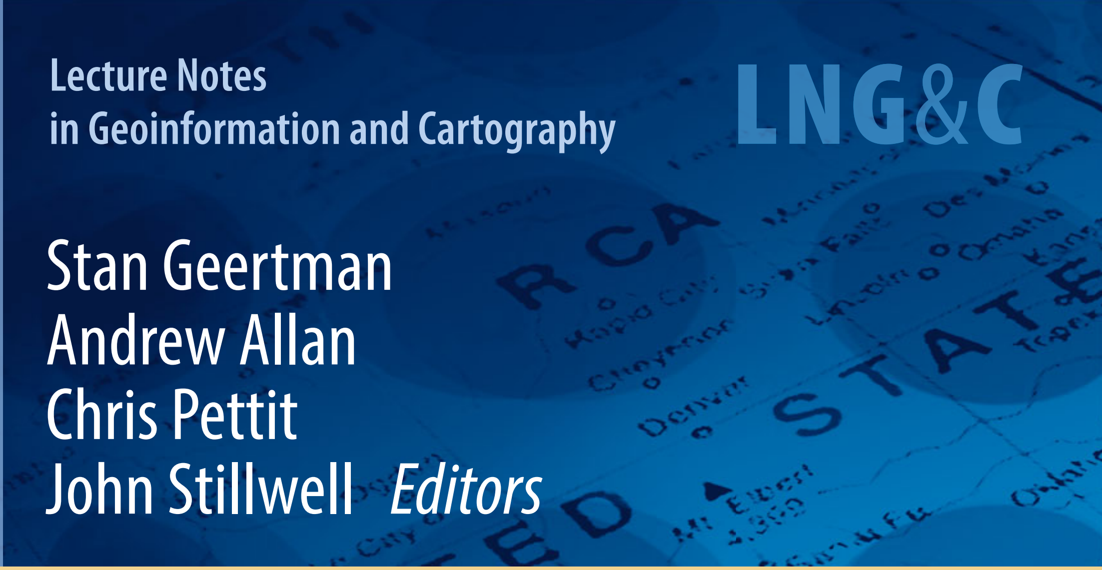
Lecture Notes
in Geoinformation and Cartography

LNG&C



Stan Geertman
Andrew Allan
Chris Pettit
John Stillwell *Editors*

Planning Support Science for Smarter Urban Futures

Springer

Lecture Notes in Geoinformation and Cartography

The Lecture Notes in Geoinformation and Cartography series provides a contemporary view of current research and development in Geoinformation and Cartography, including GIS and Geographic Information Science. Publications with associated electronic media examine areas of development and current technology. Editors from multiple continents, in association with national and international organizations and societies bring together the most comprehensive forum for Geoinformation and Cartography.

The scope of Lecture Notes in Geoinformation and Cartography spans the range of interdisciplinary topics in a variety of research and application fields. The type of material published traditionally includes:

- proceedings that are peer-reviewed and published in association with a conference;
- post-proceedings consisting of thoroughly revised final papers; and
- research monographs that may be based on individual research projects.

The Lecture Notes in Geoinformation and Cartography series also includes various other publications, including:

- tutorials or collections of lectures for advanced courses;
- contemporary surveys that offer an objective summary of a current topic of interest; and
- emerging areas of research directed at a broad community of practitioners.

More information about this series at http://www.springer.com/series/7418

Stan Geertman · Andrew Allan
Chris Pettit · John Stillwell
Editors

Planning Support Science for Smarter Urban Futures

Springer

Editors
Stan Geertman
Faculty of Geosciences, Department of Human Geography and Planning
Utrecht University
Utrecht
The Netherlands

Andrew Allan
School of Art, Architecture and Design
University of South Australia
Adelaide, SA
Australia

Chris Pettit
UNSW Built Environment
University of New South Wales
Sydney, NSW
Australia

John Stillwell
School of Geography
University of Leeds
Leeds, West Yorkshire
UK

ISSN 1863-2246 ISSN 1863-2351 (electronic)
Lecture Notes in Geoinformation and Cartography
ISBN 978-3-319-57818-7 ISBN 978-3-319-57819-4 (eBook)
DOI 10.1007/978-3-319-57819-4

Library of Congress Control Number: 2017939096

© Springer International Publishing AG 2017
This work is subject to copyright. All rights are reserved by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed.
The use of general descriptive names, registered names, trademarks, service marks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.
The publisher, the authors and the editors are safe to assume that the advice and information in this book are believed to be true and accurate at the date of publication. Neither the publisher nor the authors or the editors give a warranty, express or implied, with respect to the material contained herein or for any errors or omissions that may have been made. The publisher remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Printed on acid-free paper

This Springer imprint is published by Springer Nature
The registered company is Springer International Publishing AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Preface

The international CUPUM (Computers in Urban Planning and Urban Management) conference has been one of the premier international conferences for the exchange of ideas about and applications of computer technologies used to address a range of social and environmental problems relating to urban areas. The first conference took place in 1989 in Hong Kong and since then, this bi-annual conference has been hosted in every continent of the world, although still with the sole exception of Africa (Table 1). In 2017, delegates gathered for the fifteenth time at the University of South Australia in the city of Adelaide (Australia).

Table 1 Past CUPUM conferences

Number	Year	Place	Country
I	1989	Hong Kong	Hong Kong
II	1991	Oxford	United Kingdom
III	1993	Atlanta	USA
IV	1995	Melbourne	Australia
V	1997	Mumbai	India
VI	1999	Venice	Italy
VII	2001	Honolulu	USA
VIII	2003	Sendai	Japan
IX	2005	London	United Kingdom
X	2007	Iguazu Falls	Brazil
XI	2009	Hong Kong	China
XII	2011	Lake Louise (Calgary/Banff)	Canada
XIII	2013	Utrecht	The Netherlands
XIV	2015	Boston	USA
XV	2017	Adelaide	Australia

The CUPUM Board (Table 2) has promoted the publication of a book with a collection of the scientific papers that were submitted to the conference. The papers went through a competitive review process that resulted in the selection of what the reviewers deemed the best CUPUM papers of 2017. All these papers fit the main overarching theme of this CUPUM conference (Planning Support Systems for Resilient and Smart Urban Futures) and the slightly more specific theme of this year's CUPUM book: *Planning Support Science for Smarter Urban Futures,* published by Springer. Therein, we acknowledge that the field of Planning Support Systems (PSSytems) has broadened from a focus initially on systems to one on the science underpinning the systems: Planning Support Science (PSScience). Moreover, the contents of the book reflect the growing worldwide interest in 'smart city' developments in general and in 'smarter urban futures' in particular.

Table 2 Board of Directors of CUPUM

Name	Institute	E-mail
Andrew Allan	University of South Australia	Andrew.Allan@unisa.edu.au
Joseph Ferreira	Massachusetts Institute of Technology	jf@mit.edu
Stan Geertman (Chair of Board)	Utrecht University	s.c.m.geertman@uu.nl
Karl Kim	University of Hawaii	karlk@hawaii.edu
Kazuaki Miyamoto	Tokyo City University	miyamoto@tcu.ac.jp
Paola Rizzi	Università degli Studi di Sassari	paola.rizzi@univaq.it
Antonio N. Rodrigues da Silva	University of Sao Paulo	anelson@sc.usp.br
Renee Sieber	McGill University	renee.sieber@mcgill.ca
John Stillwell	University of Leeds	j.c.h.stillwell@leeds.ac.uk
Anthony G.O. Yeh	University of Hong Kong	hdxugoy@hkucc.hku.hk

Organizing the programme of an international conference and editing a volume of scientific papers requires dedication, time, effort and support. First of all, as book editors, we would like to thank the authors for their contributions. Initially, 70 abstract proposals were submitted as potential book chapters and we finally ended up with 26 high-quality contributions.

Second, we would like to thank the reviewers for their dedication in fulfilling the difficult task of assessing the submissions and recommending the best papers for inclusion in this book. The double-blind review process was not an easy task, for sure; it is always difficult when a large number of potential authors are going to be disappointed. The group of reviewers who assisted us in this selection process and provided the selected authors with valuable comments on their drafts were the members of the Board of Directors of CUPUM and the Advisors to the CUPUM Board (Table 3), complemented with the other members of the Scientific Committee (Robert Goodspeed, Lin Meng, Sekhar Somenahalli, Sada Karuppannan, and Qingming Zhan). By fulfilling the review process double-blind and demanding at least two reviews per submission, we believe that the review process has been conducted in a fair and equal way.

Table 3 Advisors to the CUPUM Board

Name	Institute	E-mail
Michael Batty	University College London	m.batty@ucl.ac.uk
Dick Klosterman	University of Akron	klosterman@whatifinc.biz
Michael Wegener	University of Dortmund	mw@spiekermann-wegener.de
Ray Wyatt	University of Melbourne	raywyatt3@gmail.com

Third, we would like to thank our scientific sponsors (University of South Australia, the Faculty of Art, Architecture and Design) for their contribution in time and resources to this publication. In addition, we would like to thank Springer Publishers for their willingness to publish these contributions in their academic series *Springer Lecture Notes in Geoinformation and Cartography*.

This is the third time that a selection of best papers from the CUPUM conference has been published by Springer. The first time was in 2013, when 26 papers were published in *Planning Support Systems for Sustainable Urban Development* (edited by Stan Geertman, Fred Toppen and John Stillwell), and the second time was in 2015, when 24 papers were published in '*Planning Support Systems and Smart Cities*' (edited by Stan Geertman, Joe Ferreira, Robert Goodspeed and John Stillwell). We hope more CUPUM books will follow in years to come.

Adelaide, Australia
2017

Stan Geertman
Andrew Allan
Chris Pettit
John Stillwell

Contents

Chapter 1
Introduction to 'Planning Support Science for Smarter Urban Futures'

Stan Geertman, Andrew Allan, Chris Pettit and John Stillwell

Abstract This introductory chapter establishes the context for subsequent contributions by outlining some of the major physical and social challenges that confront planners and policy-makers in different parts of the world. It then explains how the development of planning support systems has evolved into a much broader field of Planning Support Science which intersects with the emergence of data science, big data, data analytics and new urban science, thereby creating new opportunities for innovative solutions to support progress towards the development of smarter and more resilient urban futures. The structure of the book is clarified and short summary reviews of each chapter provide a composite portrait of the contents as a whole.

Keywords Planning support systems · Smart cities · Urban futures

---

S. Geertman (✉)
Department of Human Geography and Planning, Faculty of Geosciences, Utrecht University, Heidelberglaan 2, 3584 CS Utrecht, The Netherlands
e-mail: s.c.m.geertman@uu.nl

A. Allan
School of Art, Architecture and Design, University of South Australia, Adelaide, SA, Australia
e-mail: Andrew.Allan@unisa.edu.au

C. Pettit
City Futures Research Centre, UNSW, Sydney, Australia
e-mail: c.pettit@unsw.edu.au

J. Stillwell
School of Geography, University of Leeds, Leeds, UK
e-mail: j.c.h.stillwell@leeds.ac.uk

S. Geertman et al. (eds.), *Planning Support Science for Smarter Urban Futures*, Lecture Notes in Geoinformation and Cartography,
DOI 10.1007/978-3-319-57819-4_1

1 Introduction

We are living in an increasingly urbanized world; a tipping point was crossed in 2008 when more than 50% of the global population was reported to be living in urban areas (United Nations 2014). Furthermore, this urbanization process is expected to result in more than 60% of the world's forecast population of 8.5 billion to be living in urban areas by 2030 (United Nations 2014). The number of cities with over a million inhabitants is due to increase nearly 30% from 512 in 2016 to 662 in 2030 (United Nations 2016) and the number of 'megacities', those with more than 10 million residents, is forecast to rise to 41 in 2030 from 31 in 2016. In 15 years' time, the United Nations (2016) predict that 27% of the world's population will be living in cities with at least 1 million people. Whilst these statistics are themselves striking, the implications or consequences of these demographic changes are far-reaching and present major challenges. Forecasts suggest that 2 billion people living in urban areas in 2030 will be living in slum areas (UN Habitat 2003), for example. The United Nations (2016) estimate that 56% of the 1,692 cities with populations of at least 300,000 in 2014 were at risk to at least one of the six types of natural disaster (cyclones, floods, droughts, earthquakes, landslides and volcano eruptions). In fact, "*a majority of city dwellers live in cities that face high risk of disaster-related mortality or economic losses*" (United Nations 2016, p. 9).

There are many other challenges facing the world's cities which planners and policy-makers need to give their urgent attention to, such as increasing traffic congestion, which in Australia alone is expected to cost $30 billion of Gross Domestic Product (GDP) by 2030 (BITRE 2015). The increase in the number of people driving cars is causing other related problems such as the decline in air quality which is now the world's fourth leading fatal risk factor. Air quality was responsible for 5.5 million premature deaths worldwide in 2013, estimated to cost the global economy $225 billion in lost income (World Bank 2016). In fact, air pollution costs the world's economy $5.11 trillion in welfare costs (World Bank 2016). Moreover, the consequences of air pollution are not just identified as financial; they also cause major changes in people's patterns of behaviour. In December 2016, for example, it was reported in the press that tens of thousands of 'smog refugees' were leaving the cities and industrial areas of northern China to escape the 'airpocalypse' caused by the blanket of toxic fumes (The Guardian Website 2016).

We are also facing major health crises with respect to obesity and associated diseases such as type II diabetes, on the one hand, and famine and malnourishment on the other. There are 422 million people in the world with type II diabetes and, according to the World Health Organisation (WHO), numbers have quadrupled since 1980 (WHO—http://www.who.int/diabetes/en/). The United Nations Food and Agriculture Organisation (FAO) estimate that around 795 million people in the world are undernourished, most of whom are living in developing countries (FAO 2015). The world is in an age of anthropogenically-induced climate change which is resulting in increased temperatures and natural events such heatwaves, floods and sea level rises. All of these environmental factors have serious implications for cities and all who live in them. In addition, shifts are taking place in the geodemographic and geopolitical landscape with the aging society, the increasing mass migrations, and the rise of a strong anti-globalisation sentiment in the powerhouses of the Western world, as illustrated through Brexit and the emergence of Trump as the 45th President of the United States, all of which encourage uncertainty and make effective planning and decision-making that much more challenging.

It is with this shockingly sombre backdrop that we introduce this volume on 'Planning Support Science for Smarter Urban Futures.' Never has there been a more important time for communities, planners and policy-makers to work together more closely and collectively to address the pressing issues facing the cities in which we choose to live in increasing numbers. Yet several glimmers of hope have emerged in this current age of digitization, big data and smart cities, indicating that Information Technology and Communication (ICT) and data driven approaches (data science and informatics) may be brought to bear to support planners and policy-makers in dealing with some of the grand challenges facing our planet.

Planning Support Systems (PSS) can be defined simply as computer based-tools which can assist planners to more effectively undertake their day to day jobs. In the broadest sense, PSS are computer based tools which add value to the planner's work processes, including spreadsheets and websites to Geographical Information Systems (GIS) and visualization and beyond (Couclelis 2005). Another definition (Geertman 2006) considers PSS as geo-information technology-based instruments that are dedicated to supporting those involved in planning in the performance of their specific planning tasks. Whilst there are numerous other definitions of PSS available in the literature (see for example, Batty 1995; Klosterman 1997), what is common to all is they are computer-based tools to support planners in undertaking planning-specific activities.

PSS came into being in the late 1980s as described by Harris and Batty (1993). They arose through a convergence of efforts being undertaken in the areas of GIS, large-scale urban models and Decision Support Systems (DSS). PSS were in some way a response to the backlash from planners and policy-makers to top-down, black-box models which were being run to optimise city development. This is resoundingly articulated in Lee's famous 'requiem for large-scale urban models' (Lee 1973). PSS are those tools that *support* planning activities, not *replace* planners in undertaking strategic planning and other activities. This is an important distinction to the black-box land-use and transport models in the 1970s, some of which are still used today to optimise city outcomes through a series of equations. In the 1990s, a number of PSS were developed which enabled planners to interact and use these tools themselves through Graphical User Interfaces (GUIs). Planners could change parameters through the use of slider bars and other means and explore the likely implications of these changes through map visualisation, bar charts, *et cetera*. Thus planners could begin to explore *what if?* urban scenarios; for example, *what* would happen *if* the population increased for a defined urban geography by 3% per annum instead of 1.5%?

Early PSS included systems such as CommunityViz (Kwartler and Bernard 2001), INDEX (Allen 2001), What if? (Klosterman 1999), and UrbanSim (Waddell 2002). Several of these PSS, and others, have stood the test of time and in their various incarnations are still used in planning practice 20 years on, such as the open source online version of What if? (Pettit et al. 2013, 2015a, b) and the cloud-based UrbanSim due for release in 2017. In recent times, there has also been a focus on improving the user experience for planners interacting with PSS through studies and experiments undertaking more engaging interfaces such as maptables (Arciniegas et al. 2013) and the beginning of empirically-driven PSS user studies (Russo et al. 2015).

However, as Vonk et al. (2005) and others have noted, the implementation of PSS has not been without its challenges with the adoption in practice not as widespread as the PSS developer community might have hoped for (Geertman and Stillwell 2003). Yet with the emergence of the smart city, digitisation, big data and the opening of government data repositories, there are new opportunities for PSS to embrace this shift towards the digital paradigm and increase their visibility and uptake as geo-information toolkits which can support a number of urban planning tasks. It is due to this much widened perspective on PSS that we prefer to speak of an upcoming scientific field of ‘Planning Support Science’ with an emphasis on the goal of support instead of focusing just on the system-side of PSS (Geertman 2013).

Increasingly, PSS are embedded in digital data infrastructures which form an integrated whole, such as in the case of the Australian Urban Research Infrastructure Network (AURIN) online workbench which provides access to over 2,000 datasets, 100 spatial statistical tools and a constellation of PSS (Pettit et al. 2015a, b, 2017). Furthermore, for their acceptance in planning practice, PSS request an attuning to the specifics of planning practice, to the intended application, and to the context of that application. This attuning, its needs and its associated methodology have become a field of research in its own right (Geertman 2006, 2013). In addition, the upcoming concept of smart city has blurred the distinctions between systems, tools, instruments, apps, social media, big data, *et cetera*, that all by itself can fulfil an ICT-based supporting role in planning practice. It is for all these reasons that we prefer now to use the term Planning Support Science (Geertman 2013). In recent times we have also seen the rise of a new science of cities (Batty 2013) and big data and data science as applied in the context of shaping cities (Thakuriah et al. 2017). The intersection of Planning Support Science, city or urban science and data science is offering exciting new possibilities in data driven approaches to city planning.

It is in this context that this book builds upon research presented in the previous volumes of this series of PSS books (Geertman and Stillwell 2003, 2009; Geertman et al. 2013, 2015). In supplement to the most recent themes of ‘PSS for Sustainable Urban Development’ (2013) and ‘PSS and Smart Cities’ (2015), in this volume we introduce the term ‘Smarter Urban Futures’. In doing that, we emphasize the future-oriented nature of planning and our focus therein is predominantly dedicated to the urban environment. In that, in accordance with the theme of the CUPUM 2017 conference, we also emphasize the orientation towards the idea of resilient and smart urban futures. We are of the opinion that in a time of increasing human and natural disasters and global instability, the focus on smartness and resilience is a logical choice and a serious matter. For instance, just recently we have seen the emergence of resilience with, most notably, the establishment of the Rockefeller Foundation's 100 Resilient Cities Programme. The Rockefeller Foundation provides a definition of resilience as "*the capacity of individuals, communities and systems to survive, adapt and grow in the face of stress and shock, and to even transform when conditions require it*" (Rockefeller Foundation 2015, https://www.rockefellerfoundation.org/our-work/topics/resilience/).

Sanderson (2016) views resilience as an aspirational paradigm, yet it has elements of newness which could provide opportunities not previously possible in engaging planners, and decision-making in response to stress from the shocks facing our cities and all those who live in them. The term 'city resilience' is relatively new too and has been defined by da Silva (2016, p. 5) as "*the capacity of cities to function, so that the people living and working in cities—particularly the poor and vulnerable—survive and thrive no matter what stresses or shocks they encounter*". In addressing city resilience, there is a need to support planners and policy-makers with data analytics, models, simulations, dashboards, participatory frameworks and interactive tools and visualisations; so in short, a much smarter environment than most of the present. As such, PSS can provide a modest contribution to the armoury of tools and techniques required to support planners in both envisioning and realising more resilient and smarter urban futures.

The chapters that follow in the remainder of the book therefore collectively provide a state-of-the-art perspective on the general field. As editors, we have decided to separate the contents into two sections: those that are predominantly focused on explaining PSS and their applications, and those that have a wider remit or which consider smarter urban futures more explicitly. In each section, we offer a short synopsis of each chapter as a means of providing a more composite picture and a rationale for the order in which chapters are presented.

2 Planning Support Science

Cities are complex, dynamic systems whose regulation or development through planning requires increasingly sophisticated methods to understand, model, predict and formulate strategies and plans for the future. In all steps or stages of the planning process, the evidence base is derived from the existence of information about the past and present, together with details about scenarios for the future; in all cases, effective decision-making is enhanced by information and data from a diversity of sources. The volume and diversity of data types is expanding rapidly, not least as new big data sets come online, sometimes via social media. Consequently, the field of Planning Support Science is characterised by the continuous development of frameworks to incorporate new data, new types of data and new ways of linking data from different sources together for the benefit of analysts, planners and decision-makers. It is therefore unsurprising that the chapters in the first section of the book tend to reflect work ongoing on PSS in different countries around the world that is based on exploiting the data in different ways, developing new indices for measuring and monitoring change and using new methods for visualising and analysing new data sets. The first five chapters all have a primary focus on data, metrics and indicators.

The first chapter of this section (Chap. 2) written by *Claire Daniel* exemplifies the construction of a web-based mapping system as the prototype of a PSS for mapping the effects of urban planning policies. In this work, data on development permits, land uses, infrastructure and services are assembled for four cities in three different countries as the pre-requisites for automated mapping and for allowing comparisons to be made between the structure of the planning systems, the data available, the metrics that are appropriate, and the visualisation methods.

A major factor in determining whether a city or a community can survive, adapt, and develop in the face of stresses and shocks is the configuration of its component structures; its roads, buildings, vegetation, waterways, open spaces, for example. PSS have been developed in the past to measure conditions, design future scenarios, identify performance indicators and evaluate scenarios according to the extent to which they achieve the goals that have been established. One example of such a system is INDEX (Allen 2008), a tool developed by Criterion Planners of Portland Oregon which supports scenario planning at different spatial scales by measuring the resilience of scenarios. INDEX has an in-built set of indicators of land-use, urban design, transportation and the environment but users can implement indicators designed for local issues. Chapter 3, by *Fernando Lima*, *Nuno Montenegro*, *Rodrigo Paraizo* and *José Kós* explains and evaluates the implementation of a not too dissimilar system called Urbanmetrics, an indicator-based methodology which serves to measure how a neighbourhood is configured based on Transit Oriented Development (TOD) principles. The system computes indicators that consider physical proximity, topology and walkability as well as the diversity of an area and the chapter reports the results for a case study of a medium-sized city in Brasil using a multi-objective optimisation plug-in.

In Chap. 4, *Alireza Karduni*, *Isaac Cho*, *Ginette Wessel*, *Wewen Dou*, *William Ribarsky* and *Eric Sauda* provide an introduction to the possibilities of using advanced programming techniques to analyse the possibilities of enabling social network data, including tweets, to feed PSS. The prototype system, known as the Urban Activity Explorer, adopts interactive Visual Analytic Systems (VAS) to allow the exploration of very large datasets (e.g., 1 million tweets over two months) for Los Angeles, to identify hotspots of activity and their development over time, demonstrating the valuable role of mobile social media as a source of information about activities across the city.

The following Chap. 5 by *Toshihiro Osaragi* and *Noriaki Hirokawa* has the specific aim of mitigating the effects of a large earthquake, by identifying those urban fires that are most likely to spread widely and therefore by concentrating firefighting resources on these locations. The chapter introduces two new indicators; firstly, the number of buildings that are expected to be destroyed by fire spreading from one specific building, the so-called fire-spread potential index; and secondly, the burn-down potential index, the probability that a building will burn down given the outbreak of fire within the building itself but also from fire spreading from surrounding buildings. The chapter reports on agent-based simulations of the spread of fires throughout the Tokyo Metropolitan Area and the resulting surfaces for the two indexes are plotted and analysed.

One major issue for planners in both the developed and the developing world is to find suitable land for human settlement and suitable sites for new housing. Nowhere is this more apparent than in South Africa, where the Government produced a new human settlements plan in 2004 (Breaking New Ground) which aimed to eradicate informal settlements and to reinforce the Department of Housing's vision of encouraging the creation of a non-racial, integrated society through the development of sustainable human settlements and quality housing. Chapter 6 explores the spatial analysis that was undertaken to determine land that was available for an additional 100,000 housing units over the next five years. The authors, *Baleseng T. Mokoena*, *Walter Musakwa* and *Thembani Moyo* explain the methodology used to construct a new index called the Well-Located Land Index (WLLI) based on a GIS and making use of Multi-Criteria Decision Making (MCDM). The index is defined as a function of various criteria that are used to identify well-located land. These criteria were identified through a workshop involving professional and academic stakeholders and weighted using the Analytical Hierarchy Process (AHP). Different classes of suitability of land for housing are mapped using ArcGIS for the Ekurhuleni Metropolitan Municipality, not far from Johannesburg. The authors demonstrate the feasibility and appropriateness of the index to identify new housing opportunities efficiently and appropriately, but the caveat is that within the community, and amongst planners in practice, there is a marked reluctance to embrace technologies in the planning process. It is commented that innovative policies that could fulfil the goal of smarter, more resilient cities are not the problem; rather there is a lack of implementation and innovation that constrains progress.

Chapter 7 continues the theme of combining data from different sources by looking at how urban areas can be designed to be more resilient in the face of serious effects of climate change on urban forests. In a world with ever-increasing volumes of data are held in increasingly large repositories, there is a major challenge for planners to develop systems that exploit the opportunities available for more effective urban planning and design. In many cases this involves bringing together different types of data and information sets in a dynamic manner from a range of disparate sources. It has now become commonplace for local authorities in some countries to develop web-based interfaces that allow users to access information that they consider useful for understanding the spatial characteristics and dynamics of their localities (e.g., Marsden 2015). The chapter by *Nano Langenheim*, *Marcus White*, *Jack Barton and Serryn Eagleson* is closely tied to the theme of urban resilience in that the authors focus on some of the challenges confronting planners in cities in Australia caused by changing environmental conditions and explain how PSS can be used to assist decision makers utilise the available data to assemble evidence that can thereafter be used to formulate policies that encourage buy-in from local stakeholders. Two examples are used, the first exploring scenarios for urban forest design in the Melbourne suburb of Elwood, a district prone to tidal inundation from sea level rise. The second example describes the potential for combining data on street networks, traffic flows and topography and uses a pedestrian catchment modelling tool to improve accessibility to a primary school in an inner suburb of Melbourne, thereby helping the local authority formulate its infrastructure design in a way that is beneficial for school children and their parents.

