, the six BE indicators were derived for the matched 1661 CCDs only.

An 800-metre network buffer was derived from the centroid of each CCD and the indicators were calculated within this spatial scale to represent the BE characteristics of the CCDs. The 800 m buffer was selected based on the Queensland Government (2009) recommendation of TOD precinct size (10 min walking distance). The derived six indicators are:

a) Net residential density (number of dwelling units per hectare of residential zone land) (Frank et al., 2005);
b) Net employment density (number of jobs per hectare of employment generating land uses such as commerce, industry (Center for Transit-Oriented Development, 2010);
c) Land use diversity (Simson's diversity index based on the area of five types of land uses including residential, commercial, industrial, recreational, and institutional) (Kamruzzaman and Hine, 2013; Simpson, 1949) ranges from 0 (single land use) to 1 (fully diverse – all five land uses are present in equal amount);
d) Intersection density (number of 3 or more way of intersection per hectare of land) (Cervero and Gorham, 1995);
e) Cul-de-sac density (number of dead-ends per hectare of land) (Cerin et al., 2007; Stangl and Guinn, 2011); and
f) Public transport accessibility level (PTAL) – an index developed by Transport for London (2010) based on five attributes of public transport services: spatial reach (whether public transport services are located within the buffer), modes of public transport services available (bus and train in this case), frequency of the available services, ability to travel in different directions (routes), and reliability. This research derived PTAL for the morning peak period on weekday using the General Transit Feed Specification (GTFS) data. The ferry was not considered due to a lack of availability of relevant data within the GTFS datasets.

The six indicators were selected based on a review of the 21 principles proposed for the construction of TODs in the research context (Queensland Government, 2009). The principles relate to the various components of a TOD including built environment (availability and intermodal connectivity of public transport services, land use mix, residential density, land use intensity for employment, and pedestrian connectivity), locational (new development, within existing urban areas), social (social diversity and inclusion), and process (coordination, timeframes, stakeholder engagement). This research extracted the built environment related principles and identified relevant indicators