In Chap. 8 by *Jennifer Minner*, the use of geodesign, 3D visualisation and scenario planning methods and tools is examined in the management, remediation, rehabilitation and long-term planning of post mega-event locations for two test bed sites, Hemisfair Park in San Antonio, Texas and Flushing Meadows in New York City. Both sites hosted World Fairs in the past, celebratory mega-events that provided an opportunity to showcase activities, products, technological prowess and achievements. The paradox of these mega sites is that once the short-lived mega-event has passed, they lapse into a pattern of underutilisation and decay that unfortunately perpetuates the original problematic nature of such sites. This chapter highlights that the post-planning of these sites provides the opportunity for better planning and urban management because the large scale of such sites suits the use of sophisticated tools which is critically important to achieving sustainable and resilient urban areas. A design workshop held at Cornell University allowed students the opportunity to use the two case study locations to undertake planning and design studies using PSS tools such as City Engine, Envision Tomorrow, ArcGIS, Photoshop, Google Earth, Sketch-up, 3D warehouse and the GIS portals of local and federal government agencies. The geodesign PSS is examined, from which it is concluded that whilst geodesign planning tools have value, there is still considerable potential for GIS elements to be better integrated with architectural visualization software. Geodesign tools omit Building Information Management (BIM) tools, and this does limit development feasibility and resilience planning. It seems that whilst great strides have already been made in the development of geodesign PSS, there is still significant scope for improvement, particularly with regard to integration of various digital platforms and ease of use.

The following two chapters deal with an increasingly popular field of PSS development, that of urban walkability, and follow on logically from the second example used in Chap. 7. The first, Chap. 9, written by *Claire Boulange*, *Chris Pettit* and *Billie Giles-Corti*, reports on the development of a PSS that aims to improve the relationship between the build environment, walkability and health, as well as fostering collaboration between researchers working in an academic environment and urban planners. The so-called Walkability PSS has been built to promote healthy built environments and therefore create more resilient urban areas. It allows users to sketch precinct plans on a digital map using a tabletop (MapTable) interface; it then estimates that probability that an adult walks to a destination using information about the roads, the land-use types and the public transport modes that are available. The estimated probabilities are updated in real time and displayed on an interactive chart. The PSS is built on the CommunityViz 5.0 software and aims to assist planners in developing healthier communities by allowing them to test alternative planning scenarios and what the impacts will be on people's walking habits. The main focus of this chapter is not on explaining the PSS itself but on its evaluation; to this end, the chapter reports the responses of seven participants at a two-hour workshop to questions about the system's usability, suitability and potential application areas. In all cases, the study finds the Walkability PSS to be well received and relevant for understanding the impacts of alternative policies.

The second walkability Chap. 10 is by *Kayoko Yamamoto* and *Shun Fujita* and outlines the structure and function of a system that provides guidance for tourists navigating their way around the city of Yokohama in Japan, assisted by the provision of real-time information derived from social media. Tourists who are unfamiliar with the city can change their routes dynamically and visit the sights of the city more efficiently, using augmented reality technology to explore the real space that surrounds them. Navigation outdoors is facilitated by users wearing smart glasses or carrying mobile information terminals. They can also move around the city more safely because the system is designed for use in times of disaster as well as times of normality. The chapter reports how the system was evaluated by a sample of users under both scenarios.

In Chap. 11, *Yiqun Chen*, *Abbas Rajabifard* and *Jennifer Day* outline a new Application Programming Interface (API) for enabling the calculation of isochrones —lines of equal travel time—around selected nodes. Typically these are based on transportation routes such as public transport infrastructure, roads, footpaths, *et cetera*, rather than simply circular buffers around a point, and specialist software is available to construct isochrones (e.g., Microsoft's MapPoint, ESRI's Network Analyst). The new free-of-charge web service for constructing isochrones created by the authors is designed to encourage use by planners without the need to obtain proprietary software. The chapter outlines how their isochrone calculation is based on a breadth-first-search algorithm for searching graph data structures, presents the pseudo-code of their algorithm, and demonstrates the approach using road network data extracted from OpenStreetMap which has to be cleaned to ensure all isolated road links are eliminated. The web service API is exemplified using a number of isochrone scenario requests using seed points in Melbourne, i.e. compute isochrones: for N points with the same distance; for N points with N distances; for N points with different distances; and for N points showing points, links and polygons. The chapter finishes by reporting the performance of the API in terms of processing a large number of calculation requests with three isochrones search distances (500, 1000 and 1500 m) using a test area in Melbourne comprised of geographical units with populations of over 200 persons.

The penultimate chapter of this section of the book focuses on the use of microsimulation modelling at the household level. Chapter 12 is authored by *Nao Sugiki*, *Kazuaki Miyamoto*, *Akinari Kashimura* and *Noriko Otani*, and uses an agent-based household microsimulation approach to study the demographic changes that may arise over the next few decades within two different communities in the suburbs of Tokyo. The focus of the chapter is on understanding the impacts of an aging population on the composition of the suburban communities and on their quality of life. The approach that the authors have taken to building a synthetic population is original in that it relies only on Monte Carlo sampling instead of a combination of Iterative Proportional Fitting (IPF) and Monte Carlo sampling.

The final chapter in this section of the book is one which considers smart technologies for collecting social data for use in PSS and therefore provides a nice bridge to the next section. Chapter 13 is authored by *Wencheng Yu*, *Qizhi Mao*, *Song Yang*, *Songmao Zhang* and *Yilong Rong* and focuses on social sensing, the collection of observations about the physical environment from human beings or devices acting on their behalf. The authors suggest that most social sensing research and applications in urban planning hitherto have been on the structure of urban space, population flows, transport networks and citizen's activities rather than on semantic cognition and social relations. Their approach is to use methods of data cleaning, word segmentation, word clouds, sentiment analysis and topic analysis to gather citizens' thoughts, opinions and ideas on issues that will support planners' decision-making and they use the renovation of an old district of south west Beijing as a case study to test their framework. Whilst it is undoubtedly the case that there is value in the intelligence that is gathered from local people by sensing and analysed using the methods exemplified in the chapter, the way in which this information feeds into the planning process that brings about renovation and the influence that it has on decision-making remains unclear.

3 Smarter Urban Futures

During the last couple of years, the concept of 'smart cities' has been taken up by many city leaders, planners, IT companies and scholars worldwide. It appears that the field of Planning Support Science, as dealt with in the previous section, is becoming more and more part of the instrumental toolbox of smart cities. As a consequence, the boundaries between these two fields of research and practice are getting increasingly blurred. Topics like open and/or big data, city indicators, real-time data visualizations and data analytics increasingly play an important role in both fields. This is something that can be observed all around the world and at very different levels of administration in different countries. And happily, this is not just an academic debate; the fields of PSS and smart cities increasingly trigger close collaborations between governmental organizations, private firms and non-governmental organizations including academia, as is shown by many of the contributions in this book.

The first chapter of this section (Chap. 14) deals specifically with the topic of the increasing integration of PSS and smart cities. Therein, the authors, *Vinutha Magal Shreenath* and *Sebastiaan Meijer*, ascertain that big data are currently used mainly for operational understanding and as improved data sources for existing design methods. Contrarily, in their opinion, big data are hardly ever applied for long-term planning and design purposes. To overcome this deficiency, they present an application of big data for finding suitable locations for deploying charging infrastructure for vehicles, such as the Electrical Road System (ERS). With the help of these big data, potential locations are identified for placing static charging installations and relevant road segments are selected to locate dynamic charging installations. The authors conclude that the combination of big data with expert knowledge can be very valuable for the design of future urban transport systems.

In Chap. 15, *Li Meng*, *Andrew Allan* and *Sekhar Somenahalli* examine past PSS and note how they have shaped the modelling of land use and transport planning at the metropolitan scale for two Australian cities, Adelaide and Perth. The authors examine proposed new metropolitan scale models for each of these cities that, whilst complex, incorporate a more integrated and sophisticated approach that is responsive to future challenges and community preferences by exploiting the latest innovations in PSS in terms of data and new integrated modelling platforms. These two cities have similar morphologies in that their growth has been biased to their north-south axes because of geographical constraints (ocean on their western flanks and higher ground on their eastern flanks). During the mid-20th century, both of these cities were of a similar size and population, but since Western Australia has reaped the benefits of a sustained mining boom during the past half century, metropolitan Perth's population of 2 million has long eclipsed that of metropolitan Adelaide, which is now home to 1.3 million people. In the case of both of these cities, the authors note that the PSS that have been used to support the planning and modelling of Adelaide and Perth are characterized by traditional approaches that have failed to take advantage of the latest advances. In the case of Adelaide, the key restrictions appear to be that past approaches have worked and are still working, so why update data sets unnecessarily or increase modelling complexity? In the case of Perth, growth has been so rapid and intense that planners have struggled to keep pace with planning to anticipate the changes even with using the latest data and modelling technologies. However, the authors note that with competing policy priorities that include developing future resilience to looming environmental challenges, against a backdrop of a restructuring economy and the social stresses that go with that, and a fragmented ideologically rigid polity, more than ever before we require smart city policies that recognize and embrace these policy complexities. Revised metropolitan models are put forward for both Perth (PLATINUM) and Adelaide (AITLUM) that embrace the state-of-the-art in PSS, and are sufficiently sensitive and responsive to manage an era of rapid change and uncertainty.

In Chap. 16 by *Tayo Fabusuyi* and *Robert C. Hampshire*, innovative use is made of the United States Census of Public Use Microdata Sample (PUMS) to examine commuting patterns in the United States, and more specifically in the Greater Pittsburgh area, the region used as a test bed. The authors have developed a discrete choice model with commuter profiles to explore differences in commuting patterns according to place of abode and socio-economic background. The authors have a radical suggestion that is certain to generate heated debate amongst transport policy-makers and planners in doing away with rigid overarching plans driven by a regional transportation strategy, and instead having an adaptable 'on-the-fly' demand-driven policy regime. Parking is singled out as one policy area where a demand-driven approach could work through the use of smart phone apps and Vehicle Messaging Services (VMS). Innovative public-private partnerships with peer-to-peer mobility through apps such as UBER and driverless vehicle technology, currently being trialled in Pittsburgh, raise the prospect of a dynamic transportation system that will necessitate policy responses to be made in real-time. This chapter points to uncertain times ahead for regional strategic transport planning in US cities as they make a fascinating transition towards a demand-driven policy environment, where user choices of digital technologies will determine transport infrastructure investments in future.

In Chap. 17, Australian researchers *Nicholas Holyoak*, *Michael Taylor*, *Michalis Hadjikakou* and *Steven Percy* develop an integrated demand and carbon forecasting approach for residential precincts. The research project is part of an initiative of the Australian Government's Commonwealth Research Centre for Low Carbon Living which has, as part of its remit, the task of reducing future carbon emissions from Australian urban areas. Up until recently, government initiatives in Australia (such as Basix, Nathers and FirstRate5) and internationally (EnergySmart Homescale in the US, Breeam in the UK and LEED in Canada) have aimed at reducing carbon emissions by focusing efforts on modelling individual dwellings and requiring minimum baseline environmental performance standards at the planning approval stage and prior to construction occurring. Such approaches have been limited in modelling actual expected environmental performance in practice because they fail to take into account what happens at the level of the precinct, suburb and city, due to the fact that they assume a worst case operational scenario (i.e. where every urban resident consumes water, energy and resources at an 'average' rate), and they have given minimal consideration to location or particular socio-economic circumstances and behaviors of urban residents. By shifting the demand forecasting approach to the precinct level, this example of a PSS uses the latest in modelling technology, GIS and behavioral science to use a common set of inputs covering energy, transport, waste, land use characteristics and resident household types, that interact with various 'low carbon living' technologies (such as electric vehicle usage, recycling, solar photovoltaic panels, battery storage and rainwater tank use), to create various scenarios of low carbon living of households and other land uses aggregated at the urban precinct level. The researchers applied this precinct carbon emissions forecasting tool to the redeveloped master-planned Adelaide suburb of Tonsley to predict equivalent carbon dioxide emissions for the year 2035 that would be likely with the take-up of various low carbon emissions technologies in its planned urban development options. The potential of such a model to accurately forecast carbon emissions performance of large urban areas is clearly demonstrated in this chapter and it highlights the importance of transitioning from environmental performance rating schemes that focus on buildings to schemes that have the capacity to model the environmental performance of large complex urban areas.

Following on from this theme, the next contribution shows how open data about human opinions and perceptions can contribute to the proper design of public space. The author of Chap. 18, *Eleanna Panagoulia*, shows how data related to human perceptions can add value to more conventional datasets (such as income, crime, educational level, *et cetera*) for the evaluation of the urban environment. This is exemplified via a case study that focuses on mapping the gentrification rate in the San Francisco Bay Area. This phenomenon occurs rapidly in this area and as such it can be considered a challenge to visualize due to its dynamic and complex character. In response to this problem, the author proposes an accumulative analysis that consists of three methodologies that operate at different regional and local scales. The results of the three methodologies are assessed and the evaluation suggests that close engagement with technology has lead the researchers to explore a multitude of research methods, each of which has contributed to more accurate statements about the urban space.

Open data increasingly play a decisive role in the concept of smart cities, although until now mostly in the management of cities and less in the planning and decision-making activities. The next chapter exemplifies the role of the concept of smart cities in planning and decision-making. In Chap. 19, *Chris Pettit*, *Scott N. Lieske* and *Murad Jamal* present a review of the international efforts in the creation of so-called 'city dashboards'. They have looked at the role of city dashboards in communicating city data, and how they are used more broadly as a type of PSS to aid in the planning, management and monitoring of urban systems. Based on their review, they introduce the City of Sydney Dashboard, known as CityDash, and discuss its purpose, architecture and future development. They also provide a set of recommendations on how dashboards can play an important role in assisting in city planning and citizen engagement. These recommendations range from the need to consolidate information on a single web page, to providing live data feeds relevant to planners/decision-makers as well as to citizens' daily lives, and the inclusion of site analytics as a way of evaluating user interactions and preferences.

In the following Chap. 20 of this section on smarter urban futures, the topic of so-called 'city metrics' is considered. Cities use a variety of metrics to evaluate and compare their performance, for instance in their quality of life or their sustainability. Comparative analysis of city performance has been enabled by the definition and adoption of city indicators, such as ISO37120. However, for a fruitful comparison of indicators the consistency in the underlying data is of utmost importance. City indicator consistency analysis enables the possibility of consistent measurement and comparison of city performance. In their contribution, *Yetian Wang* and *Mark S. Fox* present three types of consistency analysis for automating the detection of inconsistencies in open city data: definitional consistency analysis that evaluates whether data used to derive a city indicator are consistent with the indicator's definition; transversal consistency analysis that evaluates if city indicators published by two different cities are consistent with each other; and longitudinal consistency analysis that evaluates whether or not an indicator published by a city is consistent over different time intervals. With the help of these three types of consistency analysis, a comparative analysis of city performance will yield comparable outcomes.

Ming-Chun Lee investigates in Chap. 21 scenario-based planning practices in the United States that connect regional planning frameworks to local scenario planning (characterized as ‘finger printing’ processes). The system at the core of scenario-based planning approaches is GIS, which not only allows a static spatial representation of past and current land uses but, when combined with ‘what if’ scenario software, the different policies and their societal and environmental changes can be dynamically modelled to determine likely effects and development outcomes over varying timeframes. At the local level of scenario testing, Lee stresses the importance of 2D and 3D visualization using the ESRI program CityEngine as a planning tool. Case studies are used at both the regional and local scales to illustrate how regional planning frameworks set the scene for local planning responses. The technology of the planning tool is stressed as important to the planning and design of smarter cities, by incorporating better understanding and improved informed decisions. Moreover, Lee explains that it promotes engagement with the community, results in political coalitions and builds organizational capacity. Whilst planning across scales may imply a top-down planning approach where regional priorities lock local planning into a straight-jacket, Lee argues that a holistic approach and local ‘finger printing’ can facilitate unique local needs whilst simultaneously maintaining the integrity of an essential regional perspective.

Chapter 22, by *Simone Z. Leao*, *Nam Huynh*, *Alison Taylor*, *Chris Pettit* and *Pascal Perez*, explores an innovative method that integrates a mapping scenario-based approach with both a synthetic population model and a synthetic transport model developed out of a travel diary to help investigate an urban growth scenario for Sydney, Australia’s largest city, with modelling outputs that include estimating future housing demands and centres of activity associated with daily trips or hotspots. The innovative and novel aspect of this modelling approach is that whilst the modelling itself is hypothetical (or synthetic as the authors prefer to call it), it is based on real world big data inputs, such as Australia’s national population and housing census and an actual travel diary survey. Interestingly, it is used to create actual housing and travel demand projections for a planned urban growth corridor in Sydney’s inner southern suburbs where the population is expected to double over the next 15 years. To increase the reach of the work to a general audience, the researchers developed a map-based visualization called Synt-Viz that used freely available cloud computing tools such as the Carto online mapping platform and the ESRI Story Map software. Urban planners often advocate smart growth as essential to better urban planning and management, and with the work described in this chapter, the authors have a planning analytical approach and planning support tools that go a considerable distance towards achieving this goal.

Chapter 23 by *Rida Qadri* examines the vexed question of planning and regulating street vending in New York City. In other cities, this form of retail activity is sometimes referred to as ‘pop-ups’ and they present a challenge to ‘bricks and mortar’ business establishments. Regulators and local government officers find them challenging because of their unconventional business *modus operandi*, their mobile nature, the difficulties that they pose in regulation, taxation, community complaints and the inevitable stress that they can bring to retailers and businesses in conventional premises. They defy convention. Many in the community, and tourists in particular, love the excitement, colour, vibrancy and diversity that they bring to a city's streets. Essentially this chapter poses the question of whether we can use tools (i.e., GIS, the location of 311 complaint calls and various datasets) to enrich our understanding of vending and its regulations in New York City. Perhaps not unsurprisingly, the data available on vending in New York City focuses on violations (usually initiated through citizen complaints) and the locations of venders. A model is developed that examines for particular segments of New York's city streets whether there were correlations between the rate of violations by street venders with property values or types of urban densities. Qadri asks the question about whose voice should be heard in regulating and enforcing street vending. Although this study is more exploratory than definitive on what elements result in concerns about street vending in Manhattan, the work is robust and demonstrates strongly the value of tools and smart city approaches to improve the management of street vending. Great cities value a diversity of experiences, and accommodating activities such as street vending, providing that it can be managed smartly, would raise the interest of many cities.

Ehsan Sharifi and co-authors *Alpana Sivam*, *Sadasivam Karuppannan* and *John Boland* demonstrate in Chap. 24 the use of Landsat 7/8 satellite surface cover temperature data to investigate their contribution to the analysis of the Urban Heat Island (UHI) effect in Adelaide, Australia. With much of the world's population becoming urbanized, a critically important issue is how we can plan and manage development in cities to minimize the UHI effect, a proven phenomenon whereby hard surfaces such as concrete absorb heat which elevates the ambient temperature of micro-climates in urban areas by up to 4 °C. This research utilized Landsat imagery on days of local weather extremes (including selected days when on one occasion the ambient air temperature at ground level reached a maximum of 45 °C and on another occasion, there was an overnight minimum of 3 °C) to determine various surface material temperatures such as water, various types of vegetation, asphalt, paving and natural hard surfaces. Perhaps not surprisingly, water surfaces were coolest followed by vegetation. The implications for urban planning and management in the quest for planning smarter, more resilient cities to the heat stresses of a warming world are that planners now have in Landsat imagery an incredibly powerful instrument that diagnoses hotspots in the urban fabric. From a proactive point of view, Landsat can also just as easily be used in the early planning stages, prior to development to ensure that the optimal balance of surfaces to minimize the UHI effect is incorporated into a future development. The use of Landsat data as a proactive tool to minimize the UHI effect as an example of evidence-based planning presents a much stronger case to the community, policy-makers, developers and those in government of the difference that the use of Landsat can make to tackling the effects of climate change and in helping to make cities more pleasant places to live in.

Chapter 25 by *Takuya Oki* and *Toshihiro Osaragi* reports on an agent based modelling system that examines urban vulnerability in Japan, specifically to earthquakes and the fires associated with earthquakes. This work is an excellent example of a PSS being used to investigate policies that improve urban resilience in innovative ways to create a smarter city. The three mitigation policies include mandating fire extinguishers in all buildings, mandating seismic sensors that trip electrical power circuits in all buildings when tremors are detected and evaluation of a street network's performance to ensure clear pathways after an earthquake. The work also includes 'what if' scenario testing where changes to the street network are modelled, such as what might occur with street widening. The capacity of such models to estimate property damage and casualties associated with a particular policy action makes it an essential planning support tool in earthquake prone areas, minimizing the disruption that inevitably accompanies a catastrophic earthquake event.

In Chap. 26, by *Kiichiro Kumagai*, *Hitoshi Uematsu* and *Yuka Matsuda*, an advanced approach was developed to analyse the spatial continuity of vegetation distributions using the Osaka prefecture in the Kansai District of western Japan as a case study. Continuity of vegetation in urban areas is of crucial importance to maintaining biodiversity in urban areas because it supports wildlife and plant species by facilitating much larger habitats than would be possible with small fragmented randomly distributed vegetated areas. Often contiguity in vegetated corridors correlates with a natural feature such as a riparian environment, wetland, coastline or ridge-line. However, in urban areas where natural features are not so prominent or where there are intense development pressures, vegetated areas can be lost, particularly if there is an absence of strong land-use planning controls. Contiguous vegetated areas are also vitally important to human health in urbanized areas, and the authors note that with Japan as an aging society with a declining population, green spaces are part of a government strategy to avoid urban decay and compromised quality of life. Part of this is achieved by identifying redundant urban land that can potentially be converted to green spaces, preferably in a manner that ensures that a continuous and integrated open space system is achieved. This research utilized remote sensing using Landsat OLI data with statistical testing of the Normalized Difference Vegetation Index (NDVI). The researchers examined the relationship between the assessed values of land and geographic information to ascertain the extent to which proximity to vegetation impacts on urban and suburban land prices.

As a final chapter of the book, Chap. 27 starts from the observation that whilst the number of smart city projects and applications has increased substantially in recent years, empirical insights into the extent to which different smart city aspects are factually applied are really missing. *Lisanne de Wijs*, *Patrick Witte*, *Daniel de Klerk* and *Stan Geertman* aim to shed light on the state-of-the-art in smart city applications at different scale levels, based on a predominantly quantitative empirical analysis. Thus, in addition to a literature review, an enquiry was conducted among municipalities in The Netherlands in which questions were asked of government practitioners of Dutch municipalities concerning knowledge of and ambitions in the field of different aspects of smart city initiatives. The results show that both in The Netherlands and worldwide there are huge ambitions to develop and implement smart city applications, but that to some extent actual activities are lagging behind. Reasons for this mostly relate to lack of awareness of the possibilities and lack of financial and political priority; this is especially true for smaller-sized cities. Furthermore, it is shown that some smart city aspects like smart mobility and smart environment are receiving attention much more than some other aspects such as, for instance, smart governance. It is expected that when this will be resolved, actual activities will be more likely to live up to the huge ambitions regarding the smart city concept that many commentators suggest exist.

4 Conclusions

In this volume readers are taken on a journey into the world of Planning Support Science which seamlessly flows into the world of smart urban futures where big data, city analytics and visualization approaches to real-time information provided through open data feeds and social media are becoming increasingly common. At the beginning of this introductory chapter we have set the scene with a number of global challenges as the human population continues to expand across the planet in a time of rapid urbanization. Specifically we are faced with challenges such as increasing numbers of people living in slums, demographic restructuring, increases in extreme events, declining air quality, increases in traffic congestion, and global health crises with respect to obesity and associated diseases such as type II diabetes as well as famine and undernourishment.

It is therefore timely that we see the maturing of PSS where the focus has previously been on technology development to the evolution of Planning Support Science (Geertman 2013). Likewise, in recent times, we have witnessed the rise of both city science and data science which, when combined with Planning Support Science, provide a strong underpinning to the emergence of the smart city concept. The chapters in this volume discuss a combination of innovative PSS methods, techniques and case studies which can arm the next generation of planners with the ability to tackle the global challenges head on and endeavour to make our cities more sustainable, productive and resilient.

References

Allen, E. (2001). INDEX: Software for community indicators. In R. K. Brail & R. E. Klosterman (Eds.), *Planning support systems* (pp. 229–261). Redlands, CA: ESRI Press.

Allen, E. (2008). Clicking toward better outcomes: Experience with INDEX, 1994–2006. In R. K. Brail (Ed.), *Planning support systems for cities and regions* (pp. 139–166). Cambridge, MA: Lincoln Institute of Land Policy.

Arciniegas, G., Janssen, R., & Rietveld, P. (2013). Effectiveness of collaborative map-based decision support tools: Results of an experiment. *Environmental Modelling and Software, 39,* 159–175.

Batty, M. (1995). Planning support systems and the new logic of computation. *Regional Development Dialogue, 16,* 1–17.

Batty, M. (2013). *The new science of cities*. Cambridge, MA: The MIT Press.

BITRE. (2015). Traffic and congestion cost trends for Australian capital cities. *Information Sheet 74, Bureau of Infrastructure, Transport and Regional Economics, Department of Infrastructure and Regional Development, Commonwealth Government, Canberra*. Accessed February 12, 2017 from https://bitre.gov.au/publications/2015/files/is_074.pdf

Couclelis, H. (2005). "Where has the future gone?" Rethinking the role of integrated land-use models in spatial planning. *Environment and Planning A, 37*(8), 1353–1371.

da Silva, J. (2016). *City resilience index*. ARUP. Accessed February 2017 from http://publications.arup.com/publications/c/city_resilience_index

FAO. (2015). The State of food insecurity in the world. In *Meeting the 2015 International Hunger Targets: Taking Stock of Uneven Progress*. Rome: FAO. Accessed February 21, 2017 from http://www.fao.org/3/a-i4646e.pdf

Geertman, S. (2006). Potentials for planning support: A planning-conceptual approach. *Environment and Planning B: Planning and Design, 33,* 863–880.

Geertman, S. (2013). Planning support: From systems to science. *Proceedings of the Institution of Civil Engineers: Urban Design and Planning, 166*(1), 50–59.

Geertman, S., Ferreira, J., Goodspeed, R., & Stillwell, J. (Eds.). (2015). *Planning support systems and smart cities*. Lecture Notes in GeoInformation and Cartography. Dordrecht: Springer.

Geertman, S., & Stillwell, J. (Eds.). (2003). *Planning support systems in practice*. Advances in Spatial Science. Berlin: Springer.

Geertman, S., & Stillwell, J. (Eds.). (2009). *Planning support systems best practice and new methods.* The GeoJournal Library 95. Dordrecht: Springer Science & Business Media.

Geertman, S., Toppen, F., & Stillwell, J. (Eds.). (2013). *Planning support systems for sustainable urban development*. Lecture Notes in GeoInformation and Cartography. Heidelberg: Springer.

Harris, B., & Batty, M. (1993). Locational models, geographic information and planning support systems. *Journal of Planning Education and Research*, *12*(3), 184–198.

Klosterman, R. E. (1997). Planning support systems: A new perspective on computer-aided planning. *Journal of Planning Education and Research, 17,* 45–54.

Klosterman, R. E. (1999). The What if? collaborative planning support system. *Environment and Planning B: Planning and Design, 26,* 393–408.

Kwartler, M., & Bernard, R. (2001). CommunityViz: An integrated planning support system. In R. K. Brail & R. E. Klosterman (Eds.), *Planning support systems* (pp. 285–308). Redlands: ESRI Press.

Lee, D. B. (1973). Requiem for large-scale models. *Journal of the American Institute of Planners, 39*(3), 163–178.

Marsden, R. (2015). A web-based information system for planning support in Barnsley. *Applied Spatial Analysis and Policy, 8*(2), 131–153.

Pettit, C. J., Barton, J., Goldie, X., Sinnott, R., Stimson, R., & Kvan, T. (2015a). The Australian urban intelligence network supporting smart cities. In S. Geertman, J. Ferreira, R. Goodspeed, & J. Stillwell (Eds.), *Planning support systems and smart cities* (pp. 243–259). Lecture Notes in GeoInformation and Cartography. Dordrecht: Springer.

Pettit, C. J., Klosterman, R. E., Delaney, P., Whitehead, A. L., Kujala, H., Bromage, A., et al. (2015b). The online What if? planning support system: A land suitability application in Western Australia. *Applied Spatial Analysis and Policy., 8*(2), 93–112.

Pettit, C. J., Klosterman, R. E., Nino-Ruiz, M., Widjaja, I., Tomko, M., & Sinnott, R. (2013). The online what if? Planning support system. In S. Geertman, F. Toppen, & J. Stillwell (Eds.), *Planning support systems for sustainable urban development* (pp. 349–362). Lecture Notes in GeoInformation and Cartography. Heidelberg: Springer.

Pettit, C., Tice, A., & Randolph, B. (2017). Using an online spatial analytics workbench for understanding housing affordability in Sydney. In P. Thakuriah, N. Tilahun, & M. Zellner (Eds.), *Seeing cities through big data: Research, methods and applications in urban informatics* (pp. 233–255). Cham: Springer International Publishing.

Rockefeller Foundation. (2015). *100 Resilience*. Accessed February 2017 from https://www.rockefellerfoundation.org/our-work/topics/resilience/

Russo, P., Costabile, F. M., Lanzilotti, R., & Pettit, C. J. (2015). Usability of planning support systems: An evaluation framework. In S. Geertman, J. Ferreira, R. Goodspeed, & J. Stillwell (Eds.), *Planning support systems and smart cities* (pp. 337–353). Lecture Notes in GeoInformation and Cartography. Dordrecht: Springer.

Sanderson, D. (2016). Urban disaster resiliences: New dimension from international practice in the built environment. In D. Sanderson, J. Kayden, & J. Leis (Eds.), *Urban disaster resilience* (pp. 3–15). New York: Routledge Taylor & Francis Group.

Thakuriah, P. V., Tilahun, N. Y., & Zellner, M. (2017). Introduction to seeing cities through big data: Research, methods and applications in urban informatics. In Thakuriah, P. V., Tilahun, N. Y., & Zellner, M. (Eds.), *Seeing cities through big data: Research, methods and applications in urban informatics* (pp. 1–9). Cham: Springer International Publishing.

The Guardian Website. (2016). *Smog refugees flee Chinese cities as 'airpocalypse' blights half a billion*. Accessed February 15, 2017 from https://www.theguardian.com/world/2016/dec/21/smog-refugees-flee-chinese-cities-as-airpocalypse-blights-half-a-billion

UN Habitat. (2003). *The challenge of slums: Global report on human settlements, United Nations Human Settlements Programme*. London: Earthscan.

United Nations. (2014). *World urbanization prospects: The 2014 revision, highlights*. New York: United Nations Department of Economic and Social Affairs, Population Division.

United Nations. (2016). *The World's Cities in 2016—Data Booklet (ST/ESA/ SER.A/392)*. New York: United Nations, Department of Economic and Social Affairs, Population Division. Accessed February 15, 2017 from http://www.un.org/en/development/desa/population/publications/pdf/urbanization/the_worlds_cities_in_2016_data_booklet.pdf

Vonk, G., Geertman, S., & Schot, P. (2005). Bottlenecks blocking widespread usage of planning support systems. *Environment and Planning A, 37*(5), 909–924.

Waddell, P. (2002). UrbanSim: Modelling urban development for land use, transportation, and environmental planning. *Journal of the American Planning Association, 68*(3), 297–314.

World Bank. (2016). *The cost of air pollution: Strengthening the economic case for action*. Washington, D.C.: World Bank Group. http://documents.worldbank.org/curated/en/781521473177013155/The-cost-of-air-pollution-strengthening-the-economic-case-for-action

Part I
Planning Support Science

Chapter 2
Towards the Development of a Monitoring System for Planning Policy

Claire Daniel

Abstract Cities are constantly changing and growing. Planning regulation aims to guide the development of cities to provide the best possible quality of life for the people within them. Monitoring the effects of planning policy is an important step to improve decision-making but is often limited in practice. This study involved the construction of a browser-based mapping application as a prototype monitoring system. The study uses development permit, land use, infrastructure and service data from four case study cities—London, Chicago, Melbourne and Brisbane—to explore the mechanics and necessary prerequisites for ongoing automated monitoring. The selection of four cities allowed for comparisons to be made between the cities regarding planning system structure, data availability, suitable metrics and visualization techniques. The prototype is limited to residential land uses only but successfully demonstrates bringing together disparate datasets to communicate spatially-detailed information related to the success of planning objectives in an automated fashion.

Keywords Policy monitoring system · Urban plan evaluation · Planning support system · Digital innovation in planning

1 Introduction and Context

The role of monitoring has long been part of the theory of how the process of planning should be undertaken. The rational process view of planning, inspired by wider economic theories about rational decision-making in the 1960s and 70s, outlines a number of cyclical steps representing an idealised view of the planning process (Fig. 1) (Banfield 1959; Faludi 1973). These steps, or variations thereof, remain how the planning process is generally conceived, although with broader recognition of the inherently political and value-laden nature of planning (Forester 1989; Davidoff 1965;

C. Daniel (✉)
Centre for Advanced Spatial Analysis, University College London, London W1T 4TJ, UK
e-mail: claire.f.daniel@gmail.com

S. Geertman et al. (eds.), *Planning Support Science for Smarter Urban Futures*, Lecture Notes in Geoinformation and Cartography,
DOI 10.1007/978-3-319-57819-4_2

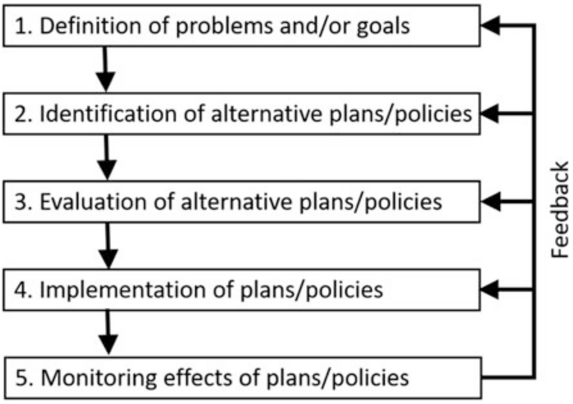


Fig. 1 Steps in the rational process view of planning (Taylor 1998, p. 95)

Friedmann et al. 1973) and importance of community involvement in decision-making (Arnstein 1975; Healey 2006). In this model, monitoring forms the final step, providing necessary feedback to restart the planning process or adjust the plan to account for new circumstances or shortcomings.

Monitoring of town planning policies can be defined as evaluating the extent of their implementation or impact. Nonetheless, although monitoring is broadly accepted in the planning profession as an important step to improve decision-making, it is often neglected. Instead, the bulk of evaluation efforts in planning are focused on the future of different plan alternatives, step three of the process in Fig. 1. Lots of work has been done on the development of urban-modelling techniques, which have been developed to examine scenarios and forecast future change. These include Land-Use Interaction Models (LUTI), Spatial Interaction Models (SIM), and more recently, Cellular Automata (CA) and Agent-Based Models (ABM) [see various overviews by Batty (2008, 2009, 2012)]. These and other forecasting techniques are frequently incorporated into planning support systems (see previous compendia, e.g., Geertman and Stillwell 2009; Geertman et al. 2015). The collection of tools that come from these techniques is sometimes referred to as urban analytics but in this chapter, the approach simply sets the context for the development of such analytics which are considered consistent and compatible with the mapping and monitoring approach proposed here.

A handful of empirical studies evaluating the effectiveness of past policies have been published. This literature is comprised of one-off studies such as Talen's (1996) publication, which evaluated the location of public facilities, and more recent articles relating to land use and growth control (Brody and Highfield 2005; Chapin et al. 2008; Alfasi et al. 2012; Long et al. 2015). Recent literature is largely silent on the concept of ongoing monitoring and, in particular, the use of computer software to complete monitoring tasks on an ongoing basis. Literature produced in the '50s, '60s and '70s in relation to the rational comprehensive planning process model indicates the need for ongoing monitoring in a new, more flexible policy environment, making reference to the maintenance of supporting information systems (see particularly

Meyerson 1956; Robinson 1965). Of this period, Calkins (1979) is perhaps the most explicit, expressing a theoretical monitoring system in a series of algebraic equations which track measurable attributes against explicitly enumerated planning goals.

Published studies providing evidence of how professional planners undertake monitoring in practice are very limited. Seasons (2003) is one of the few published who conducted surveys of officers in Ontario, Canada, to identify factors in planning practice that facilitate or impede monitoring and evaluation. The results of the interviews indicated a significant gap between ideal process theory and practice. The key reasons stated include:

- Resources: time, money and expertise—municipal resources are limited. The majority of municipalities focused resources into the review and facilitation of development proposals rather than policy research.
- Evaluation methods—evaluation methods lacked qualitative input. Methods also did not tend to allow for comparison with neighbouring municipalities to allow for meaningful benchmarking.
- Appropriate indicators—indicators tended to be linked to budgeting and resource efficiency rather than plan outcomes. There was also found to be a disconnect between the indicators used and planning policy objectives. Interviewees stated the need to be targeted and realistic with demands for monitoring data.
- Causality: linking goals and outcomes—many factors influence the built environment and it is often difficult to establish causality. Goals and objectives are often too vaguely worded to be conducive to evaluation.
- Political realities—planning goals are often seen to be less important than political exigencies.
- Organisational culture—attitudes from staff, management and political leaders varied in their support for monitoring and evaluation activities. Receptive organisations stressed the need for ongoing learning. Others saw monitoring as discretionary and yet others seemed to indicate resistance to the possibility of criticism.

Improved computing, new data sources and automation offer promising but previously unexplored solutions to many of these identified obstacles.

2 Aims and Objectives

The research looks into the pre-requisites and mechanics involved in bringing together existing datasets and methods to construct an automated monitoring system for the use of planning professionals. Through the construction of a working demonstration system, the research provides insights into data availability, data quality, system structure, useful metrics and methods of visualization but it is consistent with a wider array of urban analytics. The prototype is focused on residential land uses only, although it could be extended for other land uses using similar methods. The research is focused on four case study metropolitan government areas: London (Greater London Authority), Chicago (City of Chicago), Brisbane (Brisbane City Council) and Melbourne (City of Melbourne), for which disaggregated data on construction of residential dwellings could be sourced. The four case study cities allow comparisons to be made in the process required to transform available development data for each city into useful metrics for monitoring planning policy.

3 Introduction to Case Study Cities

Planning systems vary from city to city. The underlying regulatory framework is important in the design of a monitoring system as it will determine the form of planning outputs, including policies, development-approvals data or monitoring reports. Four case study cities were selected to allow comparisons to be made regarding planning system structure, data availability and the extent to which metrics can be generalized for different cities.

The planning system in London and the UK can be described as a 'plan-led discretionary system' (Carmona et al. 2003) with strategic plans and written objectives. At the other end of the spectrum, Chicago has a strict regulatory system centered around a zoning ordinance; although a strategic plan exists for the region, it does not have statutory weight in the consideration of development applications. The two Australian systems lie somewhere in between.

Each city has one or more strategic plans which contain objectives for the development of the city (see Brisbane City Council 2014; Chicago Metropolitan Agency for Planning 2010; City of Melbourne 2016; Greater London Authority 2016; State Government Victoria 2014). All of the four cities are growing in population and have a surprisingly similar set of objectives for residential development indicating that similar metrics could be used to measure policy success across the four cities. These objectives can be summarized as follows:

- regulations should ensure that they are not so limiting that they do not provide developable areas to accommodate population growth;
- development must provide a mix of housing sizes and types to accommodate increasing variety in family structures and living arrangements;
- a proportion of development should be affordable housing;
- high-density development should be located in special areas mapped for growth, with the amenity of established areas, marked to be retained as low-density, to be protected; and
- residential development, especially high-density development, should be conveniently located and well integrated with other land uses, within walking distance of public transport infrastructure and community facilities.

For London and both Australian cities, two separate permit systems exist for the regulation of development and construction, for buildings regulations approval, to check conformance with various building safety codes, and planning approval, which primarily considers wider impacts of development. In Chicago, only a single system exists for building permits, and for large projects the local authority also checks the application for compliance with the zoning ordinance.

Of the four systems, only the UK was identified to have legislated mandatory monitoring requirements for planning in the form of an annual monitoring report. The Greater London Authority (GLA) has some very specific objectives in its London Plan which it measures using 24 indicators. Most of the indicators relevant to residential land use are non-spatialized, based on counts of approvals with statistics aggregated by year and borough.

4 The System

4.1 Structure of the System

The task was approached using the following conceptual system structure with four stages, identified in Fig. 2.

The first component is to establish the location and density of residential dwellings in the city at a point in time. Establishing a base case is essential in order to gauge the relative magnitude of changes identified in component two. Component three involves the development of metrics to measure the relative success of policy objectives. The fourth component involves the visualization and communication of measurements.

In terms of practical program structure, the prototype utilises popular web-based visualization tools Google Maps API, HTML, JavaScript and MySQL. Scripts process the raw data and export it to an SQL database. Additional scripts then pull the clean data from the database, calculate metrics, produce and send calculated values and semi-transparent image tiles to the server for viewing in a browser-based mapping application. The program structure is outlined in Fig. 3.

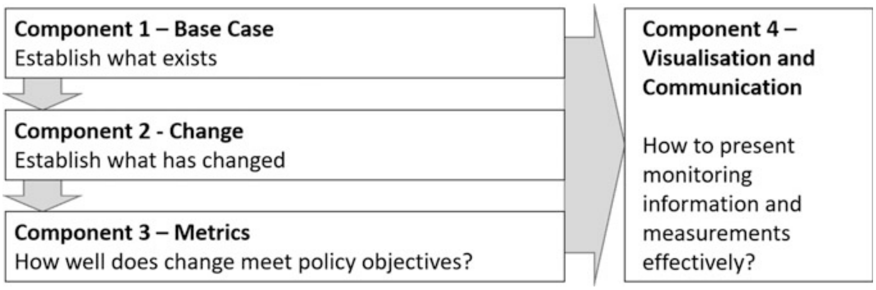


Fig. 2 Conceptual framework for monitoring system

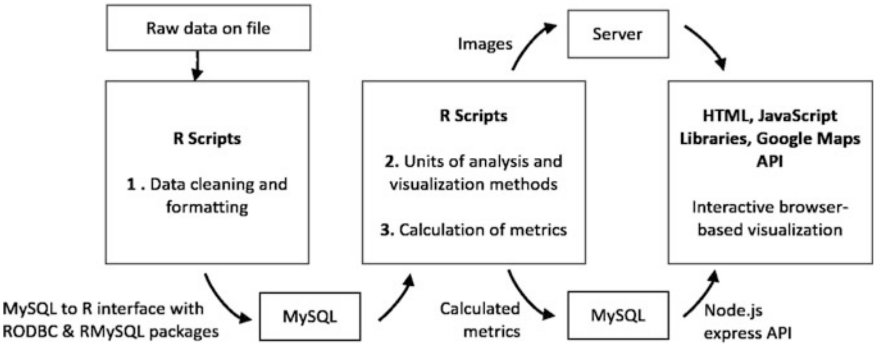


Fig. 3 Flow diagram representation of prototype monitoring system program structure

4.2 Data

4.2.1 Availability

Three types of administrative datasets are used as the foundation for the monitoring system, with each type key to one of the first three conceptual components:

- Existing land-use data—component 1 (base case)
- Development approvals or construction data—component 2 (change)
- Infrastructure and service location data—component 3 (metrics).

The land-use and development datasets and their relative levels of detail are outlined in Table 1.

Spatial datasets relating to infrastructure and service location are available from a variety of different sources with varying degrees of accuracy and coverage. For the prototype, road network and open space data was sourced from OpenStreetMap. Public transport data was downloaded from the various city transit agencies in General Transit Feed Specification (GTFS) format. Additional open space data was sourced for London from the 'Greenspace information for Greater London' (GiGL) dataset, and Chicago parks from the city's open data portal.

4.2.2 Processing Requirements

Scripts were developed to reformat data into a consistent format for programming metrics as outlined in Table 2.

Most data processing involved simple but extensive sub-setting to reach the point outlined in Table 2. This task, exhausting when done manually, is accomplished through scripts which perform tasks automatically, such as removing irrelevant records, applying consistent field names and translating coordinate reference systems for web mapping.

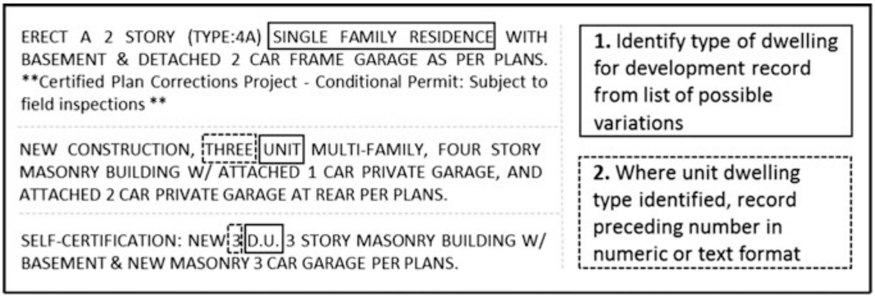
Table 1 Comparison of land-use and development datasets for each case study city across key dimensions

		Brisbane	London	Chicago	Melbourne
Land-use datasets	Source	Brisbane City Council 'Land Use Activity Dataset'	Ordnance Survey 'Address Base Plus'	Chicago Metropolitan Agency for Planning 'Land Use Inventory'	Melbourne City 'Census of Land Use and Employment'
	Open	No	No	Yes	Yes
	Spatial resolution	Site polygon	Address point	Merged site polygon	Site polygon
	Updates	Every six months	Every six weeks	Every five years	Every two years
Development datasets	Source	Brisbane City Council 'Building Completions Certificates'	Greater London Authority 'London Development Database'	City of Chicago 'Building Permits'	Melbourne City 'Census of Land Use and Employment'
	Open	No	No	Yes	Yes
	Spatial resolution	Site polygon	Address point	Address point	Site polygon
	Period	2010-2015	2006–2015	2006–2015	Difference between 2011 and 2015

Table 2 Input data requirements for prototype monitoring system

Land-use data	Development data	Infrastructure and service location data	
		Public transport	Other
Unique identifier (parcel/property) Date of inventory Number of dwellings Location of dwellings Information on dwelling type	Unique identifier (development project) Date of development Number of dwellings Location of dwellings Information on dwelling type	Location and ID of stops Location and ID of routes Timetable data associated with each route and stop	Location, extent and ID of public parks Location of roads

Some datasets required more complex processing. For example, small-area census data on dwelling numbers and a land-parcel spatial dataset was used in conjunction with the land-use dataset for Chicago to approximate the number of dwelling per parcel. In addition, details relating to the type of development in Chicago were found in a text description field and required parsing as shown in the example in Fig. 4.



ERECT A 2 STORY (TYPE:4A) SINGLE FAMILY RESIDENCE WITH BASEMENT & DETACHED 2 CAR FRAME GARAGE AS PER PLANS. **Certified Plan Corrections Project - Conditional Permit: Subject to field inspections **

NEW CONSTRUCTION, THREE UNIT MULTI-FAMILY, FOUR STORY MASONRY BUILDING W/ ATTACHED 1 CAR PRIVATE GARAGE, AND ATTACHED 2 CAR PRIVATE GARAGE AT REAR PER PLANS.

SELF-CERTIFICATION: NEW 3 D.U. 3 STORY MASONRY BUILDING W/ BASEMENT & NEW MASONRY 3 CAR GARAGE PER PLANS.

1. Identify type of dwelling for development record from list of possible variations

2. Where unit dwelling type identified, record preceding number in numeric or text format

Fig. 4 Text parsing procedure for Chicago development dataset

4.2.3 Key Data Quality Issues and Limitations

Temporal resolution is a key limitation of the datasets. For instance, the land-use dataset sourced for Brisbane is dated 30 June 2014, resulting in just over a year in which change can be monitored in the prototype system. Whilst characteristics of recent development may be measured independently, they are less meaningful without the context of the previous land use. This is a limitation for cities without a land-use inventory or that have only just begun to assemble one.

Alongside temporal resolution there is a large difference in the attribute resolution between datasets of similar types for different cities. Data attributes often reflect the administrative procedures required to process an application and are not necessarily the best for ongoing monitoring purposes. For instance, in Chicago's building approvals dataset, 119 of the 131 fields were devoted to information such as contractor identification and fee payment.

A development approval usually denotes permission to undertake a specific construction or development project and does not guarantee that the project will go ahead. The procedure for tracking completed development varied for each city. In Brisbane, a building completion certificate is issued upon the completion of a project and a mandatory recording system is in place. Although a similar system exists in the UK, it is not mandatory for building inspectors to record their final checks with councils and separate surveys often have to be made with completion dates often approximated to the end of financial year, as shown in Fig. 5. Some of these limitations may be mitigated in practice with greater access to internal data sources.

4.3 Aggregation and Visualization

Aggregation and visualization of data is required in order to reveal patterns and relationships between measures for the disaggregated development data. Four

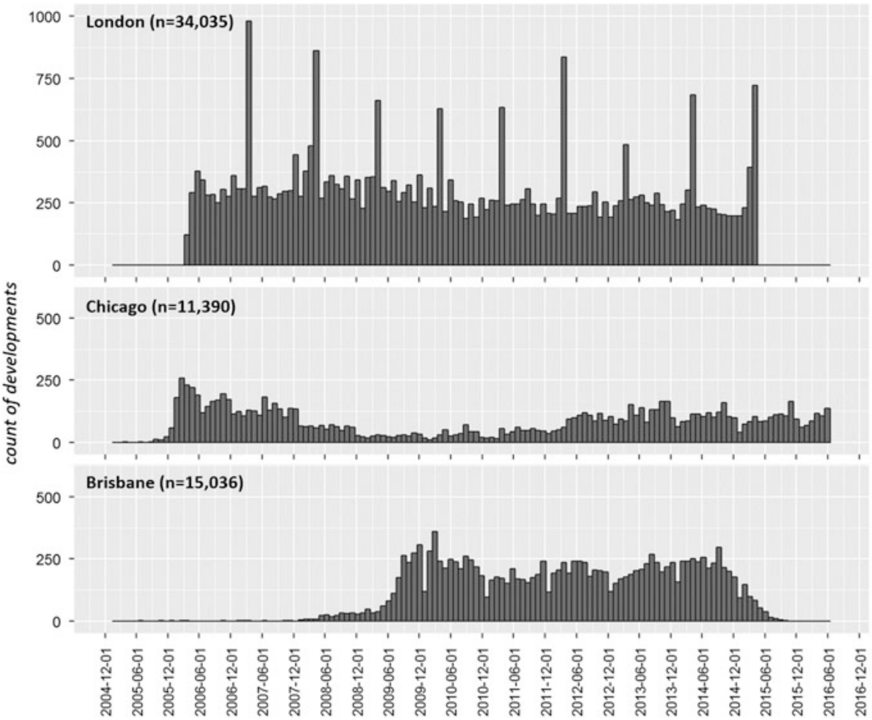


Fig. 5 Histograms showing number of developments per city over time (30 day intervals; no temporal data available for Melbourne)

methods were tested: point mapping, choropleth mapping, cluster identification and mapping, and kernel density mapping, in order to compare the processing requirements and output of each.

4.3.1 Point Mapping

A simple map showing the locations of development sites. Point symbols may differ by category or the size and colour may be graduated according to value of indicator (Fig. 6).

4.3.2 Choropleth Mapping (Administrative Areas)

Data may be aggregated to the administrative level and displayed as a choropleth map of aggregate or average values (Fig. 7).

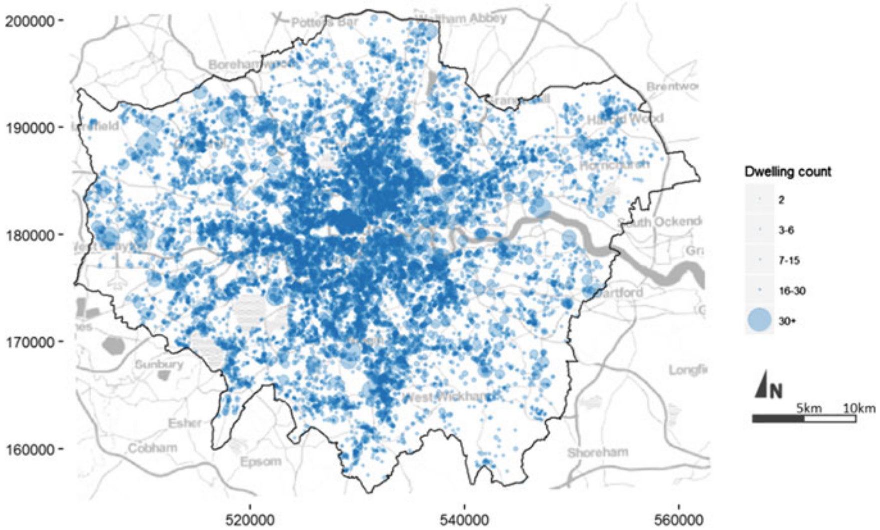


Fig. 6 Point map of completed development records in London, size by number of dwellings (April 2011–2015)

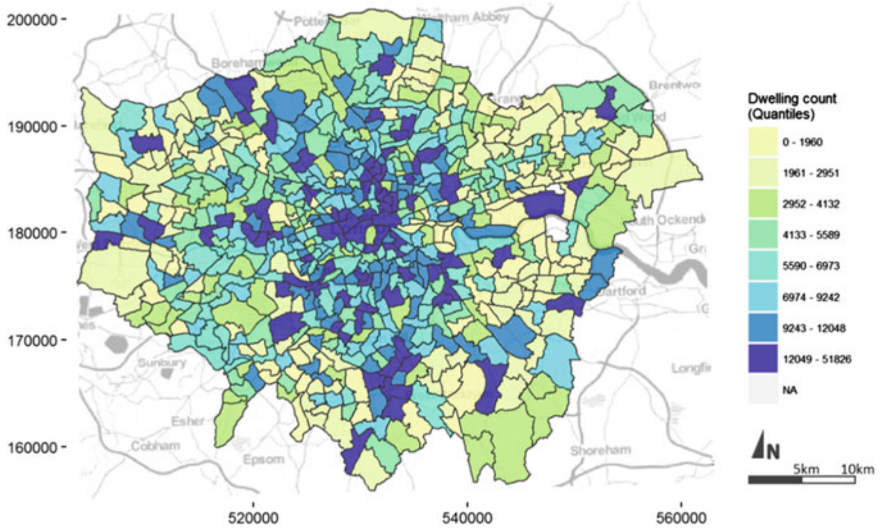


Fig. 7 Choropleth map of completed development records in London coloured by number of dwellings per electoral ward (April 2011–2015)

4.3.3 Cluster Identification and Mapping

An agglomerative hierarchical clustering algorithm was used to define regions for aggregation, based on the spatial distribution of the development sites. For the

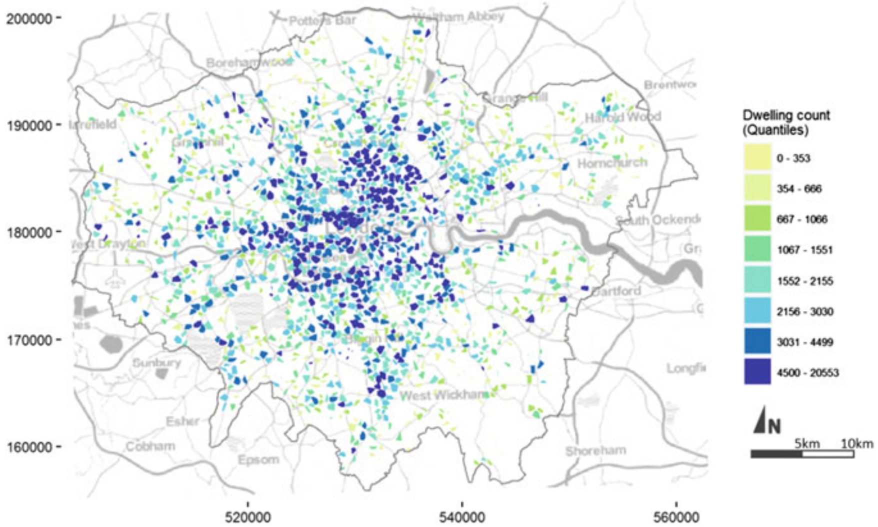


Fig. 8 Convex hull map of clusters of completed development records in London coloured by number of dwellings (April 2011–2015)

prototype the algorithm was defined so that the furthest distance between points in each cluster did not exceed 800 m (Fig. 8).

4.3.4 Kernel Density Mapping

Kernel density mapping (commonly referred to as ‘heat mapping’) is a standard technique for mapping density of point objects whilst avoiding the need to assign the points to a zone. In essence, it is a method for smoothing data according to its variation and density. For the prototype system, a custom conic kernel was used with values decreasing from the centre according to a simple linear function of the height of each kernel (number of dwellings) to the edge of the kernel (bandwidth of 800 m) (Fig. 9). The pixel values of the Kernal Density Estimation (KDE) may also be combined to produce a ‘density profile’ allowing for comparison between any desired geographic units. In addition, different raster surfaces can also be combined in the calculation of metrics, using any desired equation across the values of the corresponding cells.

For retaining spatial detail, it was found that point mapping was most appropriate for categorical variables and for measures applicable to each development site in isolation. Where relationships between points is relevant, or the concept ‘density’ or ‘intensity’ needed to be conveyed, the kernel density map display was chosen as the best method for the display and aggregation of data. This method has the advantage of its ability to preserve the detail of spatial distribution whilst

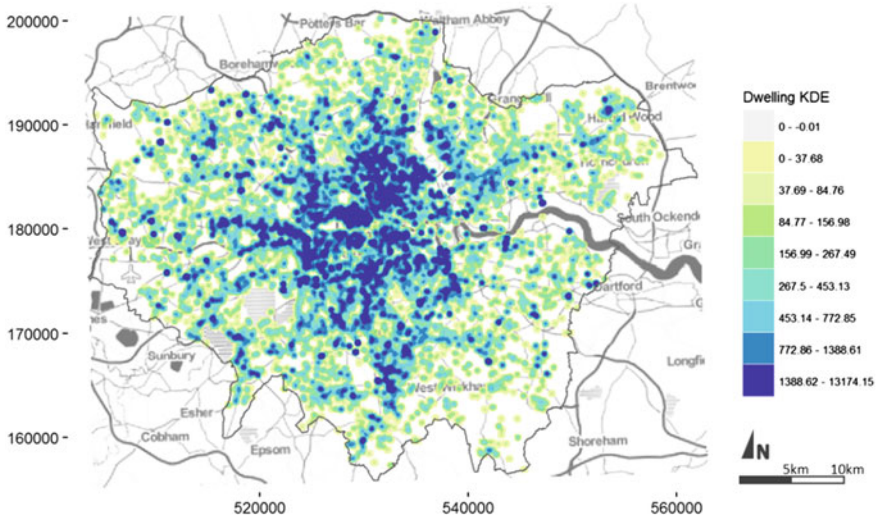


Fig. 9 KDE map of completed development records in London coloured by dwelling intensity (April 2011–2015)

displaying information about the spatial relationship between points, with the value of each pixel a result of aggregated scores for overlapping kernel neighbourhoods.

4.4 *Metrics*

Choosing what to measure is the greatest challenge for the development of a monitoring system. The strategic plan for the city is very broad and the potential combinations of measurements stretch into the thousands. In the end, it was decided to restrict metrics to three common residential planning objectives identified in the review of policies of all four cities to serve as a 'demonstration' project.

- Mix of housing types—development should provide a mix of dwelling types and sizes to cater for demographic diversity and change.
- Access to public transport and services—residential dwellings should be located within walking distance of frequent public transport and facilities such as public open space. The denser the development, the more convenient the location should be.
- Conformity with spatial plan—planning policies identify specific areas of the city where development is encouraged and other areas where development should either be limited or prohibited.

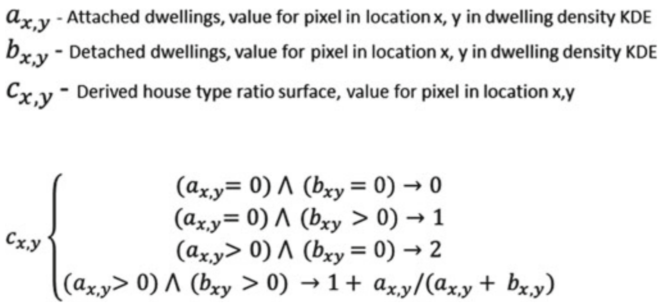
Table 3 Chosen metrics

	Objective 1—Mix of dwelling types	Objective 2—Access to public transport and services	Objective 3—Conformity with spatial plan
Simple	Ratio between numbers of detached dwellings and residential apartments	Number of facilities within 800 m buffer of new development site	Whether development site falls inside or outside identified strategic growth areas
Complex	Diversity index based on numbers of bedrooms provided in each newly developed dwelling	Distance to nearest facilities along road network	Whether development site is appropriate with regards to fine-grained spatial development plan (zoning)

A very simple measurement and a slightly more involved measurement were chosen for each as an example of what is possible (Table 3). In practice, subtleties around measurement decisions could be chosen to align most closely to goals and objectives specific to the particular city.

4.4.1 Mix of Dwelling Types

The development data available for most cities limited options for the measurement of housing diversity to a simple ratio of attached and detached housing. The metric has been designed to combine two dwelling total KDE surfaces for attached and detached housing types. A value of ‘1’ indicates all detached dwellings and a value of ‘2’ indicates entirely attached dwellings, as shown in Figs. 10 and 11.



$a_{x,y}$ - Attached dwellings, value for pixel in location x, y in dwelling density KDE

$b_{x,y}$ - Detached dwellings, value for pixel in location x, y in dwelling density KDE

$c_{x,y}$ - Derived house type ratio surface, value for pixel in location x,y

$$c_{x,y}\begin{cases}(a_{x,y}=0)\wedge(b_{xy}=0)\rightarrow 0\\(a_{x,y}=0)\wedge(b_{xy}>0)\rightarrow 1\\(a_{x,y}>0)\wedge(b_{xy}=0)\rightarrow 2\\(a_{x,y}>0)\wedge(b_{xy}>0)\rightarrow 1+a_{x,y}/(a_{x,y}+b_{x,y})\end{cases}\tag{1}$$

Fig. 10 Housing type ratio equation for combining attached and detached dwelling total KDEs

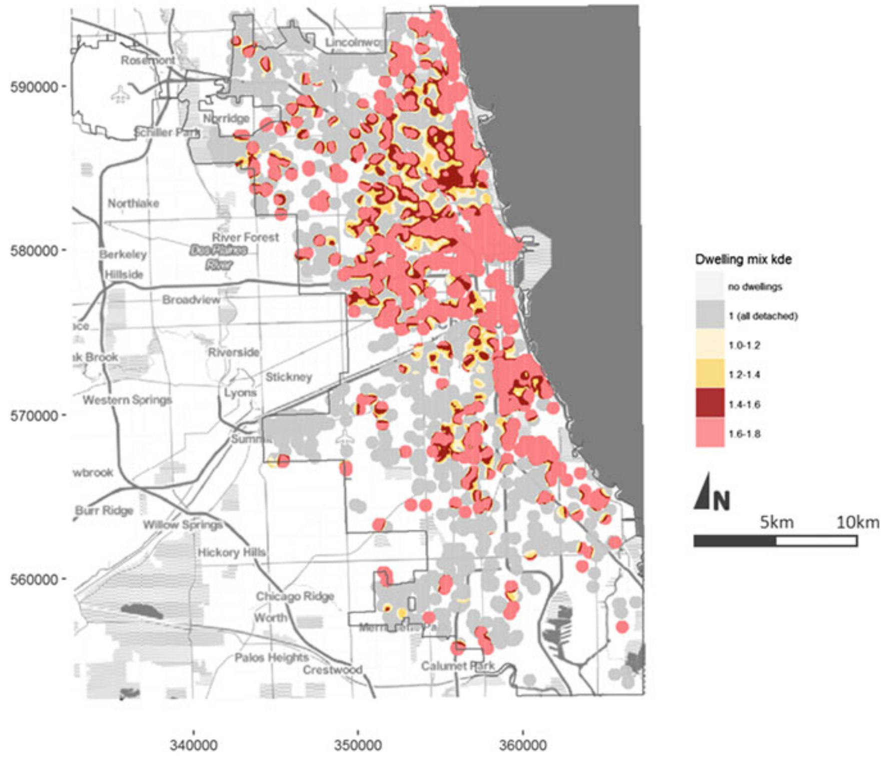


Fig. 11 Housing ratio combined KDE for Chicago building permits

$a^n_{x,y}$ - Dwelling density KDE for dwellings of type 'n' number of bedrooms, value at location 'x, y'

$c_{x,y}$ - Derived diversity index surface, value for pixel in location 'x, y'

$$c_{xy}\begin{cases}\left(\sum a^n_{x,y} = 0\right) \rightarrow 0 \\ \left(\sum a^n_{x,y} > 0\right) \rightarrow 1 - \sum\left(a^n_{x,y}/\sum a^n_{x,y}\right)^2\end{cases} \tag{2}$$

Fig. 12 Simpson's Diversity Index equation for combining dwelling total KDEs for different dwelling types

Fig. 13 Diversity surface for completed residential development in London (2006–2016) by number of bedrooms

Unlike other cities, the London Development Database provides information on the number of bedrooms for most complete development records. Dwelling total KDEs were calculated for each dwelling type and combined using the Simpson's Diversity Index equation outlined in Fig. 12. This calculation reflects the 'evenness' of dwelling numbers in each category by calculating the probability that, if chosen randomly, two development records would be of a different type. The scale ranges from zero (least diverse) to one (most diverse) (Fig. 13).

4.4.2 Access to Public Transport and Services

In order to calculate the frequency of service at a stop during peak hour (Fig. 14), the following process was undertaken using GTFS data:

1. Specify a single representative weekday.
2. Get the ID of all services that run on that day from the calendar file.
3. Get the IDs of all trips associated with services that run on that day.
4. Subset stop times data frame to include only those trips.
5. Define peak times and further subset stop times dataset.
6. Group stop times subset by stop ID.
7. Sum the number of trips per stop.

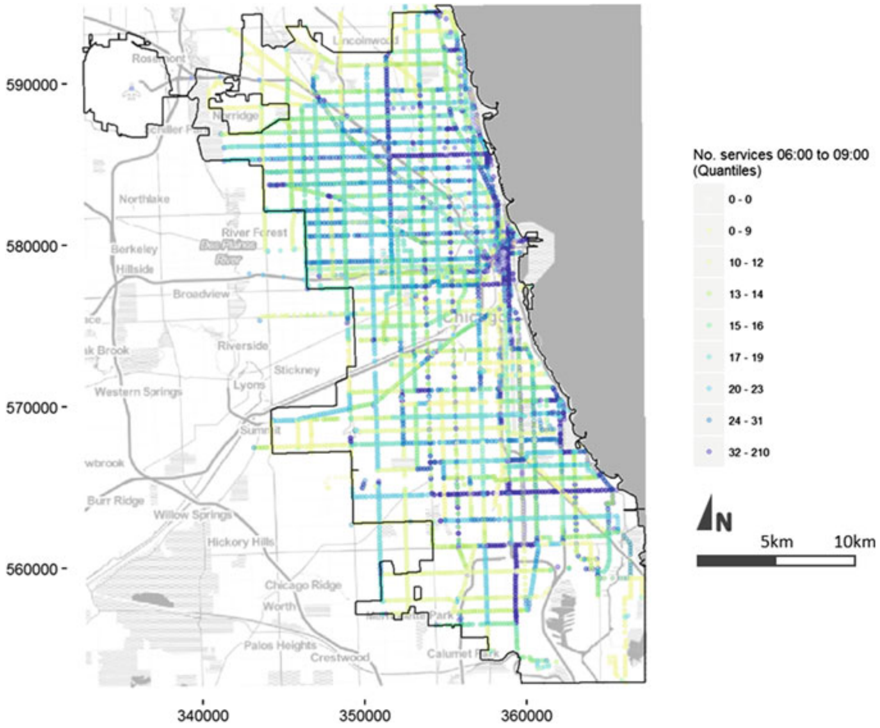


Fig. 14 Number of public transport services per stop from 06:00 to 09:00 on a Wednesday, City of Chicago

As a simple measure, spatial buffer overlay functions were used to determine whether stops serviced on average every ten minutes during peak hour fell with the 800 m radius of development records. As a more complex measure, road network spatial data from OpenStreetMap was converted into a network using the iGraph package and used to calculate distances (Fig. 15).

4.4.3 Conformity with Spatial Plan

Spatial buffer and overlay functions were used to determine whether development records fell within areas defined in the spatial plan for the city at a strategic level and, where relevant, at a more detailed zoning level. Compliance and non-compliance can be shown with point symbols, similar to above.

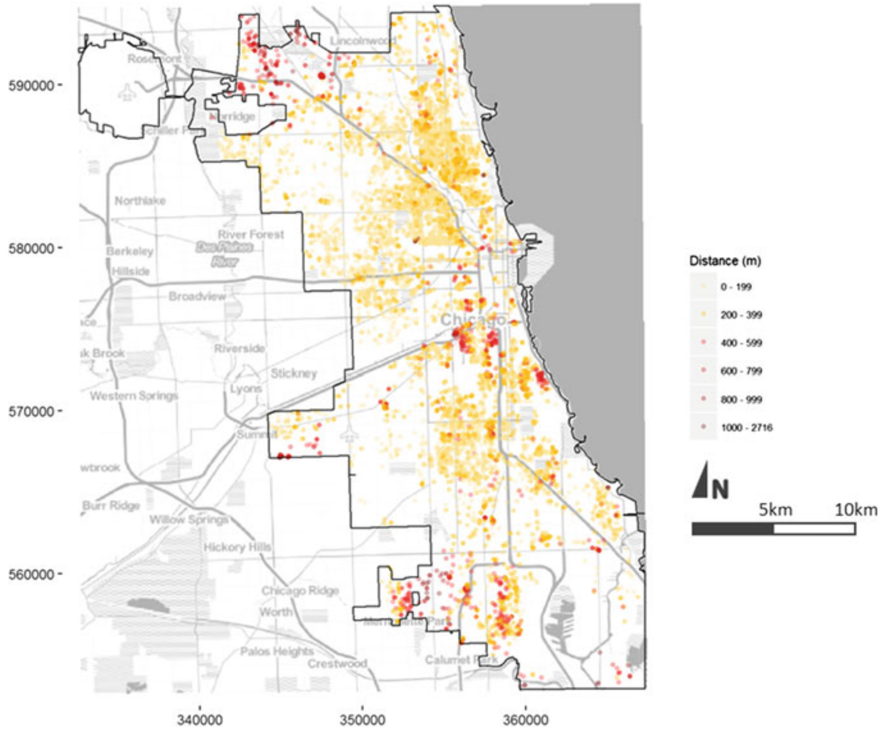
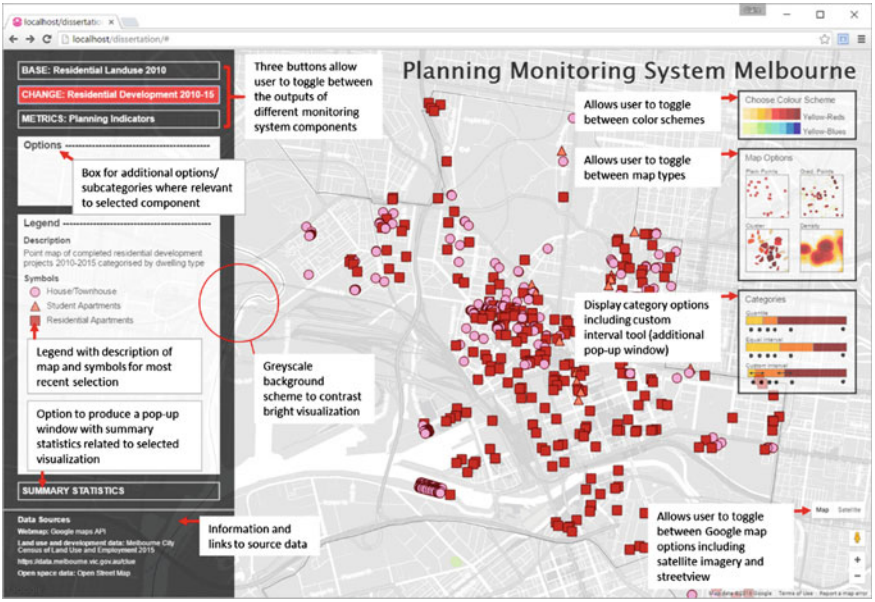


Fig. 15 Distance along road network to a public transport stop serviced on average at least every 10 min or more during morning peak hour

4.5 Website Format and Design

Figure 16, 17, 18 outline the relevant features of the website which displays the outputs of the prototype monitoring system, drawing data both from the API to the database on the server and to the semi-transparent image tiles which display the outputs of calculated metrics.

Browser-based visualization was found to be superior to the static map outputs, with the primary advantage of the web-based system being the ability to interactively pan and zoom to areas of interest with the context of a detailed map or satellite imagery. Graphic buttons organize the information, and provide clear and efficient means of sorting through and exploring available information to a degree that is impractical for a print-based system, with each component of the monitoring system including display options for four different map types, three colour schemes, three classification schemes, as well as various additional options.



BASE: Residential Landuse 2010

CHANGE: Residential Development 2010-15

METRICS: Planning Indicators

Options

Legend

Description

Point map of completed residential development projects 2010-2015 categorised by dwelling type

Symbols

- ○ House/Townhouse
- △ Student Apartments
- ■ Residential Apartments

SUMMARY STATISTICS

Data Sources

Webmap: Google maps API

Land use and development data: Melbourne City Census of Land Use and Employment 2015

https://data.melbourne.vic.gov.au/clue

Open space data: Open Street Map

Three buttons allow user to toggle between the outputs of different monitoring system components

Box for additional options/ subcategories where relevant to selected component

Legend with description of map and symbols for most recent selection

Option to produce a pop-up window with summary statistics related to selected visualization

Information and links to source data

Greyscale background scheme to contrast bright visualization

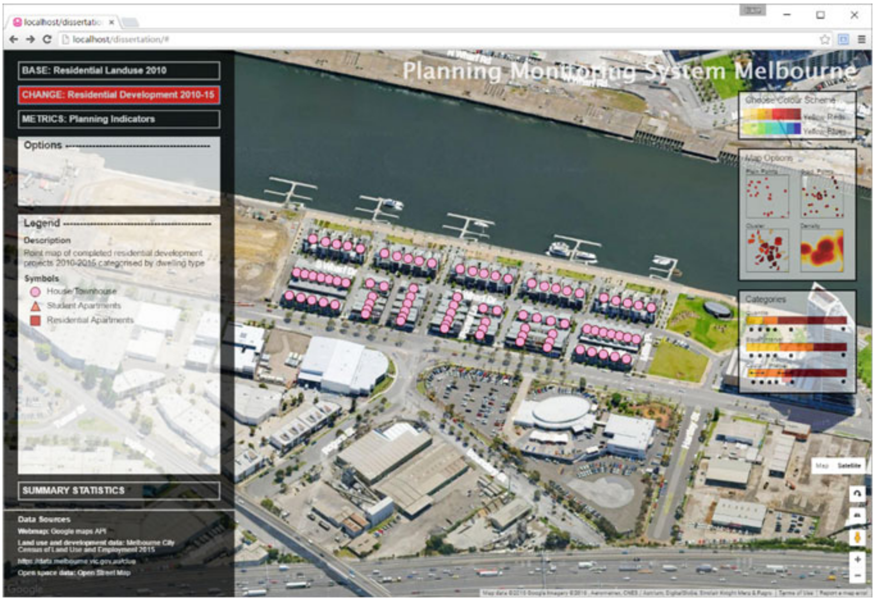
Allows user to toggle between color schemes

Allows user to toggle between map types

Display category options including custom interval tool (additional pop-up window)

Allows user to toggle between Google map options including satellite imagery and streetview

Fig. 16 Website features



BASE: Residential Landuse 2010

CHANGE: Residential Development 2010-15

METRICS: Planning Indicators

Options

Legend

Description

Point map of completed residential development projects 2010-2015 categorised by dwelling type

Symbols

- ○ House/Townhouse
- △ Student Apartments
- ■ Residential Apartments

SUMMARY STATISTICS

Data Sources

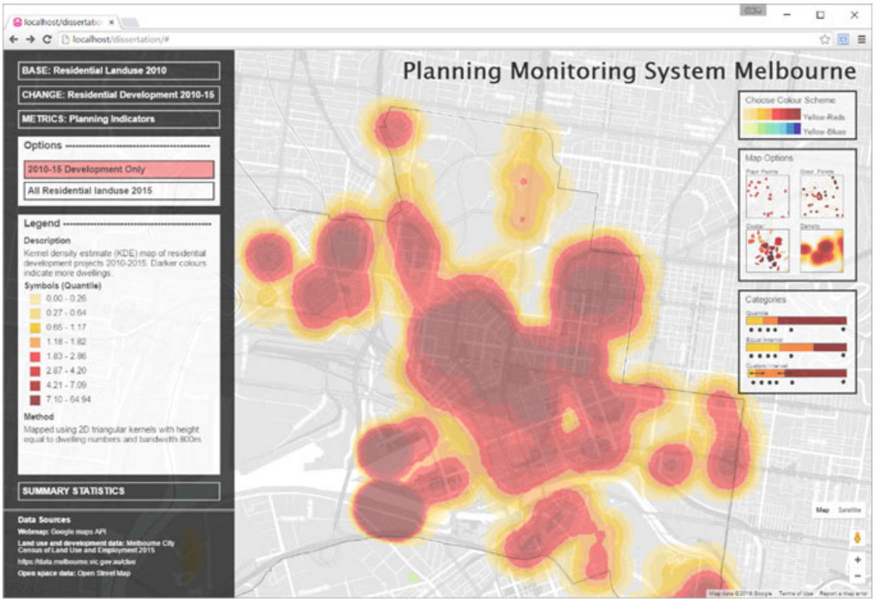
Webmap: Google maps API

Land use and development data: Melbourne City Census of Land Use and Employment 2015

https://data.melbourne.vic.gov.au/clue

Open space data: Open Street Map

Fig. 17 Google satellite imagery visualization option allowing detailed picture of a new development site in South Melbourne



BASE: Residential Landuse 2010

CHANGE: Residential Development 2010-15

METRICS: Planning Indicators

Options

2010-15 Development Only

All Residential landuse 2015

Legend

Description

Kernel density estimate (KDE) map of residential development projects 2010-2015. Darker colours indicate more dwellings.

Symbols (Quantile)

- 0.00 - 0.26
- 0.27 - 0.64
- 0.65 - 1.17
- 1.18 - 1.82
- 1.83 - 2.86
- 2.87 - 4.20
- 4.21 - 7.09
- 7.10 - 64.94

Method

Mapped using 2D triangular kernels with height equal to dwelling numbers and bandwidth 800m.

SUMMARY STATISTICS

Data Sources

Webmap: Google maps API

Land use and development data: Melbourne City Census of Land Use and Employment 2015

https://data.melbourne.vic.gov.au/clue

Open space data: Open Street Map

Fig. 18 Density map display option, number of dwellings recently developed

5 Potential for Practical Application

Where they exist, current monitoring outputs from planning authorities tend to use simple measures, summarized annually, for the entire authority area. This has limited use for planning regulations, which operate down to the scale of a neighborhood or individual block of land. This monitoring system proposes a platform to visualize indicators at temporally and spatially disaggregated scales.

This tool will help address many of the identified obstacles for monitoring in professional town planning practice. Foremost, automation of tasks reduces a lot of the effort involved in compiling indicator measurements. The prototype system shows that although the resolution and quality of available data varies, it is possible to turn raw data from four separate planning administrative systems into a meaningful and comparable web-visualization with minimal human intervention. As outlined above, in some cases improvements could be made to the way input data is collected and published by city authorities to make this process easier. Examples of improvements include ensuring essential attributes such as the number of dwellings are recorded in different fields, recording dates in development datasets as the actual day the construction completion certificate is issued and recording greater detail in attributes, such as number of bedrooms as is the for the London Development Database.

As in other areas of local government, the availability of open data, the potential of crowdsourced data and web-scraping may change political realities in the reluctance to adopt monitoring for fear of criticism in urban planning. The prototype systems for Melbourne and Chicago have been built using entirely public data, sourced from their respective open data portals.

It is now more than two decades since quantitative evaluation and modelling methods, proposed in the '60s and '70s by authors such as McLoughlin (1969), Chadwick (1971) fell out of favour with the planning profession. New sources of disaggregated data about the city are now available in digital format alongside increased storage space and computer processing speed to handle it. The existence of tools to assist with quantitative monitoring does not make the need for qualitative and community feedback any less important. Indeed, outputs from the prototype system are produced in standard spatial data formats that could easily be integrated into other planning support systems or participatory GIS system for public consultation.

The prototype system does not entirely ameliorate challenges regarding the complexity of planning objectives and defining success. It is, however, able to demonstrate the potential for the automated calculation of a range of spatial metrics related to planning objectives, highlighting areas of new dwellings that are relatively better or worse measured against any indicator. The minimum value which is considered 'acceptable' then becomes a political decision, depending on local context and trade-offs between other perceived benefits of the development location.

Similarly, the prototype monitoring system is, in itself, unable to determine cause-and-effect relationships between planning policy and development outcomes. The sheer complexity of city systems means it remains extremely challenging to isolate factors sufficiently to make definitive statements in almost any context. In addition, due to data limitations, the time period within which city change could be measured is very short and did not readily line up with most plan implementation dates. What the monitoring system provides is a platform that, if updated with data over a sufficient period of time, can be used to compare outcomes before and after the implementation data of a specific policy and between areas in the city where a specific policy applies or does not apply.

6 Further Work

User testing is an essential step in making the prototype system operational which was outside the scope of the study. Previous research into the development and use of planning support systems shows that adoption rates still remain low (Geertman et al. 2015). Many urban planning professionals, whilst experts in regulatory and administrative systems, are not specifically trained in statistics, and testing the system for usability is essential, particularly in relation to the proposed kernel density surface metrics.

The system currently has a limited scope but has the potential to be expanded to other types of development and metrics can be customized almost infinitely. Again, user testing is critical to define how well the selected policy priorities for the prototype system fit professional practice and what priorities should be given to possible extensions. Further technical improvements should also be explored, especially improvements to program efficiency and processing speed.

The scope of this research regarding generated outputs was largely descriptive as the study focused on the mechanics of system development. Nevertheless, through the unique combination of multiple datasets and definition of standard metrics, the outputs of the prototype system have the potential to provide comparative insights into the recent growth of all four cities. Development approvals and completions data has rarely been used in previous studies but has the potential to provide interesting insights into urban change.

7 Conclusions

This study investigated the data, measurement and visualization requirements for the construction of a prototype monitoring system as a necessary prerequisite for measuring the success of planning policy in an ongoing and automated fashion. A review of the literature found that, whilst the importance of monitoring is not disputed in planning theory, it is largely neglected in both academic studies and planning practice. The study fits neatly within this gap.

The prototype system is programmed as an interactive web-mapping application utilising Google Maps API, HTML, SQL and R Scripts. The system combines existing land-use, development, infrastructure and services data to visualize indicators of change and compliance with policy objectives. Four case study cities—London, Chicago, Brisbane and Melbourne—allowed comparisons to be made in the process required to transform available development data for each city into useful metrics for monitoring planning policy. A small number of indicators were developed to serve as a demonstration of potential measures that could be calculated using the available datasets for each city. These measures focused on three of the identified common planning-policy objectives: promotion of a mix of dwelling types; access to public transport and facilities; and conformity with spatial land-use or growth plans. Visualization methods that preserved the greatest level of spatial disaggregation were favoured for the prototype system, being point mapping for categorical and isolated metrics, and kernel density mapping for metrics requiring aggregation or to convey information on relative intensity.

The chosen metrics, combined with the visualization outputs, provide a successful demonstration of how planning objectives can be measured in a standardized and ongoing fashion. The prototype system can help to address many of the identified obstacles for monitoring in professional town-planning practice, foremost the automation of tasks required to clean data and compile indicator measurements, but also by extending current techniques to preserve information at a spatially disaggregated scale and in an accessible format, and future work should be directed to user testing and extending current capabilities in association with user feedback. Monitoring the actual effects of policy has long been an ideal of planning, being necessary to improve decision-making, but is often limited in practice. This project demonstrates the potential of bringing together new sources of data and technology as a tool to bring the profession a few steps closer to this ideal.

References

Alfasi, N., Almagor, J., & Benenson, I. (2012). The actual impact of comprehensive land-use plans: Insights from high resolution observations. *Land Use Policy, 29*(4), 862–877.

Arnstein, S. R. (1975). A working model for public participation. *Public Administration Review, 35*(1), 70–73.

Banfield, E. C. (1959). Ends and means in planning. *International Social Science Journal, 11*(3), 361–368.

Batty, M. (2008). Fifty years of urban modelling: Macro statics to micro dynamics. In S. Albeverio, D. Andrey, P. Giordano, & A. Vancheri (Eds.), *Fifty years of urban modelling: Macro statics to micro dynamics* (pp. 1–20). Heidelberg: Physica-Verlag.

Batty, M. (2009). Urban modeling. In R. Kitchen & N. Thrift (Eds.), *International encyclopedia of human geography* (pp. 51–58). Amsterdam: Elsevier.

Batty, M. (2012). A generic framework for computational spatial modelling. In A. J. Heppenstall, A. T. Crooks, L. M. See, & M. Batty (Eds.), *Agent-based models of geographical systems* (pp. 19–50). Dordrecht: Springer.

Brisbane City Council. (2014). Brisbane city plan 2014. http://eplan.brisbane.qld.gov.au/. Accessed 1 Jul 2016.

Brody, S. D., & Highfield, W. E. (2005). Does planning work? Testing the implementation of local environmental planning in Florida. *Journal of the American Planning Association, 71*(2), 159–175.

Calkins, H. W. (1979). The planning monitor: An accountability theory of plan evaluation. *Environment and Planning A, 11*(7), 745–758.

Carmona, M., Carmona, S., & Gallent, N. (2003). *Delivering new homes: Processes, planners and providers*. London: Routledge.

Chadwick, G. F. (1971). *A systems view of planning; towards a theory of the urban and regional planning process* (1st ed.). Oxford: Pergamon Press.

Chapin, T. S., Deyle, R. E., & Baker, E. J. (2008). A parcel-based GIS method for evaluating conformance of local land-use planning with a state mandate to reduce exposure to hurricane flooding. *Environment and Planning B: Planning and Design, 35*(2), 261–279.

Chicago Metropolitan Agency for Planning. (2010). Go to 2040 Comprehensive Regional Plan. http://www.cmap.illinois.gov/about/2040. Accessed 1 Jul 2016.

City of Melbourne. (2016). Melbourne Planning Scheme. http://planningschemes.dpcd.vic.gov.au/schemes/melbourne. Accessed 1 Jul 2016.

Davidoff, P. (1965). Advocacy and pluralism in planning. *Journal of the American Institute of Planners, 31*(4), 331–338.

Faludi, A. (1973). *Planning theory*. Oxford: Pergamon.

Forester, J. (1989). *Planning in the face of power*. Berkeley: University of California Press.

Friedmann, J., Nisbet, R., & Gans, H. J. (1973). The public interest and community participation: Toward a reconstruction of public philosophy. *Journal of the American Institute of Planners, 39*(1), 2–12.

Geertman, S., Ferreira, J., Goodspeed, R., & Stillwell, J. (Eds.). (2015). *Planning support systems and smart cities*. Cham: Springer International Publishing.

Geertman, S., & Stillwell, J. (Eds.). (2009). *Planning support systems best practice and new methods*. Dordrecht: Springer.

Greater London Authority. (2016). The London Plan 2011, The spatial development strategy for London Consolidated with Alterations since 2011. www.london.gov.uk/what-we-do/planning/london-plan/current-londonplan. Accessed 1 Jul 2016.

Healey, P. (2006). *Collaborative planning: Shaping places in fragmented societies* (2nd ed.). Basingstoke: Palgrave Macmillan.

Long, Y., Han, H., Tu, Y., & Shu, X. (2015). Evaluating the effectiveness of urban growth boundaries using human mobility and activity records. *Cities, 46,* 76–84.

McLoughlin, J. B. (1969). *Urban and regional planning: A systems approach*. London: Faber.

Meyerson, M. (1956). Building the middle-range bridge for comprehensive planning. *Journal of the American Institute of Planners, 22*(2), 58–64.

Robinson, I. M. (1965). Beyond the middle-range planning bridge. *Journal of the American Institute of Planners, 31*(4), 304–312.

Seasons, M. (2003). Monitoring and evaluation in municipal planning: Considering the realities. *Journal of the American Planning Association, 69*(4), 430–440.

Victorian Government. (2014). Plan Melbourne, Metropolitan Planning Strategy. www.planmelbourne.vic.gov.au/Plan-Melbourne. Accessed 1 Jul 2016.

Talen, E. (1996). After the plans: Methods to evaluate the implementation success of plans. *Journal of Planning Education and Research, 16*(2), 79–91.

Taylor, N. (1998). *Urban planning theory since 1945*. London: Sage Publications.

Chapter 3
Urbanmetrics: An Algorithmic-(Para) Metric Methodology for Analysis and Optimization of Urban Configurations

Fernando Lima, Nuno Montenegro, Rodrigo Paraizo and José Kós

Abstract This chapter describes and evaluates the implementation of Urbanmetrics, a computational planning support methodology based on a set of algorithmic-parametric tools, developed to measure and optimize urban configurations through metrics related to principles derived from Transit Oriented Development (TOD)—an urban development model that advocates walkable, compact and mixed-use neighborhoods, centered around transport stations. More specifically, Urbanmetrics is used to analyze and improve urban configurations according to TOD principles such as transit acessibility, walkability, diversity and density. Urbanmetrics allows one to consider simultaneously physical metrics (e.g., distance), topological measures (e.g., connectivity and integration), and mathematical operations (e.g., algebraic, geometric) as fitness functions in optimization processes, to achieve improved solutions for urban arrangements within TOD scope. A principle-index-tool triad supports Urbanmetrics. That is, for each addressed principle, there is one or more corresponding indexes to measure and optimize the performance of a given area, accordingly to TOD criteria.

Keywords Urbanmetrics · Transit Oriented Development · Optimization · Generative systems · Urban planning

---

F. Lima (✉)
Faculdade de Arquitetura e Urbanismo, Universidade Federal de Juiz de Fora,
Juiz de Fora, Minas Gerais, Brazil
e-mail: fernando.lima@arquitetura.ufjf.br

N. Montenegro
Universidade de Lisboa, Lisbon, Portugal
e-mail: nunomontenegro@fa.ulisboa.pt

R. Paraizo · J. Kós
Universidade Federal de Santa Catarina, Rio de Janeiro, Brazil
e-mail: rparaizo@ufrj.br

J. Kós
e-mail: jose.kos@ufsc.br

S. Geertman et al. (eds.), *Planning Support Science for Smarter Urban Futures*, Lecture Notes in Geoinformation and Cartography,
DOI 10.1007/978-3-319-57819-4_3

1 Introduction

Fuel combustion in motor vehicles is responsible for up to 75% of urban air pollution (Global Fuel Economy Initiative 2016), while outdoor air pollution was associated with 3.7 million premature deaths in 2012 (World Health Organization 2014). Besides contributing to carbon emissions, the adopted logic of organizing cities is responsible for great inconveniences in contemporary urban centers (e.g., automobile dependence, slow-moving traffic, fragmented spatial patterns, less social interactions). Transit Oriented Development (TOD) is, in turn, an urban development model that became one of the key planning paradigms aimed at creating compact, walkable, mixed-use communities centered around high quality transport systems. As long as TOD makes possible the creation of vibrant livable communities without depending on an automobile for mobility, it is being increasingly promoted in several cities of the world as a sustainable policy (Calthorpe 1993; Vale 2015). Although there is no universally accepted definition of TOD, it is often described in a physical manner: an area of compact mixed-use buildings served by a multi-modal mobility network within walkable distance (Cervero and Kockelman 1997; Calthorpe and Fulton 2001; Suzuki et al. 2013; Vale 2015). In this logic, basic urban needs are easily accessible without demanding automobiles or spending large amounts of time in commuting, with the intention of supporting more autonomous and sustainable neighborhoods.

TOD is characterized by a few main features: proximity to transport stations and a functional relationship with them, as well as compact, mixed-use neighborhoods that encourage walking, cycling, and the use of public transit by residents, employees, shoppers and visitors. In other words, it should encourage the use of public transportation by creating neighborhoods with compact urbanization, diversity in land use and urban design geared to the pedestrian—where one can walk to the stations and other amenities. The primary principles of TOD consist of: (a) transit accessibility—locating amenities, employment, retail shops and housing around transit hubs; (b) walkability—the ability that a particular neighborhood has to connect housing and amenities points through distances that can be traveled on foot; (c) diversity—providing a mix of uses, densities and housing types in the same district; (d) density for mass transit—encouraging infill and redevelopment within existing neighborhoods, allowing the system to run efficiently (Cervero and Kockelman 1997; Calthorpe and Fulton 2001; Dittmar and Ohland 2004; Suzuki et al. 2013).

According to several authors, there is a demand for instruments and methods that assist the actors involved in the discussion, proposition and evaluation of projects based on the DOT logic to be implemented in a more successful way

(Dittmar and Ohland 2004; Suzuki et al. 2013; Vale 2015). In other words, there have not been sufficiently developed standards or systems to help the actors involved in the process of bringing successful TOD projects into existence. On the other hand, TOD is a multivariable dependent system, as long as it relies on geometric and measurable parameters (or metrics) for assessing its performance, and for planning more autonomous neighborhoods. Therefore, it represents a kind of complex proposition, derived from some variables considered as crucial in achieving its objectives, what makes TOD an ideal case for computational implementation (Lima et al. 2016).

In accordance with Dittmar et al. (2004), "*TOD requires the participation of many actors and occurs in a fragmented regulatory environment, adding complexity, time, uncertainty, risk, and cost to projects*" (p. 10). However, these authors also state that "*there are no standards or systems to help the actors involved in the development process to bring successful transit-oriented projects into existence*" (Dittmar et al. 2004, p. 10). Nevertheless, in the last years, creative work has gone towards the deployment of computer-aided decision support tools. Thus, it is very important to develop standards and definitions, creating products and delivering support systems. In this sense, "*these visual preference-oriented tools are slowly being merged with a kind of simulation tool that can start to measure the outcomes of changed design*" (Bernstein 2004, p. 245).

In this context, this chapter describes and evaluates the implementation of Urbanmetrics, a computational planning support methodology, assisted by a set of algorithmic-parametric tools. This methodology is developed to calculate indexes that enable one to measure and optimize urban configurations according to principles derived from Transit Oriented Development (TOD). The purpose of the framework is to analyze and improve urban configurations through a set of TOD measurable principles such as transit accessibility, walkability, diversity and density. More specifically, Urbanmetrics allows one to consider simultaneously physical metrics (e.g., distance), topological measures (e.g., connectivity, integration and depth) (Hillier and Hanson 1984) and results of mathematical operations (e.g., algebraic, geometric) as fitness functions in optimization processes, in order to achieve more efficient solutions for urban configurations within TOD scope. Thus, Urbanmetrics implementation seeks to contribute for the achievement of smarter urban futures. There are also other planning support systems that consider indexes for analyzing urban configurations. The INDEX tool by Criterion Planners (Allen 2008) is one of those.

Thus, this chapter is structured in the following sequence: initially we provide a description and a presentation of the developed methodology and set of tools; an implementation of the methodology in a case study is then presented; the results are discussed; and the chapter finishes with some conclusions.

2 Urbanmetrics: Methodology and Tools

Urbanmetrics[1] is a computational[2] methodology supported by a set of algorithmic-parametric tools[3] that seeks to assist urban planners and developers on TOD oriented planning processes, as well as on urban planning tasks in contexts of a similar nature. In summary, Urbanmetrics aims to promote decision-making processes, providing instruments that manage huge amounts of data and perform complex calculations. We propose the use of this methodology to cross relevant information and provide decisions supported by data obtained in a computational environment. The ultimate goal is to facilitate the management of solutions in planning processes that consider measurable aspects, through the association of computational resources and metrics for performance evaluation.

A principle-index-tool triad supports Urbanmetrics. That is, for each TOD principle addressed, there is one or more corresponding index calculated by an algorithmic-parametric tool that enables the objective measurement (and thus, optimization) of the performance of a given area, accordingly to objective criteria. More specifically, the core concept of Urbanmetrics' methodology is to use algorithmic tools to calculate urban metrics that can be used to analyze the performance of a given urban area, or can be set as fitness functions on optimization tasks. In this sense, the proposed methodology makes use of the following tools:

(i) a Physical Proximity Calculator—measures a physical proximity index, an indicator that calculates the smaller physical distances (considering slopes) between the nearest target (station or amenity) and one (or all) origin(s) in a neighborhood;
(ii) a Topological Proximity Calculator that contemplates space syntax principles (Hillier and Hanson 1984) for calculating the smaller topological distances (number of steps) between a target (station or amenity) and one (or all) origin (s) in a neighborhood;
(iii) an Amenities Variety Calculator that performs the calculation of the average physical distances (considering slopes) between all targets (amenities) and one (or all) origin(s) in a neighborhood;
(iv) an Amenities Recurrence Calculator that calculates the ratio of the number of targets (amenities) and the total number of origins of an examined area;

---

[1] This nomenclature derives from the concept that sustains the developed methodology: the implementation of a set of urban measurable attributes (or metrics) as parameters in computational tasks that seek to make it possible to analyze and optimize the performance of urban areas configurations. There are also other appropriations for the term 'Urbanmetrics', such as a real estate consulting firm and a software.

[2] Despite of being essentially computational, Urbanmetrics can also be used to analyze manually-constructed scenarios.

[3] Urbanmetrics advocates a non-commercial and open source set of tools developed as algorithmic codes for share in Rhinoceros®/Grasshopper® 3D modelling software. Basic Knowledge in the aforementioned platform is required for a proper use and understanding of the tools.

Table 1 Reference values for PPC

Proximity value	Meaning
1	Excellent proximity—less than 5-min walk
0.5	Good proximity—10-min walk
0	Disregarded proximity—more than 20-min walk

(v) a Mixed-use Index Calculator (Hoek 2008) that computes the ratio between residential and non-residential areas in a location, in order to analyze its diversity; and

(vi) a Spacematrix Calculator that calculates spacematrix density indicators (Pont and Haupt 2010) in order to support goals definitions and decision-making processes.

2.1 Physical Proximity Calculator (PPC)

The PPC measures the distance between a target (transport stations and/or amenities[4]) and one (or all) locations(s) in a neighborhood (origins). In this regard, the proposed algorithm calculates the path(s) with smaller physical distance(s) between a target and one (or all) destination(s) in a district, considering slope(s) in the path (s). Thus, if a given plot (origin) is within 400 m (5 min walk) from a target, it is assigned with a value of 1. The score decreases as the distance approaches 1.6 km (20 min walk) and a 0 index is awarded for distances greater than 1.6 km (Table 1).

The PPC also makes it possible to apply penalty factors (according to the acclivity) for estimating a score to classify the proximity to the station. For instance, in relation to a particular locality, if a station is 0.4 km away (5 min walk), then the maximum index (1) is assigned for this plot. If the station is a 1 km away from a plot, but with a 10% acclivity, then a 10% penalty is applied. It establishes a simple and direct relationship to differentiate paths according to their acclivity, but as long as it works on a parametric environment, it is possible to adopt other criteria for penalization. Figure 1 illustrates the calculation logic of the PPC algorithm.

2.2 Topological Proximity Calculator (TPC)

The TPC calculates proximity considering topological metrics, using concepts from space syntax theory (Hillier and Hanson 1984). This tool can be used in a

---

[4] The considered amenities categories in this work are: Educational, Food, Retail, Entertainment, Recreation, Health and Others. The proposed methodology can be used to consider other categories, depending on the researcher needs.

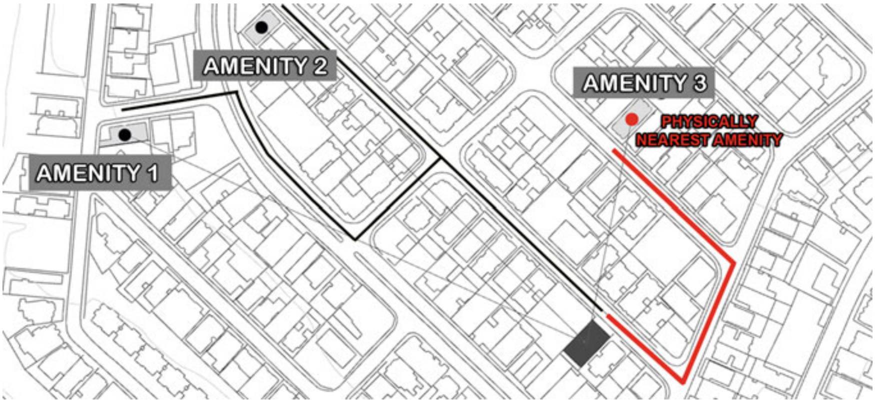


Fig. 1 The PPC calculation logic. This tool calculates the shortest path (considering slopes) from a particular location to all amenities in a category, identifying the nearest amenity to this location (considering physical proximity) and calculating an index based on its physical distance (in the above example, *amenity 3*)

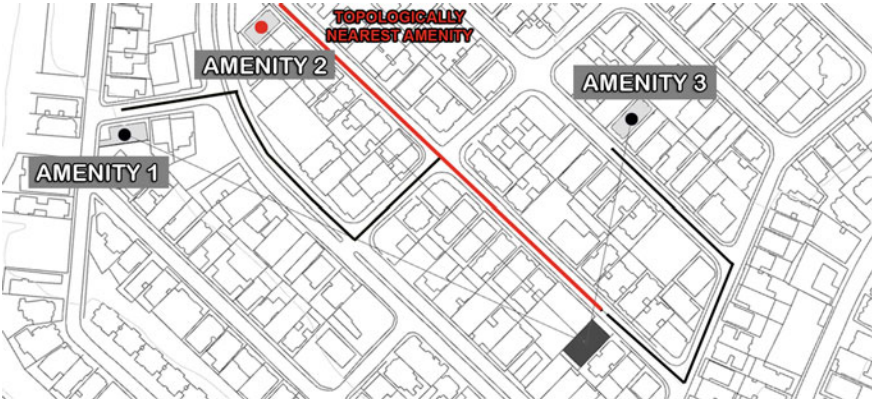


Fig. 2 The TPC calculation logic. This tool calculates the shortest path (considering the number of changes of direction) from a particular location to all amenities in a category, identifying the nearest amenity to this location (considering topological proximity) and calculating an index based on its topological distance (in the above example, *amenity 2*)

complementary way to the tools that use physical metrics. In this sense, the TPC aims to calculate: (a) the pathways with the smallest topological distances between origins and targets of a locality; and (b) the integration/depth of the spaces of a given area. That is, this tool calculates the number of direction changes (topological steps) needed to reach one or more targets from a given origin, and also indicates which spaces are more integrated—which means identifying which streets are more accessible and, consequently, have greater relevance in the dynamics of an urban area. Figure 2 illustrates the TPC calculations.

Fig. 3 AVC calculation logic. This tool performs the calculation of the average physical distance from a particular location (origin) and all nearby amenities in a category

2.3 Amenities Variety Calculator (AVC)

The AVC aims to measure another important aspect for the evaluation of the walkability of a given location: the proximity between an origin (one or more plots in a neighborhood) and all the targets (amenities) within walkable reach. In this sense, this tool calculates the average distances between a given source and all the nearby targets in a given category of urban services. The AVC algorithm works in a complementary way to the PPC because, while the former considers only the distance to the nearest amenity, the AVC assigns an index considering the average physical distance between all the targets and the origin in question. Thus, while PPC measures the distance from the closest service to an origin, AVC considers the distances between the same source and all the targets reported in the same category, as shown in Fig. 3. This index is important because it allows differentiating origins that have a lot of close targets (greater diversity of services) from those that only have good proximity to a single target. To promote better walkability, it is also important to consider the diversity of the available services, and not just the proximity to a single target.

2.4 Amenities Recurrence Calculator (ARC)

The ARC also aims to measure the walkability of a particular area, and works in a complementary way to the PPC and AVC tools. While the former tools calculate the lowest physical distance to the nearest target and the average physical distance to all targets, respectively, the ARC has characteristics, as it calculates the proportion of the number of targets reported (in each category of services) and the total number of locations in a surveyed area, as shown in Fig. 4.

Fig. 4 The ARC calculation logic. This tool calculates a ratio between the number of amenities in each category and the total number of locations (origins) in a given area

This algorithm, whose basic operation consists of counting targets within a radius of 20 min of walking and dividing this value by the number of lots in the same area, is important for analyzing the supply of services in each neighborhood, an aspect equally important to measure the capacity that a given locality has to connect dwellings and various urban services by distances that can be traveled on foot.

2.5 MiXed-use Index Calculator (MXIC)

The MXIC aims to measure the diversity of a neighborhood. For this, MXIC incorporates the MiXed-use Index (MXI) (Hoek 2008), a concept that calculates the proportion between the sum of all the residential and non-residential areas of a locality, making a comparison between these proportions. The closer the ratio between areas is 50/50, the greater the diversity an urban area has. This algorithm has great importance in the context of Urbanmetrics, because it allows the assessment of the diversity of a certain area before and after potential interventions. In some approaches, the MXI index may even be configured as one of the objective functions of an optimization task, in the search for areas with greater diversity. Figure 5 shows the MXIC calculation base and Table 2 presents its references.

2.6 SPacematrix Calculator (SPC)

The SPC implements codes for calculating density attributes from studied areas, informing three fundamental indicators proposed by Pont and Haupt (2010): intensity

Fig. 5 The MXIC calculation logic. This tool calculates the ratio between all residential areas (*in green*) and all non-residential areas (*in magenta*), seeking to assess the diversity of a given neighborhood, according to Hoek (2008)

Table 2 Reference values for MXI (Hoek 2008)

MXI value	0	50	100
Meaning	No house present	50/50 balance	100% residential use
District type	Single use	Mixed-use	Single use
Examples	Office park	City center	Newtown
	Factory Complex	Semi central	Suburbia

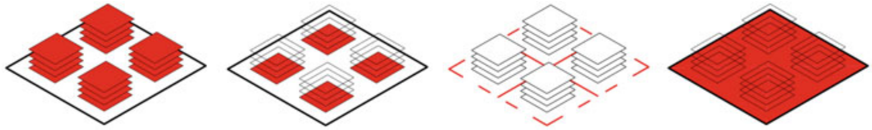


Fig. 6 The SPC inputs: total area of floors, occupation area, network of streets and the total area of aggregation—in this case, a neighborhood (Pont and Haupt 2010)

using the Floor Space Index (FSI); coverage using the Ground Space Index (GSI) and Network (N) density. Thus, once the required inputs are informed (contours of the analyzed area and its buildings, number of buildings floors, and design of the streets), the algorithm informs the FSI, GSI and N of an analyzed area. This tool has great importance in the context of Urbanmetrics, since it allows the calculation and visualization of information about the density of urban areas in real time, allowing the dynamic evaluation of urban contexts studied and the proposed interventions/ modifications. Figure 6 illustrates the elements that this algorithm uses.

3 Case Study

This case study comprises the application of the proposed methodology to the existing district of Cascatinha in the city of Juiz de Fora, Brazil (Fig. 7). The main goal of this study is to evaluate Urbanmetrics' potential to frame an area within the scope of TOD. Despite of being a predominantly residential neighborhood, the chosen district has a great potential to be a more autonomous and sustainable neighborhood, presenting some features that make it an ideal sample for evaluation of the proposed methodology, such as: (a) a suitable extension for TOD implementation (approx. 1 km diameter); (b) relatively low density; (c) no transport station; (d) topographical complexity; (e) available areas for new buildings; (f) vicinity to important amenities such as a park, a hospital, a university, and a shopping center, among others; (g) closeness to the city center, and; (h) a good placement in the urban network, linking directly the city center to important city regions. This is a key scenario for assessing Urbanmetrics towards more efficient TOD-oriented planning because, besides demonstrating typical issues of the sprawling city paradigm, a situation found in several cities around the world, it also presents some important features for evaluating the methodology implementation.

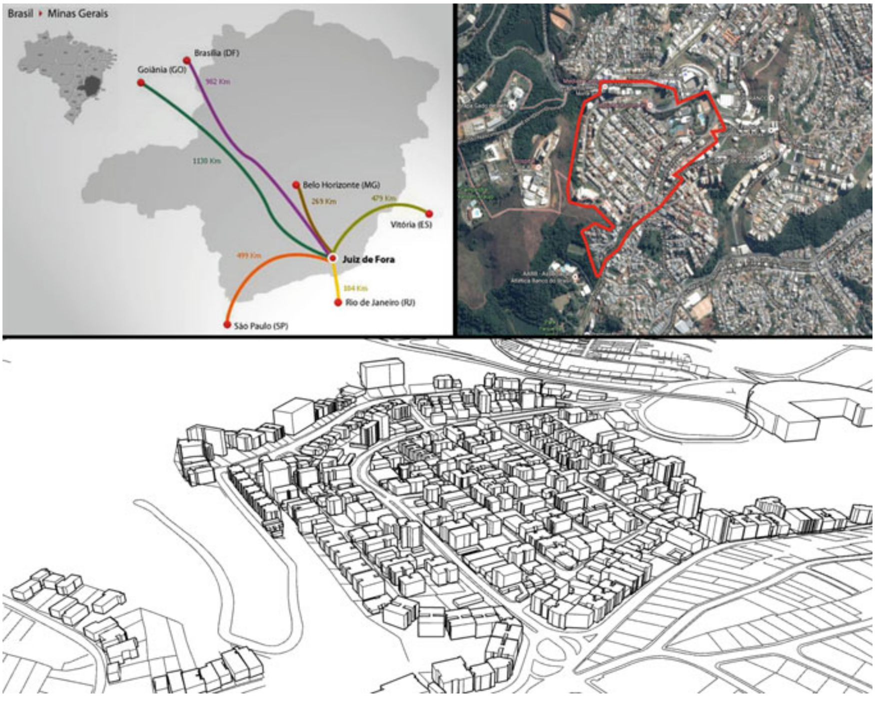


Fig. 7 The geographical location and a 3D model of the case study's neighborhood

3.1 Approach Workflow

The approach implemented in this case study relies on a logic of identification, evaluation and optimization of relevant TOD metrics, aiming at an efficient support methodology for TOD-oriented planning processes. Within this framework, we create a Rhinoceros/Grasshopper[5] parametric model of the selected neighborhood, to manage geometric and measurable features related to TOD principles. In that sense, the following information was obtained and transferred to the analysis model: (a) the footprints, number of levels, uses (residential and non-residential) and topographical positioning of each building inside the district, in order to measure distances, slopes, possible connecting paths, diversity and density indicators; (b) the location of each one of the amenities in the neighborhood, according to the aforementioned considered categories, in order to measure proximity, diversity and variety of amenities; (c) the identification of available areas for new buildings (vacant lots and non-consolidated places), seeking to provide room for new construction and to modify the diversity of the district; the topographical network of neighborhood's streets, with the view to consider slopes and distances for measuring the PPC, the AVC and the ARC operations; and (d) the design of blocks and lots, in order to provide density (spacematrix) assessment.

Octopus, a Grasshopper plug-in for applying evolutionary principles to problem solving, was used to search for many goals at once, producing a set of optimized trade-off solutions between the extremes of each goal. Thenceforth, Urbanmetrics tools used district data, emulated by mathematic entities, as input for optimization and simulation operations, aiming to increase transit acessibility, walkability and diversity related indexes, by the following sequence of algorithmic operations, respectively: (i) the evaluation of different scenarios for the occupation of vacant plots, automatically calculating MXI and spacematrix indicators, in order to identify diversity and density limitations or potentialities within the TOD scope. In this case study, the TPC was used to measure the integration of each one of the available lots, allowing the identification of higher occupations for places with greater integration; (ii) the search for the best location for inserting a transport station—as long as the district does not have one—considering the total constructed area of each lot. Thus, it was sought to prioritize the station's proximity to places with higher potential to house (living or working) more people; (iii) the search for the best location for inserting a new amenity for each category, aiming to increase indexes related to walkability—PPC, AVC, ARC and TPC—with only a single new amenity for category. Figure 8 shows the approach workflow.

---

[5] Rhinoceros is a 3D modelling application software that uses the Grasshopper plugin, a graphical algorithm editor that enables one to parametrically manage models.

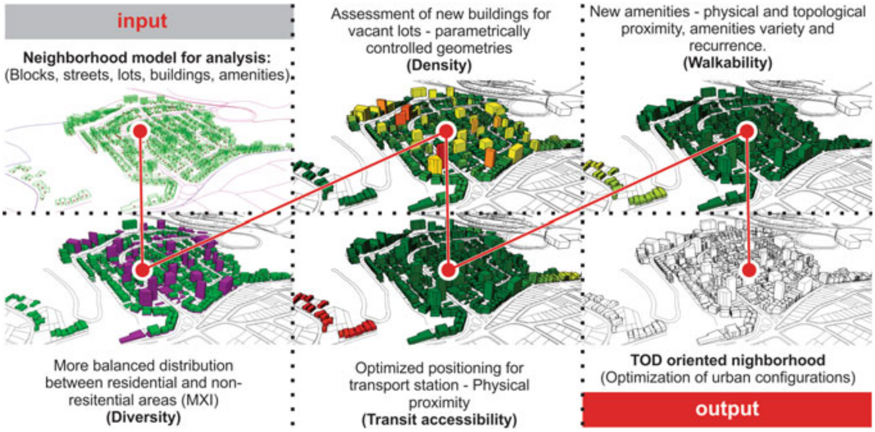


Fig. 8 Approach workflow

4 Results

The implementation of our methodology provided some changes to the arrangement of the neighborhood, suggesting a better performance from the scope of the TOD principles. In summary, the new settings provided: (i) an excellent transit accessibility, since the optimized insertion of a transport station permitted a high average station proximity score (Table 3 and Figs. 9 and 10); (ii) a greater walkability, as long as the optimized addition of new amenities provided an increase of the neighborhoods PPC, AVC, ARC and TPC indexes in all analyzed categories, as shown in Table 3 and Figs. 9 and 10; (iii) a neighborhood with more diversity, since the proposition of new buildings and their functions provided a more balanced MXI, seeking a greater equilibrium between residential and non-residential places (Table 3); (iv) a more suitable density for a Transit Oriented Neighborhood, since parametrically controlled urban geometries made it possible to regulate density, in a manner that supports more people (working or living) closer to transport hubs, as shown in Table 3. The PPC and MXIC indexes (both global and partial) increased after optimization tasks, suggesting that amenities became more closer and more balanced within the new district´s arrangement, as Figs. 9 and 10 also show.

5 Discussion and Conclusions

The implementation of Urbanmetrics indexes as fitness functions on computational systems, has allowed the production of a huge variety of potential solutions. Some more are more suitable, others less so. The placement of different amenities, the simulation of different occupation scenarios for vacant lots, as well as the regulation

Table 3 Results: Indexes before and after Urbanmetrics implementation

General Information

Total area of the neighborhood (ha)	42.48	**42.48**
Total number of blocks	17	**17**
Total number of lots	426	**426**
Total number of buildings	397	**423**

Transit Accessibility

Distances for the proposed station

Lowest	Average	Weighted average	Highest
20 m	335 m	302 m	1053 m

Physical proximity for the station

Lowest	Average	Weighted average	Highest
0.40	0.95	0.98	1

Walkability (before/after)

Physical proximity—partial

Category	Lowest		Average		Highest	
Educational	0.73	0.74	0.97	0.99	1	1
Food	0.68	0.68	0.98	0.99	1	1
Retail	0.62	0.60	0.98	0.98	1	1
Entertainment	0	0.42	0.53	0.94	0.96	1
Recreation	0.59	0.75	0.89	0.98	1	1
Health	0	0.58	0.80	0.96	1	1
Others	0.56	0.58	0.97	0.99	1	1

Physical proximity—global

Lowest		Average		Highest	
0.54	0.72	0.88	0.98	0.99	1

Amenities variety—partial

Category	Lowest		Average		Highest	
Educational	0.36	0.43	0.59	0.73	0.76	0.82
Food	0.39	0.39	0.88	0.88	0.97	0.97
Retail	0.44	0.44	0.92	0.91	0.99	0.99
Entertainment	0	**0.40**	0.53	**0.76**	0.96	**0.96**
Recreation	0.36	**0.56**	0.64	**0.73**	0.94	**0.94**
Health	0	**0.30**	0.42	**0.69**	0.79	**0.81**
Others	0.26	**0.28**	0.91	**0.82**	1	**1**

Amenities variety—global

Lowest		Average		Highest	
0.36	**0.46**	0.70	**0.79**	0.79	**0.86**

Amenities recurrence—partial

Category	Lowest		Average		Highest	
Educational	0.017	0.019	0.023	0.026	0.024	0.026
Food	0.059	0.061	0.061	0.064	0.061	0.064

(continued)

Table 3 (continued)

Walkability (before/after)						
Retail	0.043	0.045	0.043	0.045	0.043	0.045
Entertainment	0.000	0.002	0.002	0.005	0.002	0.005
Recreation	0.007	0.012	0.012	0.014	0.012	0.014
Health	0.000	0.007	0.013	0.016	0.014	0.017
Others	0.024	0.026	0.024	0.026	0.024	0.026
Amenities recurrence—global						
Lowest		Average		Highest		
0.021	**0.025**	0.025	**0.028**	0.026		**0.028**
Topological proximity—partial						
Category	Lowest		Average		Highest	
Educational	0	0	1.57	1.43	5	5
Food	0	0	1.41	1.08	7	5
Retail	0	0	1.68	1.35	7	5
Entertainment	0	0	5.49	2.35	10	7
Recreation	0	0	2.51	1.97	8	7
Health	0	0	1.84	1.51	6	6
Others	0	0	1.70	1.41	6	6
Topological proximity—global						
Lowest		Average		Highest		
0.57	0.29	2.31	1.59	7		5.89
Diversity and density						
Mixed-use (MXI)	Residential		Non-residential			
	0.84	0.58	0.16	0.42		
Spacematrix						
FSI		GSI		N		
0.77	1.12	0.23	0.26	0.21	0.21	

of increasing density according to the distance to the station, provided many combinations and arrangement possibilities. Considering that this range of potential solutions allows the enlargement of analysis, discussion and intervention possibilities, contributing to more efficient proposals, this approach relies on a logic of interaction and feedback, aiming at an efficient design process that allows greater dialogue between the different actors of the process. In this sense, it is vital to think about the employment of a flexible digital environment, capable of responding to changes throughout its implementation. In this context, Urbanmetrics proved to be helpful in order to provide dynamic assessment and optimization of principles derived from TOD. The positioning of the station was supported by optimization tasks that allowed the identification of, among hundreds of options, the solution that provided the lowest average distance between the station and all other lots. In this sense, the PPC index of the station was as high as it could get, considering the

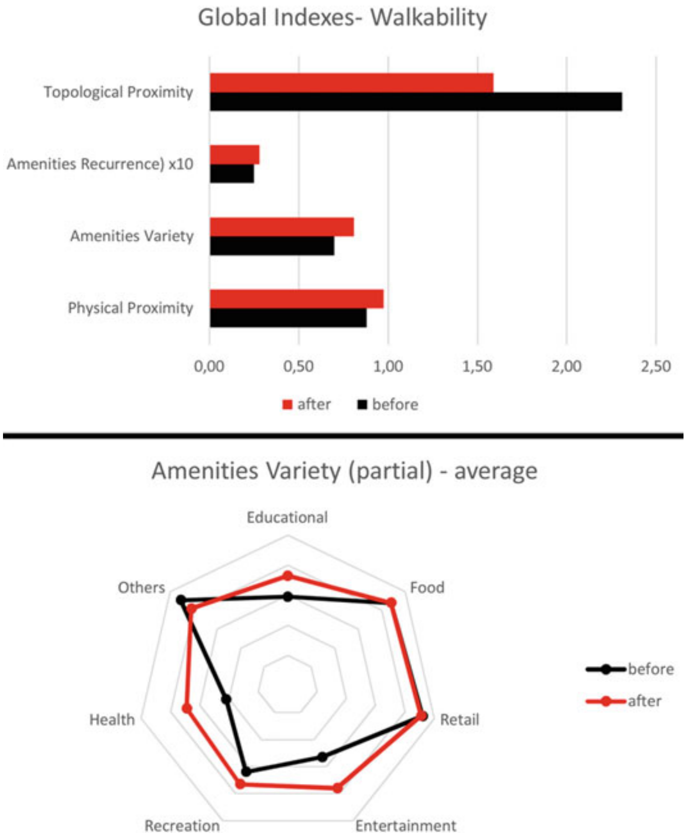


Fig. 9 Comparison of results: neighborhood's performance before (*in black*) and after (*in red*) Urbanmetrics implementation

district's configuration and the limitation of one station for it. Besides, the locations with worse station PPC scores were easily identifiable, which is a good starting point for further actions for transit accessibility improvement (the adoption of secondary modes for connecting these locations and the station, for example).

Multi-objective optimization addressed simultaneously multiple conflicting criteria for walkability related index answers, linking data and performing calculations that would be more difficult to perform by traditional means. While the PPC indexes considered only the nearest amenities, the AVC indexes considered all surrounding amenities, seeking a greater balance (Fig. 11). This trade-off context was a key for providing greater proximity, variety and recurrence indexes, meaning that services are nearer and in larger quantities along the district, which suggests more walkability. On the other hand, it also allowed one to see which areas of the district are better or less well supported in relation to different categories.

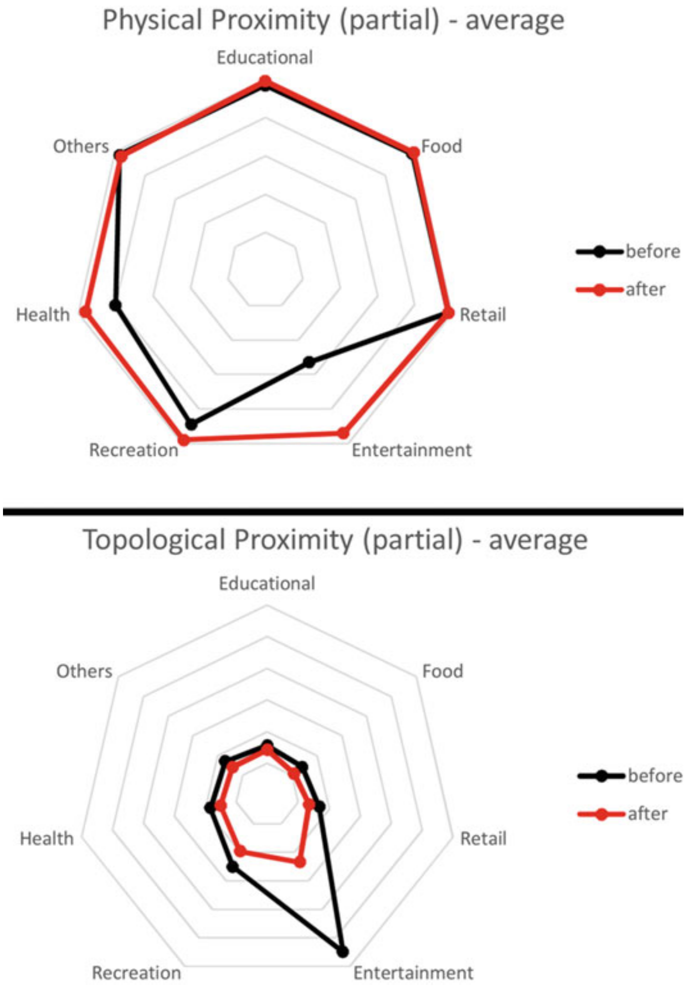


Fig. 10 Comparison of results: neighborhood's performance before (*in black*) and after (*in red*) Urbanmetrics implementation

Multi-objective optimization provided a set of solutions that are intended to be considered equally good (Pareto-optimal solutions). It is an important possibility for urban planning processes, as long as it strengthens the planners' role in considering 'nonprogrammable' aspects, for stipulating subjective criteria and priorities for decision making.

Despite of not being directly optimized, density indicators played an important role in this approach, as long as they enable the visualization and evaluation of different scenarios for vacant areas occupation, guiding interventions and giving hints from building potential and mix of uses distribution. The MXIC and SPC indicators proved to be useful in the algorithmic implementation of this approach,

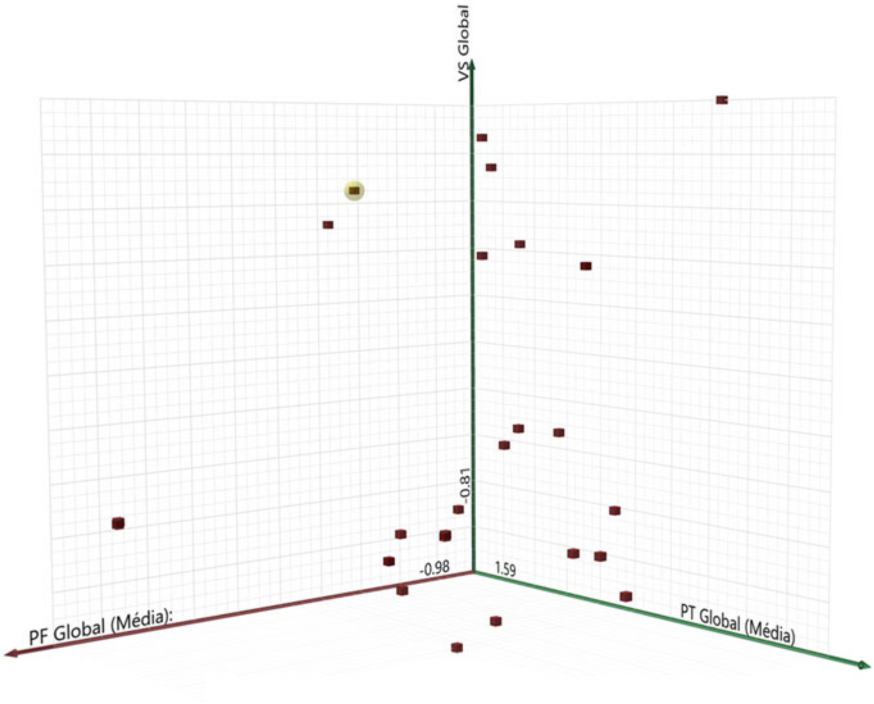


Fig. 11 Octopus optimization plugin results interface. Each *dot* in the graphic represents an optimized solution, within the Pareto frontier. The *axes* in the graphic represent each of the fitness functions adopted

given that they consider objective features for measuring diversity and density, respectively.

Despite the usefulness of a computational tool for supporting TOD-oriented urban planning processes through evaluation and optimization of specific urban features, we identify some limitations in the presented methodology. We recognize that Urbanmetrics does not fully incorporate the diverse features that can influence the measurable principles of an urban area, and for this reason, we emphasize that it is meant to be used as an instrument of recommendation.

This chapter presents a computational planning support methodology that seeks to facilitate the management of solutions in TOD planning processes, in order to delineate a starting point for computational approaches towards more efficient TOD proposals and also for smarter urban futures. Therefore, this study demonstrates the approach's potential towards a more efficient TOD implementation methodology, seeking the development of more autonomous and sustainable neighborhoods and cities.

Acknowledgements The authors would like to thank the Brazilian National Council for Scientific and Technological Development (CNPq), the Architecture, Urbanism and Design Investigation Center (CIAUD) from University of Lisbon and the post-graduation program in Urbanism from Federal University of Rio de Janeiro (PROURB), for supporting this research and the presentation of this work.

References

Allen, E. (2008). Clicking toward better outcomes: Experience with INDEX, 1994 to 2006. In R. Brail (Ed.), *Planning support systems for cities and regions* (pp. 139–166). Cambridge, MA: Lincoln Institute of Land Policy.

Bernstein, S. (2004). The new transit town: Great places and great nodes that works for everyone. In H. Dantzig & G. Ohland (Eds.), *The new transit town: Best practices in transit-oriented development* (pp. 232–248). Washington, DC: Island Press.

Calthorpe, P. (1993). *The next American metropolis: Ecology, community and the American dream*. New York: Princeton Architectural Press.

Calthorpe, P., & Fulton, W. (2001). *The regional city: Planning for the end of sprawl*. Washington, DC: Island Press.

Cervero, R., & Kockelman, K. (1997). Travel demand and the 3Ds: Density, diversity, and design. *Transportation Research Part D: Transport and Environment, 2,* 199–219.

Dittmar, H., Belzer, D., & Autler, G. (2004). An introduction to transit-oriented development. In H. Dittmar & G. Ohland (Eds.), (Org.). *The new transit town: Best practices in transit oriented development*. Washington, DC: Island Press.

Dittmar, H., & Ohland, G. (Eds.). (2004). *The new transit town: Best practices in transit-oriented development*. Washington, DC: Island Press.

Global Fuel Initiative. (2016). Available in: http://www.globalfueleconomy.org/

Hillier, B., & Hanson, J. (1984). *The social logic of space*. Cambridge: Cambridge University Press.

Hoek, J. (2008). The MXI (Mixed use Index). An instrument for anti-sprawl policy?. In *Proceedings of the 44th ISOCARP Congress 2008*.

Lima, F. T., Kos, J. R., & Paraízo, R. C. (2016). Algorithmic approach toward Transit-Oriented Development neighborhoods: (Para)metric tools for evaluating and proposing rapid transit-based districts. *International Journal of Architectural Computing, 14*(2), 131–146.

Pont, M. B., & Haupt, P. (2010). *Spacematrix: Space, density and urban form*. Rotterdam: NAi Publishers.

Suzuki, H., Cervero, R., & Iuchi, K. (2013). *Transforming cities with transit: Transit and land-use integration for sustainable urban development*. Washington, DC: Word Bank.

Vale, D. S. (2015). Transit-oriented development, integration of land use and transport, and pedestrian accessibility: Combining node-place model with pedestrian shed ratio to evaluate and classify station areas in Lisbon. *Journal of Transport Geography, 45,* 70–80.

World Health Organization. (2014). 7 million premature deaths annually linked to air pollution. Available at: http://www.who.int/mediacentre/news/releases/2014/air-pollution/en/

Chapter 4
Urban Activity Explorer: Visual Analytics and Planning Support Systems

Alireza Karduni, Isaac Cho, Ginette Wessel, Wewen Dou,
William Ribarsky and Eric Sauda

Abstract Urban Activity Explorer is a new prototype for a planning support system that uses visual analytics to understand mobile social media data. Mobile social media data are growing at an astounding rate and have been studied from a variety of perspectives. Our system consists of linked visualizations that include temporal, spatial and topical data, and is well suited for exploring multiple scenarios. It allows a wide latitude for exploration, verification and knowledge generation as a central feature of the system. For this work, we used a database of approximately 1,000,000 geolocated tweets over a two-month period in Los Angeles. Urban Activity Explorer's usage of visual analytic principles is uniquely suited to address the issues of inflexibility in data systems that led to planning support systems. We demonstrate that mobile social media can be a valuable and complementary source of information about the city.

Keywords Social media · Visual analytics · Planning support · Big data · Human activity

---

A. Karduni (✉) · E. Sauda
School of Architecture, University of North Carolina at Charlotte,
1306 Ivy Meadows Dr. #511, Charlotte, NC, USA
e-mail: akarduni@uncc.edu

E. Sauda
e-mail: ejsauda@uncc.edu

I. Cho · W. Dou · W. Ribarsky
Department of Computer Science, University of North Carolina at Charlotte, Charlotte, USA
e-mail: Icho1@uncc.edu

W. Dou
e-mail: Wdou1@uncc.edu

W. Ribarsky
e-mail: Ribarsky@uncc.edu

G. Wessel
School of Architecture, Art, and Historic Preservation,
Roger Williams University, Bristol, USA
e-mail: gwessel@rwu.edu

S. Geertman et al. (eds.), *Planning Support Science for Smarter Urban Futures*, Lecture Notes in Geoinformation and Cartography,
DOI 10.1007/978-3-319-57819-4_4

1 Introduction

Urban planning professionals address a diverse range of issues from public transportation and affordable housing to environmental sustainability and economic development. Urban planners' focus on solutions and policies that improve and optimize urban systems requires an understanding of complex and dynamic urban behavior. To help support decision-making about urban issues, analysts often turn to reports and information on prior trends and patterns of human activity, including commerce, mobility and lifestyle needs. However, existing sources of information about human behavior have significant limitations. Some sources offer a broad snapshot of these complexities with large time gaps (e.g., U.S. census is conducted every 10 years, and American Community Survey estimates are published every year); others are time consuming, expensive and offer only a small sample of the intended information (e.g., questionnaires with small sample sizes and public meetings with sparse attendance), and many present temporal, topical and spatial information separately with no effective way to understand them together.

The explosive growth of social media has resulted in a huge amount of data (e.g., more than 500 million tweets/day) (Twitter Usage Statistics—Internet Live Stats 2017). This offers new opportunities to analyze human activity. Mobile devices allow people to stay connected with others while recording a user's time, location, thoughts and interests. These traces of user activity generate large datasets with great potential for understanding aggregated behavior (Ruths and Pfeffer 2014). Making sense of these large-scale datasets, however, requires the use of new techniques. Our work proposes the use of visual analytics, a field of analytical reasoning facilitated by interactive visual interfaces coupled with computational techniques. Visual analytics is a rapidly growing subfield of computer science that has evolved from information visualization and analytic reasoning with a particular focus on interaction. It has made inroads in managing cognitive load, pattern recognition and search procedures, particularly in very large data sets (Thomas and Cook 2006). A primary goal of our work is to provide planners with opportunities to manage and interpret unique, large-scale data sets such as those generated from social media.

Our research is focused on developing a Visual Analytics Systems (VAS) that presents spatial, temporal and topical information simultaneously and allows for feedback from experts in an easy-to-use web-based platform. Our system is designed to allow users to explore disparate forms and patterns of information, as opposed to a top-down system with fixed and predetermined capacities, evaluative criteria and outcomes. Our exploratory approach allows participants to gather a variety of insights about a single topic by using diverse, inter-related types of information. Previously, we conducted a survey among design and planning professionals to determine their workplace and research needs in software. This information guided the first version of our Visual Analytics Interface called the Urban Space Explorer. This interface was designed for exploration of the spatial, temporal and topical aspects of social media data as a proxy for human activity.

Following the development of our visual analytics system, we conducted a comprehensive user study of planning researchers and practitioners to gain feedback regarding the usability of our system.

This chapter focuses on our ongoing efforts to develop and improve our interface for planning professionals. The Urban Activity Explorer provides planners with a variety of tools to explore cities according to their specialized interests as well as to annotate and add knowledge back to the system. Urban Activity Explorer's new features include searching for specific terms in the dataset, focusing on a specific region and exploring topical and temporal data within that region, and annotating information in specified regions and then retrieving those annotations at a later time. These advancements contribute to our larger effort to develop an exploratory interface for planning professionals using unique, large-scale data.

We begin with a review of scholarship on social media, Planning Support Systems (PSS) and Visual Analytics Systems (VAS), and explain how these domains influence and are incorporated into our work. Next, we describe the variety of features within the interface that offer users new methods to explore large-scale data in relation to their interests. Finally, we will conclude by describing our next steps and challenges to further test and improve our research.

2 Literature Review

2.1 Social Media

The explosive growth of mobile devices and social media in the recent years has created new opportunities for people to communicate and interact as they live and move within cities. Data communicated through social media services such as Twitter, Instagram, Foursquare and Facebook, in contrast to previous data sources and methods, are continuously produced by diverse populations during the course of their everyday activities. It is this aspect of our work that can be described as predominately 'bottom up', in contrast to the many existing methods that are 'top down' (e.g., U.S. census data). These data are very rich in terms of time granularity, content, geographic information and availability. Utilizing these data sources can create new streaming (i.e., approaching real time) methods for understanding complex aspects of human activity in cities. Analyzing and utilizing these large and unstructured datasets for urban analysis has many challenges and requires new methods in computation and data analysis (Kitchin 2013).

Different methods have been created to obtain new knowledge from social media in different domains. Shakaki et al. (2010) used real time Twitter data to sense occurrences of extreme events by considering each Twitter user a 'sensor' and using various location estimation methods to find centers of earthquakes in Japan so that notifications could be sent to registered users. Topic modeling and event detection have been used by Dou et al. (2012) to sense and tell the story of Occupy

Wall Street protest events. Other notable applications of social media data include news extraction for journalistic inquiry (Diakopoulos et al. 2010), situational awareness and crisis management (MacEachren et al. 2011), and summarizing important political issues from the perspective of political institutions (Stieglitz and Dang-Xuan 2013).

Many urban scholars have utilized data derived from social media services and mobile devices to shed light on various urban phenomena. Researchers at MIT's Senseable City Lab utilized Location Based Services (LBS) data from cellphone towers to map the intensity of activity across time and space (Ratti et al. 2006). Wessel studied how social media, place and food networks interact and overlap with each other and can ultimately transform the meaning of place (Wessel 2012). Location information from social media has also been used to identify active city centers in regions (Sun et al. 2016).

These are a few examples of sophisticated analyses conducted using social media data in urban settings. However, these methods and data sources are not easily accessible to urban planners and researchers and are not yet geared towards their goals and needs.

2.2 Planning Support Systems

Urban planners have historically relied on various forms of Geographic Information Systems (GIS), urban modeling, and statistical software with the hopes of making more accurate planning and policy decisions. Klosterman traces the historical development of software used by planners from faith in large-scale urban models in the 1960s, to microprocessor-based programs in the 1980s, to the widespread availability of GIS programs in the 1990s (Klosterman 1997). He makes the case for PSS as an "*information framework that integrates the full range of current (and future) information technologies useful for planning*" (Klosterman and Pettit 2005, p. 477). More specifically, PSS are dedicated to planners' analytic, forecasting, or design tasks that fit within the workflow of planning professionals (Harris and Batty 1993). The diversity of PSS types and techniques include large-scale urban models, rule-based models, state-change models, and cellular automata models. These PSS provide planners with tools to investigate land-use change, comprehensive projections, three-dimensional visualization, and impact assessment.

We hope to build upon the work of PSS by recognizing that in order for pervasive large-scale data sets and analytic methods to benefit the planning profession, PSS must adapt to planners' specific needs and provide planners with flexible exploration among datasets. We view PSS as an opportunity to address multiple planning concerns in an intuitive manner. We developed a software tool that allows planners to interpret valuable social media data as a proxy for elements of cities integral to their tasks. By accessing publicly available social media data, we hope to expand upon the idea of Volunteered Geographic Information Systems (VGIS) and the idea of humans as social sensors (Goodchild 2007) by sensing patterns and meaning from the unstructured data streaming in the real world. We also aim to enable interpretation and collaboration between planners by allowing annotations to be shared. Finally, our system does not focus on future projections, instead seeking to understand present patterns of behavior.

2.3 Visual Analytic Systems

Interactive VAS are a form of analytical reasoning facilitated by interactive visual interfaces coupled with computational methods such as machine learning, pattern recognition and statistical analysis. Important features include the ability to deal with high-dimensional data sets, present information visually, and allow users to interact with this information thereby building knowledge and decision-making capability. Visual analytics assumes analysis is better undertaken as a symbiosis between the computational power of computers and the sense-making capacity of human users (Keim et al. 2008). These types of interfaces have been created to allow for exploration of very large datasets with a diverse range of goals. Vairoma and Wirevis are examples of VAS; Vairoma combines topical, spatial and temporal analyses of Rome in a multi-view interface to enable historians to easily navigate related articles from multiple perspectives (Cho et al. 2016); Wirevis allows for analysis of financial transaction data and uses wire tags to identify suspicious behavior (Chang et al. 2007). Current research on VAS focuses on the cognitive processes of the user and emphasizes the need for a process of user exploration starting with discovery, leading to verification and ultimately to knowledge creation (Chen et al. 2009). This approach is consistent with the underlying desire for PSS to develop systems that are responsive to users' expertise, evaluation and input.

Our system aims to use the lessons learned from advancements in VAS and PSS by iteratively learning from professional usage and getting feedback from users, as well as introducing novel big data analytics methods for understanding human behavior from social media data.

3 Urban Activity Explorer

Urban Activity Explorer evolved from research on our previous system based on feedback from planning researchers and professionals (Karduni et al. 2017). In order to utilize the richness of social media data and its potential for understanding human activities within cities, our team created a visual analytics interface by first conducting a survey of 96 urban planning and design professionals. The survey helped us to identify their main data and information needs and how social media data can be used to alleviate those needs. We then incorporated those findings within the first version of our system called Urban Space Explorer. Urban Space Explorer was a web-based multi-view interface that allowed users to explore geolocated tweet data in Los Angeles. Our system allowed the user to explore the dataset through multiple interlinked views. Interaction with each of the views would change the state of other views to allow the users to explore different spatial and temporal aspects of the dataset. The multiple views of Urban Space Explorer included: activity density, a flow of Twitter users view, a word cloud, a flow and tweet timeline, language and tweet topics.

The activity density view was created as a proxy for concentrations of different kinds of social media activity (Fig. 1(1)). The view utilized a dynamic heatmap visualization that updated based on the current scale of the map. This feature enabled the users to dynamically study densities from different scales. The timeline view showed the number of tweets per hour for a day and the word cloud highlighted the most frequent keywords. Zooming in and out on the map would update the timeline and word cloud visualization to correspond only to the observed area (Figs. 1(2) and 1(3)). Selecting a time range would consecutively show a heatmap of density for the selected time. The heatmap would also respond to a set of pre-calculated topics which were derived from the tweets using the Latent Dirichlet Allocation algorithm (Blei et al. 2003). The user could select each topic and view a heatmap, timeline, and word cloud corresponding to that specific topic (Fig. 1(6.5)).

To model the flow of users we created a new method that utilized Djistra's shortest path algorithm (Dijkstra 1959) on the street network using GISF2E (Karduni et al. 2016) to create a network from OpenStreetMap data and ArcPy to calculate the shortest paths between a series of locations for each user (see https://goo.gl/jfrdIc). The method allowed us to visualize a large number of trajectory data derived from the locations of users by calculating the shortest path between consecutive tweet points on the street network (Fig. 1(4)). Moreover, our system afforded studying a specific region as the origin or destination of tweet users by viewing the lines which flow into the region or out of the region. To complement the flow map, we created a visualization that encoded the start and end points of

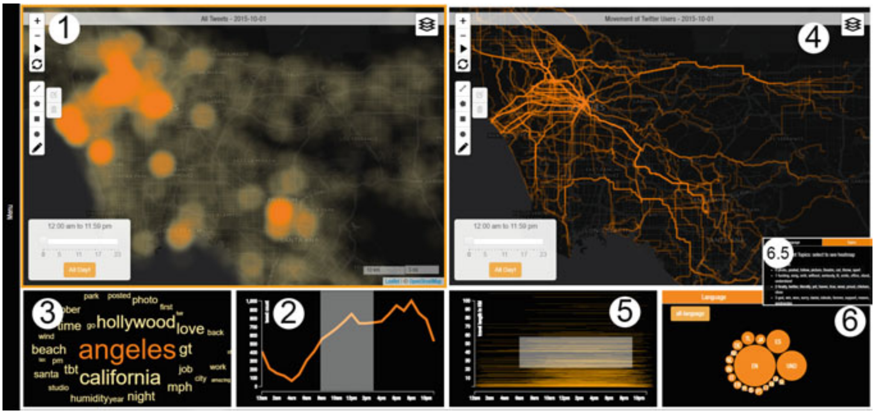


Fig. 1 Urban Space Explorer user interface

movement at the x axis and the length of travel at the y axis. This allowed users to simultaneously query time of travel as well as length of travel (Fig. 1(5)). Our system also enabled users to study the movements of Twitter users who tweeted in different languages (Fig. 1(6)). Other notable affordances of Urban Space Explorer include a time slider and animation for both flow and density, synchronized map views, changing background layers, the ability to add graphic overlaps, and a calendar to change the day of the dataset.

The development of Urban Activity Explorer as a system specifically tailored to PSS began as a follow-up to the implementation and user studies of our earlier system. We conducted a series of user studies to understand the degree of usefulness of our application and how it can be incorporated within the workflow of urban planners. Most of our study participants were interested in incorporating our interface and social media data within their tasks. However, the purely exploratory nature of Urban Space Explorer would not allow users to focus on a specific domain problem. In order to improve our system, we introduced a navigation bar with a search box that would allow users to input terms and create visualizations. User's interactions for this new feature include (Fig. 2):

A. Type a keyword in the search box and click submit.
B. View heatmap, timeline, and word cloud related to tweets containing the keyword[s].

Our users were also interested in conducting before-and-after analysis for specific events or areas to observe the reflections of a policy, design, or event through social media data. In response, we developed a tool to allow users to view tweets before and after a certain time in a specific region (Fig. 3A–D). User's interactions for this new feature are:

A. Draw a polygon on any area and click.
B. A dialog box appears with a timeline for all the tweets in that region.
C. Select a time range on the context graph, which updates the main time graph.
D. View the word cloud for that time range for a selected area.

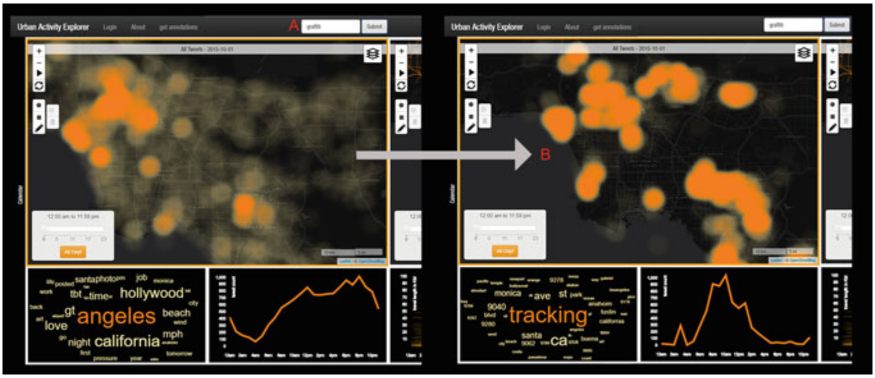
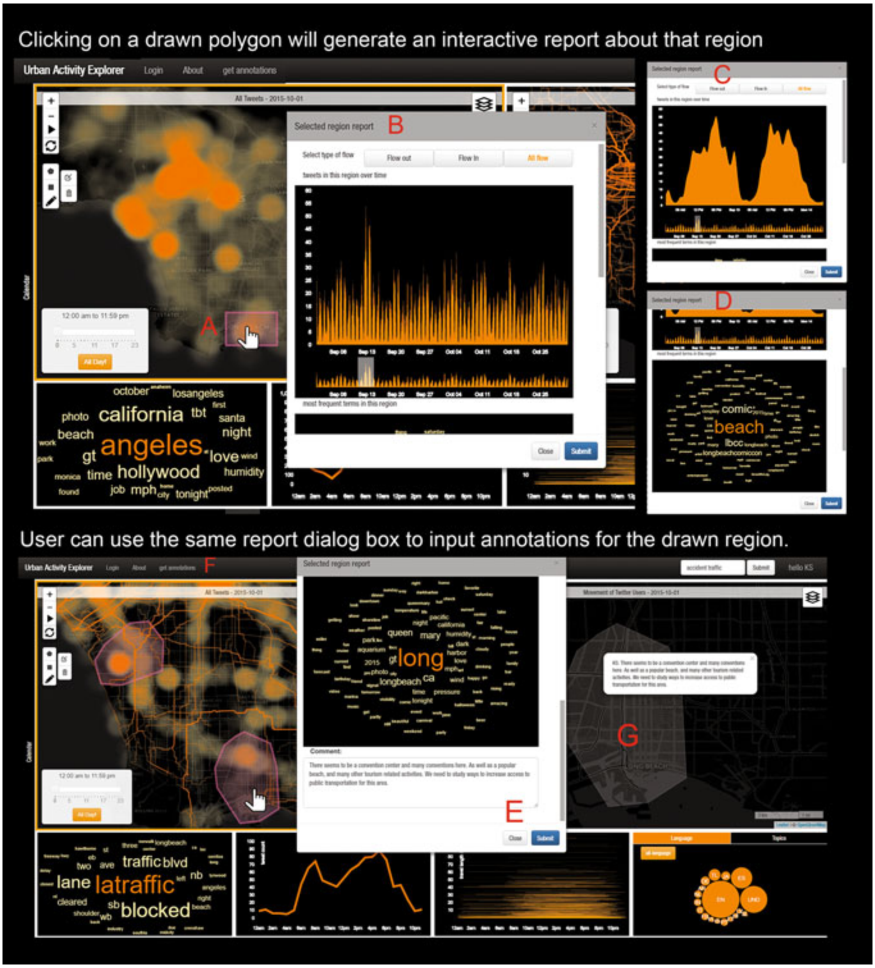


Fig. 2 Searching for terms in Urban Activity Explorer


Clicking on a drawn polygon will generate an interactive report about that region

User can use the same report dialog box to input annotations for the drawn region.

Comment:

There seems to be a convention center and many conventions here. As well as a popular beach, and many other tourism related activities. We need to study ways to increase access to public transportation for this area.

Fig. 3 Focusing on a specific region, getting reports for that region, and annotating that region

Last, the user study revealed the planners' need to save and share their knowledge and findings. Urban Activity Explorer now affords annotation, saving and sharing the results with other users (Fig. 3E–G). After logging into our system, the user can input and save annotations by:

E. Using any drawn polygon dialog box, the logged-in user can insert annotations for that specific area.
F. A logged-in user can click on the "get annotations" button on the top navigation bar and view previously annotated areas on the map.
G. Clicking on each area will reveal the annotation.

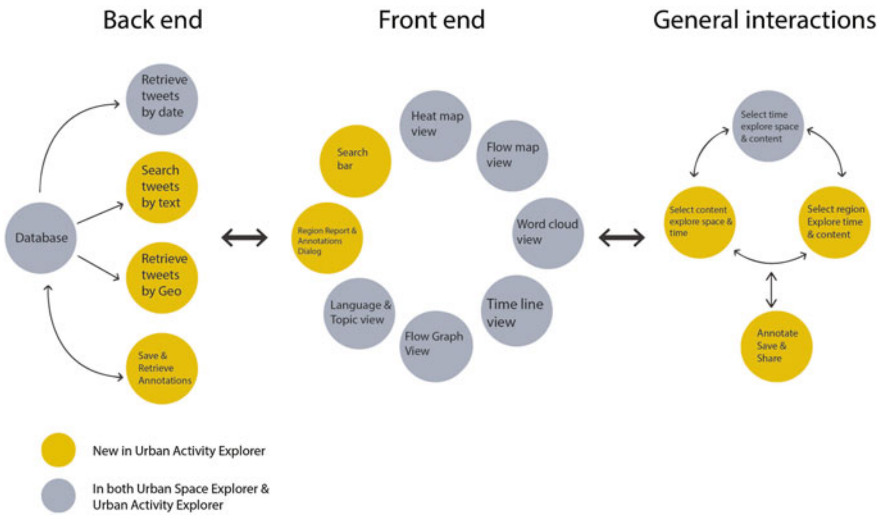


Fig. 4 General structure and interactions of Urban Activity Explorer

Aside from these new features in Urban Activity Explorer, there are modifications that were made in response to our user studies to ensure the system is as usable and intuitive as possible. These modifications include:

- the user can now visualize flow data for a desired tweet language for all of the dataset in contrast to only a single day in the previous version;
- the origin destination buttons for visualizing flows in and out of a drawn area are now moved to the report dialog created in Urban Activity Explorer; and
- all drawn layers and annotations can be toggled off and on.

In Urban Space Explorer, users had the ability to select a specific day or time, and then explore relationships between different aspects of social media data. Urban Activity Explorer adds features so that users can now select a region and explore both time and content. They can search for specific content and then explore space and time related those content. Furthermore, the user can annotate Urban Activity Explorer and retrieve their findings in the future. Figure 4 shows the general structure of our system.

4 Urban Activity Explorer and PSS

We have designed Urban Activity Explorer to study human activity by tapping into the vast potentials of social media data. Our goal is to develop an interface that serves the needs of diverse planning professionals. To illustrate the capabilities of our system, the following includes example situations that a planner may encounter, some of which are derived from our previous user studies with planners.

A city transportation manager would like to study urban areas with high traffic and frequent accidents. By searching the terms “traffic” and “accident”, the user can view a geographic map of all tweets that contain those keywords. The map highlights tweets around major arterials, as well as highly dense regions. The user can explore tweet content to find major reoccurring events and activities that might cause high traffic and in consequence high accidents. Furthermore, the user can focus on each of the regions and find time ranges during which more accidents have happened. Using the annotation system, the user can save the findings and share with others.

In addition to transit related issues, other uses of our system may include identifying areas with a positive or negative response to murals and public art to allocate future funding, surveying tweets in urban areas and main streets for signs of struggling business activity to determine areas in need of reinvestment, reviewing patterns of migration across time among different cultural groups to plan for future housing development, evaluating the quality and use of open spaces and parks to efficiently allocate custodians and resources, and identifying areas with an established pedestrian realm and potential market for introducing bike share systems or locating bike paths.

We recognize that urban planning is a very diverse profession with many specialized tasks. Our system uses open source technology and can be applied to other datasets and can therefore bring the powers of a visual analytics system to many planning tasks. Our system is open source and we invite individuals or organizations to use or adapt our system with other datasets.

5 Conclusions and Future Work

We have demonstrated the unique advantages that Urban Activity Explorer offers as a PSS. First, Urban Activity Explorer is a bottom-up tool, using heterogeneous data collected by social media without pre-judging the important issues from above. While this approach can be difficult computationally, we demonstrate how the use of a sophisticated VAS can overcome these difficulties. This presents us with two important advantages over top-down systems: we can understand emergent issues that can easily be missed by goals and methods decided in advance, and the ability to obtain data already streaming in abundance can allow our system to respond quickly. While our system currently does not work with streaming data, our team is working to create a version of Urban Activity Explorer which handles streaming data from social media.

Second, social media data is unique in that it presents temporal, spatial and topical information together. This affords us the opportunity to discover linkages and meanings that are often obscured by rigid isolation of data on incompatible layers. Social media data are messy, but they are intrinsically interconnected. Our interface includes advanced data analytic methods not previously accessible to planners in a system that is easy to use and does not require advanced technical knowledge by the user. Moreover, Social media brings about some attention worthy risks including privacy of users' data and low quality and accuracy information such as fake news or bot created content. Our system only focuses on aggregations of publicly available data, hence minimizing the risks of individuals' privacy. Important future steps include further anonymization of data and utilizing automated methods to better guarantee the accuracy of the information.

Third, visual analytics offers a rich field of scholarship for understanding how human users and computational power can work together in a complementary system. The rapid development of knowledge discovery within visual analytics is particularly important to PSS, as it provides theoretical overview and practical methods for providing the kind of support that will allow the integration of meaningful computation to the complex issues facing planners.

Several important issues remain unresolved. Unlike earlier systems such as GIS, implementation of VAS systems as PSS will unlikely to be sponsored by a single government or organization. The nature of social media data is so heterogeneous that they will probably not supplant earlier systems, but will rather add an ability for exploration and nuance that can be stifled by top-down systems. Urban Activity Explorer is open source to make widespread implementation possible, but we foresee a series of systems operating in parallel rather than a single unified system.

Finally, verification of our preliminary findings will need to be done to study our assumption concerning the relationship of the available social media data to broader behavior in the city. All mobile social data sources have built-in strengths, limits and occlusions that must be explicitly considered. Our analysis of Twitter data correlating geo-located tweets (2% of the total) with all tweets must be verified to support the generalization of our spatial analysis. An ethnographic study 'in the wild' of social media users will begin soon with the goal of understanding the frequency of tweets and the relationship of tweets to face-to-face communication, spatial location, and movement. In the end, planners must understand not data alone, but humans and data together.

References

Blei, D. M., Ng, A. Y., & Jordan, M. I. (2003, January). Latent dirichlet allocation. *Journal of Machine Learning Research, 3,* 993–1022.

Chang, R., Ghoniem, M., Kosara, R., Ribarsky, W., Yang, J., Suma, E., et al. (2007). Wirevis: Visualization of categorical, time-varying data from financial transactions. In *IEEE Symposium on Visual Analytics Science and Technology, 2007, VAST 2007* (pp. 155–162). IEEE.

Chen, M., Ebert, D., Hagen, H., Laramee, R. S., Van Liere, R., Ma, K.-L., et al. (2009). Data, information, and knowledge in visualization. *IEEE Computer Graphics and Applications, 29*(1), 12–19.

Cho, I., Dou, W., Wang, D. X., Sauda, E., & Ribarsky, W. (2016). VAiRoma: A visual analytics system for making sense of places, times, and events in roman history. *IEEE Transactions on Visualization and Computer Graphics, 22*(1), 210–219.

Diakopoulos, N., Naaman, M., & Kivran-Swaine, F. (2010). Diamonds in the rough: Social media visual analytics for journalistic inquiry. In *IEEE Symposium on Visual Analytics Science and Technology (VAST), 2010* (pp. 115–122). IEEE.

Dijkstra, E. W. (1959). A note on two problems in connexion with graphs. *Numerische Mathematik, 1*(1), 269–271.

Dou, W., Wang, X., Skau, D., Ribarsky, W., & Zhou, M. X. (2012). Leadline: Interactive visual analysis of text data through event identification and exploration. In *IEEE Conference on Visual Analytics Science and Technology (VAST), 2012* (pp. 93–102). IEEE.

Goodchild, M. F. (2007). Citizens as sensors: The world of volunteered geography. *GeoJournal, 69*(4), 211–221.

Harris, B., & Batty, M. (1993). Locational models, geographic information and planning support systems. *Journal of Planning Education and Research, 12*(3), 184–198.

Karduni, A., Kermanshah, A., & Derrible, S. (2016). A protocol to convert spatial polyline data to network formats and applications to world urban road networks. *Scientific Data, 3*(160046). doi:10.1038/sdata.2016.46

Karduni, A., Cho, I., Wessel, G., Ribarsky, W., Sauda, E., Dou, W. (2017). Urban space explorer: A visual analytics system for understanding urban social media activities. *IEEE Computer Graphics and Applications—Special Issue Geographic Data Science*.

Keim, D., Andrienko, G., Fekete, J.-D., Görg, C., Kohlhammer, J., & Melançon, G. (2008). Visual analytics: Definition, process, and challenges. In A. Kerren, J. Stasko, J.-D. Fekete, & C. North (Eds.), *Information Visualization Human-Centered Issues and Perspectives* (pp. 154–175). Lecture Notes in Computer Science 4950. Berlin: Springer.

Kitchin, R. (2013). Big data and human geography: Opportunities, challenges and risks. *Dialogues in Human Geography, 3*(3), 262–267.

Klosterman, R. E. (1997). Planning support systems: A new perspective on computer-aided planning. *Journal of Planning Education and Research, 17*(1), 45–54.

Klosterman, R. E., & Pettit, C. J. (2005). An update on planning support systems. *Environment and Planning B: Planning and Design, 32*(4), 477–484.

MacEachren, A. M., Jaiswal, A., Robinson, A. C., Pezanowski, S., Savelyev, A., Mitra, P. et al. (2011). Senseplace2: Geotwitter analytics support for situational awareness. In *IEEE Conference on Visual Analytics Science and Technology (VAST), 2011* (pp. 181–190). IEEE.

Ratti, C., Frenchman, D., Pulselli, R. M., & Williams, S. (2006). Mobile landscapes: Using location data from cell phones for urban analysis. *Environment and Planning B: Planning and Design, 33*(5), 727–748.

Ruths, D., & Pfeffer, J. (2014). Social media for large studies of behavior. *Science, 346*(6213), 1063–1064.

Sakaki, T., Okazaki, M., & Matsuo, Y. (2010). Earthquake shakes Twitter users: Real-time event detection by social sensors. In *Proceedings of the 19th International Conference on World Wide Web, 2010* (pp. 851–860). ACM.

Stieglitz, S., & Dang-Xuan, L. (2013). Social media and political communication: A social media analytics framework. *Social Network Analysis and Mining, 3*(4), 1277–1291.

Sun, Y., Fan, H., Li, M., & Zipf, A. (2016). Identifying the city center using human travel flows generated from location-based social networking data. *Environment and Planning B: Planning and Design, 43*(3), 480–498.

Thomas, J. J., & Cook, K. A. (2006). A visual analytics agenda. *IEEE Computer Graphics and Applications, 26*(1), 10–13.

Twitter Usage Statistics—Internet Live Stats. (2017). http://www.internetlivestats.com/twitter-statistics/

Wessel, G. (2012). From place to nonplace: A case study of social media and contemporary food trucks. *Journal of Urban Design, 17*(4), 511–531.

Chapter 5
A Decision Support System for Fighting Multiple Fires in Urban Areas Caused by Large Earthquakes

Toshihiro Osaragi and Noriaki Hirokawa

Abstract Extinguishing multiple fires resulting from large earthquakes is particularly difficult because such fires break out simultaneously in numerous locations. Therefore, effective disaster mitigation requires immediate identification of those fires that are most likely to spread widely. In this chapter, a Fire-Spread Potential (FSP) index, which defines the number of other buildings that could be expected to be destroyed by fire-spread from particular buildings, is calculated and applied to an aftermath simulation of a hypothetical scenario. We then constructed an agent-based simulation model to describe firefighter activities and used the FSP values to evaluate the decision-making support needed to fight multiple fires simultaneously. The chapter demonstrates that FSP values could be effectively used for firefighter decision-making support in order to identify high-risk buildings, thereby mitigating the disaster.

Keywords Multiple fires · Large earthquake · Effective disaster mitigation · Fire Spread Potential · Firefighter activity · Decision making support

1 Introduction

1.1 Research Background

Dealing with multiple simultaneous fires in the aftermath of a large earthquake is a daunting task, and there will exist areas where more fires are expected than local firefighting capabilities can guarantee will be brought under control. Therefore, in order to minimize total fire damage, it is essential that fires be fought in order of

---

T. Osaragi (✉) · N. Hirokawa
School of Environment and Society, Tokyo Institute of Technology,
2-12-1-M1-25 Ookayama, Meguro-ku, Tokyo 152-8552, Japan
e-mail: osaragi.t.aa@m.titech.ac.jp

N. Hirokawa
e-mail: hirokawa.n.aa@m.titech.ac.jp

S. Geertman et al. (eds.), *Planning Support Science for Smarter Urban Futures*, Lecture Notes in Geoinformation and Cartography,
DOI 10.1007/978-3-319-57819-4_5

priority, where that priority is determined according to the expected extent of damage if a fire is left unchecked. Hence, we need to develop a Decision Support System (DSS) for fighting multiple fires in urban areas when a large earthquake occurs.

For firefighting operations, the Tokyo Fire Department (TFD) classifies the entire Tokyo Metropolitan Area according to priority (earthquake firefighting zones 1–5) based on factors such as the Fire-Risk Rank (Tokyo Fire Department 2013, Tokyo Metropolitan Government 2013). Its strategy is to immediately combat fires starting in Zones 1 and 2, which are in the vicinity of evacuation sites, and in other cases, to combat fires in high-priority zones after a certain standby period.

Fujii and Itoigawa (2005) analyzed the relationship between firefighting operational procedures (priority) and fire-spread area, and demonstrated the importance of fighting fires in order of fire-spread risk when the number of fires predicted is greater than the number of fire engines. They modeled urban areas using earthquake firefighting zones and a 250 m grid to increase simulation speed, but they did not consider the fire resistance levels of individual buildings or the characteristics of the urban area.

In contrast, Sasaki and Sekizawa (2014) examined a method for determining firefighter destinations based on the fire-spread risks of buildings. More specifically, they examined a method for determining on which building firefighters should focus their efforts by estimating the number of buildings that would be destroyed by fire after a certain time. While the perspectives and relationships in their paper are extremely useful, their discussion is based on the results of simulations of conflagration spread up to two hours after an initial fire outbreak, and the study does not examine fire damage when fires are left to take their own course. Additionally, they assume that information on the location of buildings can be identified, which does not allow for the information uncertainty in the chaos that follows a large earthquake.

Research on predicting damage due to fire-spread can be broadly divided into methods based on fire-spread simulations carried out by the TFD (2001) and Himoto and Tanaka (2006), and a method based on fire-spread clusters carried out by Kato et al. (2006). Furthermore, the fire-spread simulation models can be broadly classified as empirical models based on large urban fire historical data and theoretical models using physics-based knowledge.

For example, while the elaborate model developed by Himoto and Tanaka (2006) can take into account the spread of fire through openings and due to, for example, the scattering of sparks, it requires a large amount of data, and is difficult to apply to extensive urban areas. The fire-spread cluster model (Kato et al. 2006) uses fire-spread limit distances to identify groups of buildings with high potential of fire-spread, also known as fire-spread clusters, and the computation load is small. However, the model cannot take account of factors such as wind direction and speed, earthquake epicenter variations, and variations in fire-spread direction.

1.2 Research Objectives

In this chapter, we propose a Fire-Spread Potential (FSP) index for individual buildings to assist the fighting of multiple simultaneous fires occurring in the aftermath of a large earthquake. We also verify the effectiveness of a method for determining where firefighters will focus their efforts using these indices. Specifically, we do the following: (1) construct a fire-spread simulation model that takes into account fire-spread direction, wind direction/wind speed, *et cetera*; (2) propose FSPs for each building based on the results of fire-spread simulations; (3) verify the reduction in the number of buildings destroyed by fire when firefighters combat fires in order of decreasing building-level FSP in the aftermath of a large earthquake; and (4) examine situations in which the reported location of the burning building is imprecise, given the chaos occurring in the aftermath of a large earthquake.

2 FSP and Burn-Down Potential (BDP)

2.1 Outline of Fire-Spread Simulation Model

The fire-spread simulation model was constructed using fire-spread limit distances from the heat-emitting buildings (Iwami et al. 2006) and a fire-spread speed model (TFD 2001). More specifically, groups of buildings to which fire may spread from a burning building are first extracted based on the fire-spread limit distances, and connected to networks by fire-spread routes. In such situations, since FSP depends on the construction materials/fire resistance levels of the buildings on the heat-emitting and heat-receiving sides, the network of fire-spread routes is directional.

For example, fire spreads easily from wooden to fire-resistant buildings, whereas it spreads with difficulty from fire-resistant to wooden buildings (Fig. 1). Next, fire-spread speed equations are used to estimate whether a fire will spread. The fire-spread speed equations consist of an equation for the speed of fire-spread inside

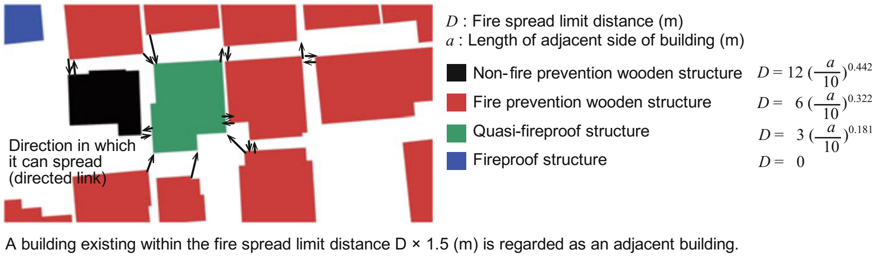


Fig. 1 Relationships between adjacent buildings due to fire-spread limit distance

a building and an equation for the speed of fire-spread between neighboring buildings.

The speed of fire-spread inside a building is estimated from its fire resistance level, building use, building side length (approximately, the square root of the building area), wind speed, and maximum ground surface acceleration (Si and Midorikawa 1999; Midorikawa et al. 1994; Hirokawa and Osaragi 2016). The speed of fire-spread between neighboring buildings is estimated from its fire resistance level and building use on the heat-emitting and heat-receiving sides, wind speed, maximum acceleration at ground surface, and number of stories.

In this chapter, a large-scale fire-spread simulation is implemented by calculating the time at which a neighboring building ignites using the fire-spread speed and the distance between neighboring buildings, and then searching for the fire-spread routes that give the shortest times to ignition in the fire-spread route network. However, since wind direction/speed and heat received from multiple buildings are not taken into account in the fire-spread limit distances (Iwami et al. 2006), for convenience, their underestimation is dealt with by multiplying the fire-spread limit distances by 1.5.

2.2 *Outline of Fire-Outbreak Model*

For the fire outbreak probability of each building, values estimated by the TFD according to building use, measured seismic intensity, season/time period, and whether or not the building collapses (TFD 1997, 2005) are used. There are a total of 19 building-use categories, and measured seismic intensity is estimated using surface ground characteristics and distance from epicenter at the building site (Fujimoto and Midorikawa 2005).

2.3 *FSP Definition*

FSP is defined as the total number of buildings destroyed by fire when fire breaks out in one building (B_i) if the fire is left to take its own course. In other words, the FSP of building B_i can be estimated by assuming that it is the origin of the fire and then simulating the spread of the fire until it does not advance any further (Fig. 2).

$$FSP_i = \sum_{j=1}^{n} d_{ij} \tag{1}$$

where d_{ij} is the variable whose value is 1 if the fire from building B_i reaches building B_j, 0 if not.

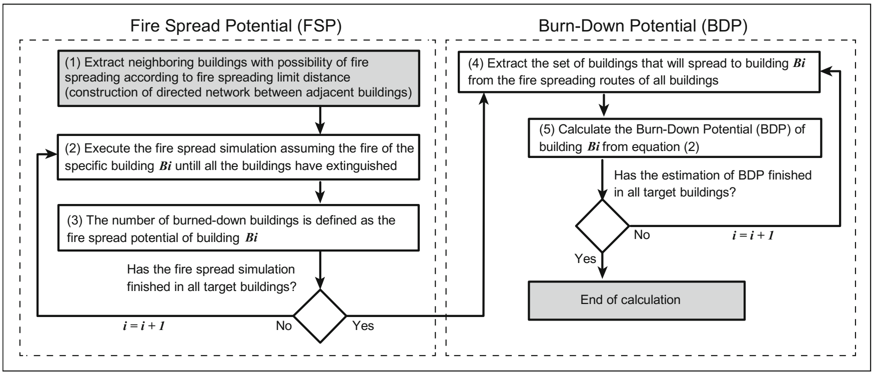


Fig. 2 Calculation procedure of FSP and BDP

2.4 BDP Definition

The BDP of building B_i is defined by the following equation:

$$BDP_i = 1 - \prod_{k=1}^{n} (1 - q_k) d_{ki} \tag{2}$$

where q_k is the fire outbreak probabilities of building B_k. The value of d_{ki} is already obtained when finding the FSP. Hence, there is no need to carry out the fire-spread simulation again (Fig. 2).

3 FSP and BDP Estimation Results

3.1 Study Area and Simulation Assumptions

Fire-spread is simulated with regard to all buildings within the Tokyo Metropolitan Area (2,784,123 buildings). The wind is assumed to be from the north with a speed of 8 m/s, and the fire outbreak is assumed to occur on a winter evening, which is when the greatest number of fires take place. Additionally, to make the influence of ground properties and characteristics of the urban area easier to understand, rather than assuming a specific epicenter, it is assumed that seismic waves arrive at a uniform speed of 30 cm/s in the engineering bedrock (TFD 2013; Tokyo Metropolitan Government 2013).

3.2 Spatial Distribution of Mean Number of Fires and Total Number of Fire Engines

Figure 3 shows the spatial distribution of the mean number of fires (from 1,000 fire-outbreak simulations), as well as the spatial distribution of that value minus the total number of fire engines in each fire department's jurisdiction. In approximately half of the jurisdictions, the number of fires is 10 or more greater than the total number of fire engines, and in some jurisdictions, the number of fires is 30 or more greater than the total number of fire engines.

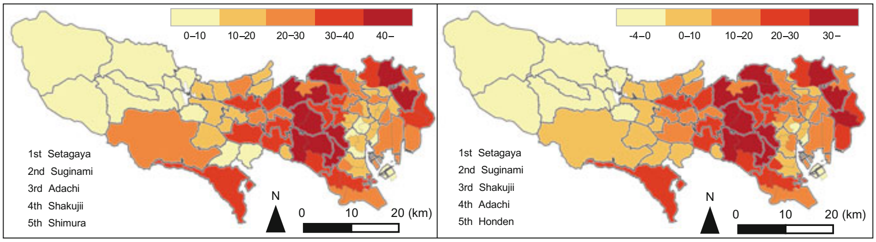
In these areas, it is highly likely that there will be insufficient firefighting capability when multiple simultaneous fires occur, so there is a strong need for enhancement of firefighting capability and reasoned selection of those buildings that are given priority during firefighting.

3.3 FSP Estimation Results

Figure 4a shows the spatial distribution of FSP (mean value in 500 m grid). In, for example, Nogata and Oi, a mean of 300 or more buildings could burn down as a result of a fire outbreak in just one building. The risk is particularly high in jurisdictions where the number of fires is greater than the total number of fire engines (Fig. 3b) and the FSP is high.

3.4 BDP Estimation Results and Fire Risk Comparison

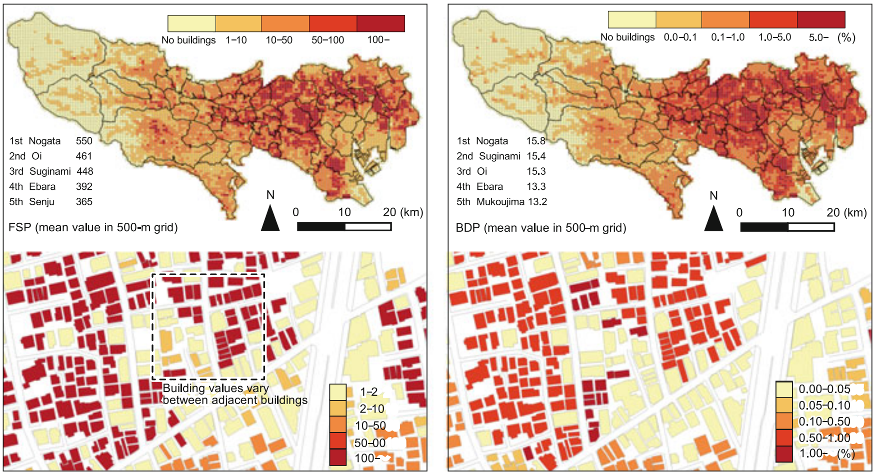
Figure 4b shows the spatial distribution of BDP (mean value in 500 m grid), while Fig. 5a shows the ratios obtained by dividing BDP by fire outbreak probability. In



(a) Spatial distribution of the number of fire outbreaks (mean value in a firefighting jurisdiction)

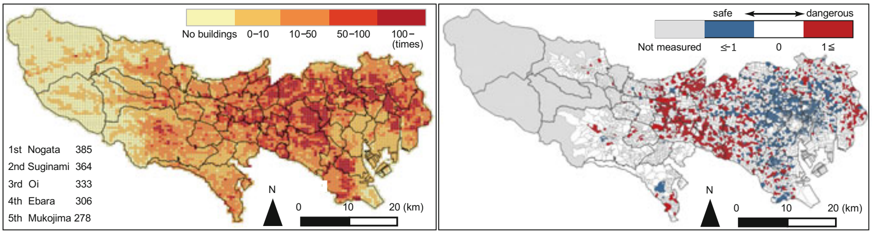
(b) Spatial distribution of [the number of fire outbreaks - the number of pumping cars] (mean value in a firefighting jurisdiction)

Fig. 3 Spatial distribution of the number of fire outbreaks and the difference (the number of fire outbreaks minus the number of pumping cars)



(a) Spatial distribution of Fire-Spread Potential (FSP) (b) Spatial distribution of Burn-Down Potential (BDP)

Fig. 4 Spatial distribution of FSP and BDP



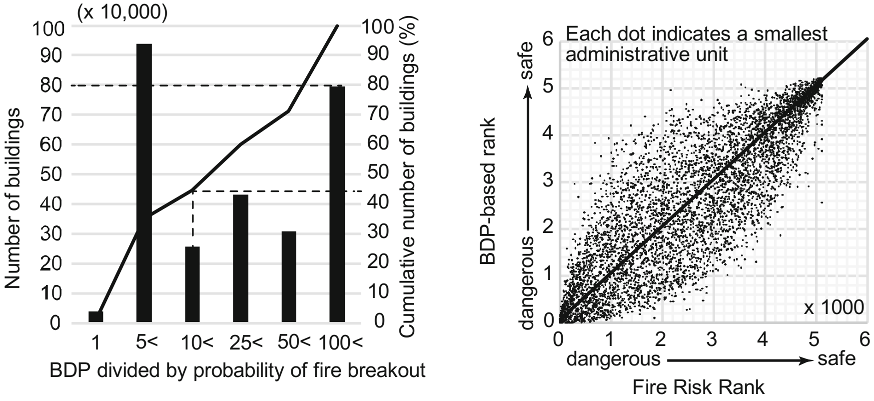
(a) BDP divided by the probability of fire breakout (mean value in 500-m grid)

(b) BDP minus Fire Risk Rank (Tokyo Metropolitan) for smallest administrative unit

Fig. 5 A value of BDP divided by the probability of fire breakout and the difference between BDP-based rank and FRR

the five jurisdictions where this ratio is highest, the BDP is 250 times or more greater than the fire outbreak probability, which confirms the risk of fire-spread in the urban area. Furthermore, for approximately 50% of buildings in the Tokyo Metropolitan Area, this ratio is 10 times or more, and for more than 800,000 buildings, it is 100 times or more (Fig. 6a).

The Fire-Risk Rank (FRR) (Tokyo Metropolitan 2013) is also an index that is based on fire-spread simulations, but the rank of each city block according to fire-spread risk is significantly different from the BDP-based rank (Fig. 6b). More specifically, the BDP-based rank is high at the boundary between Tokyo's townships and wards and in the northeast, but low in the city center (Fig. 6b). This difference lies in the fact that (1) for FRR, a six-hour fire-spread simulation is carried out with outbreaks of fire set in nine places every 250 m, whereas (2) for



(a) Ratio of BDP and fire breakout probability

(b) BDP-based ranking and Fire-hazard Measurement ranking

Fig. 6 Relationships between BDP-based rank and FRR

BDP, a fire-spread simulation is carried out until the fire-spread converges, without any time limit, and it is assumed that a fire breaks out from each of the buildings one by one.

4 Proposal for Fire Brigade Mobilization Based on FSP

4.1 Determining Where the Firefighters Will Combat Blazes Based on FSP

Among the buildings in which fires start according to the fire-outbreak simulation (approximately 2,000 buildings), there is a mean of 445 buildings that have an FSP of 50 or more buildings. Since this is less than the total number of fire engines possessed by the TFD (489 engines) (Fire Chiefs' Association of Japan 2015), it is possible that the number of buildings destroyed by fire can be reduced if fires are extinguished with priority given to buildings with a high fire-spread risk. Therefore, the effectiveness of firefighters extinguishing fires in order of priority, starting with buildings with the highest FSP, can be examined.

In these simulations, to make it easier to understand the influence of the method (strategy) of determining firefighting destinations, it is assumed that the FSPs of all buildings in which fires break out are known. It is also assumed that one firefighter team combats only one burning building within its jurisdiction and is able to bring that fire under control. In this case, the number of teams that can fight fires is assumed to be equal to the number of useable fire engines, and the burning buildings that the firefighters do not combat are left to take their own course.

Simulations are carried out again for 1,000 cases in which fires break out in different buildings, and the total number of buildings destroyed by fires left to take their own course is estimated. Here again, in order to simplify the analysis, the possibility of firefighters failing to extinguish a fire due to arriving late at the scene is not considered.

4.2 Reduction in the Number of Buildings Destroyed by Fire When Firefighters Combat Blazes Based on the FSPs of Burning Buildings

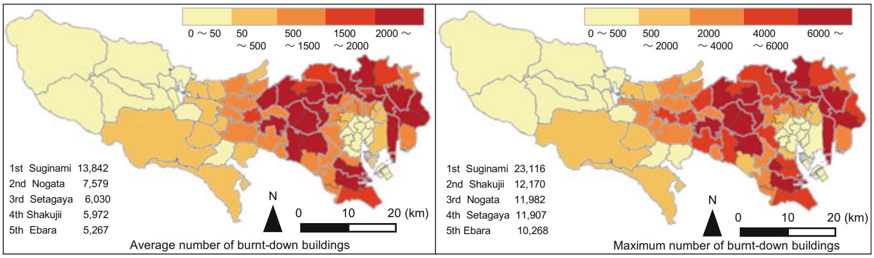
The strategy of determining the firefighter destinations in random order among reported fires not yet assigned to firefighters (strategy 1) is compared with that of determining destinations by priority given to buildings with high FSP values (strategy 2). When firefighters combat fires in random order, the percentage of jurisdictions in which the mean number of buildings destroyed by fire exceeds 500 is 64.6% (53 jurisdictions). In contrast, when firefighters combat fires based on FSP, this percentage is 13.4% (11 jurisdictions) (Fig. 8a). In regard to the maximum number of buildings destroyed by fire, whereas strategy 1 results in a maximum of 2800 or more buildings destroyed by fire in 50.0% of jurisdictions (41 jurisdictions), strategy 2 results in a maximum of approximately 800 buildings (Fig. 8b).

The above results suggest that determining firefighting destination based on the FSPs of the burning buildings could reduce the final amount of damage. However, even if firefighting is based on FSP, the mean number of buildings destroyed by fire could be 1500 or more in the 23 of the western wards of Tokyo (Fig. 7b). In this area, there is a need to enhance firefighting capabilities and review jurisdictional limits, as well as to implement measures such as promoting building fireproofing (Fig. 8).

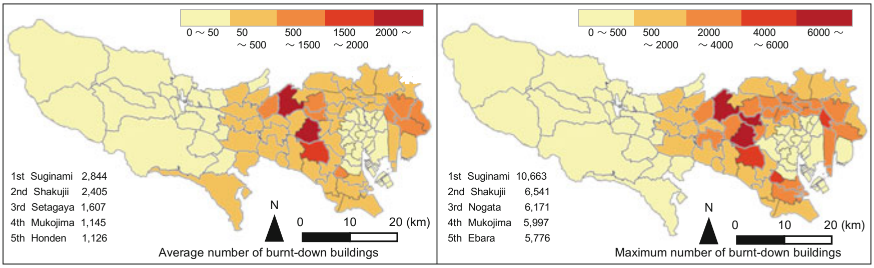
4.3 Influence of Uncertainty About Reported Buildings

In the chaotic situation that follows a large earthquake, information uncertainty is a problem. For example, when a report of a fire does not specify a particular building but is instead based on a neighboring landmark, there is uncertainty about the location information. Therefore, the influence of the burning building differing from the reported building is examined. Specifically, a reported building is selected using uniform random numbers from the buildings within a certain distance (10–100 m) from a burning building, after which a simulation to determine firefighting destination is carried out (Fig. 9).

Figure 10 shows the spatial distribution of an increase in the mean number of buildings destroyed by fire when there is a positional discrepancy of 10–65 m

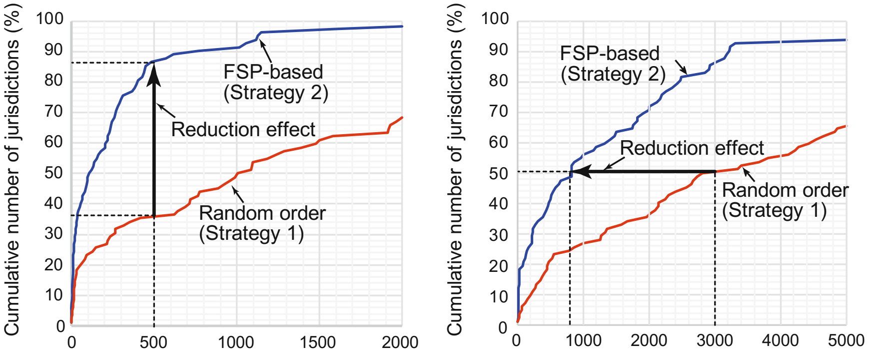


(a) Number of burnt-down buildings when combating fires in order of notification (Strategy 1)



(b) Reduction in the number of burnt-down buildings when combating fires based on FSP (no positional information error) (Strategy 2)

Fig. 7 The number of burnt-down buildings when combating fires based on FSP (mean value in firefighting jurisdiction)

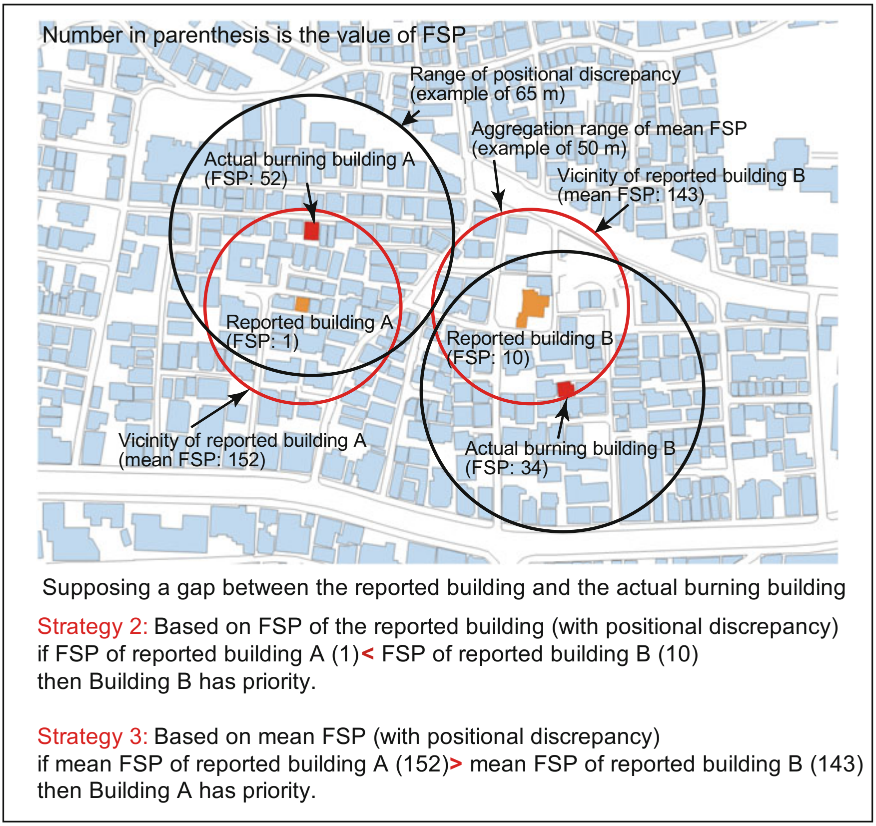


(a) Average number of burnt-down buildings (b) Maximum number of burnt-down buildings

Fig. 8 Reduction in the number of burnt-down buildings by FSP-based strategy

between the reported building and the burning building. This increase varies greatly between Tokyo's suburban townships and the inner wards. Specifically, when the positional discrepancy is 10 m, in the inner ward areas, there are regions where the mean number of buildings destroyed by fire increases by 200 or more, whereas in the township areas, the increase in almost all regions is 10 or less.

This is considered to be due to building density differences (Fig. 11a). In other words, in suburban townships, where the area of each building is large and the ratio

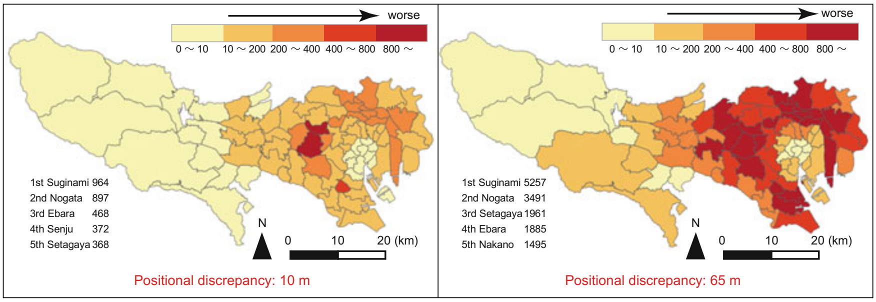


Supposing a gap between the reported building and the actual burning building

Strategy 2: Based on FSP of the reported building (with positional discrepancy)
if FSP of reported building A (1) < FSP of reported building B (10)
then Building B has priority.

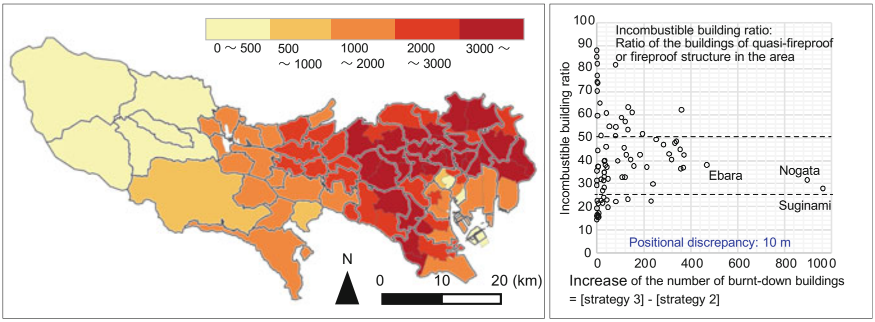
Strategy 3: Based on mean FSP (with positional discrepancy)
if mean FSP of reported building A (152) > mean FSP of reported building B (143)
then Building A has priority.

Fig. 9 Example of decision making on combating fires based on mean FSP



Increase of the number of burnt-down buildings = [strategy 2 with positional discrepancy] - [strategy 2 without positional discrepancy]

Fig. 10 Effects of positional discrepancy between the reported building and the burning building



(a) Building density: number of buildings / jurisdictional area (km ^{2})

(b) Increase in the number of burnt-down buildings and the proportion of incombustible buildings

Fig. 11 Increase in the number of burnt-down buildings and the proportion of incombustible buildings

of open space is high, the influence of an approximately 10 m discrepancy is small. On the other hand, in the inner ward areas, where buildings with differing fire resistance levels, such as fire-resistant buildings and wooden buildings, are packed closely together, there are jurisdictions in which a difference of 300 or more arises in the mean number of buildings destroyed by fire.

Looking at Fig. 11b, it can be seen that the ratio of non-combustible buildings is 25–50% in jurisdictions where the increase in mean number of buildings destroyed by fire is high, and it is evident that they consist of a mixture of buildings with differing fire resistance levels. Additionally, when the discrepancy is 65 m, there are jurisdictions in which the mean number of buildings destroyed by fire increases by 1,000 or more. Therefore, in the inner ward areas, where the influence of a positional discrepancy between the reported building and the burning building is large, there is an increased need to pay attention to the accuracy of location information (Osaragi et al. 2016).

Looking at the mean value for all jurisdictions when the discrepancy is 65 m, it can be seen that the mean number of buildings destroyed by fire increases by approximately threefold, so the influence of errors in location information cannot be ignored (Fig. 12).

4.4 Reduction in the Number of Buildings Destroyed by Fire Using Mean FSP

Next, the effectiveness of determining firefighting destinations based on the mean FSP in the neighborhood of the reported building (mean FSP) as a countermeasure for discrepancies between reported buildings and burning buildings is examined. Specifically, the mean FSP within a certain distance from the reported building (25, 50, and 75 m) is calculated, and firefighters combat fires based on the priority given to reported buildings for which this value is high (strategy 3) (Fig. 9).

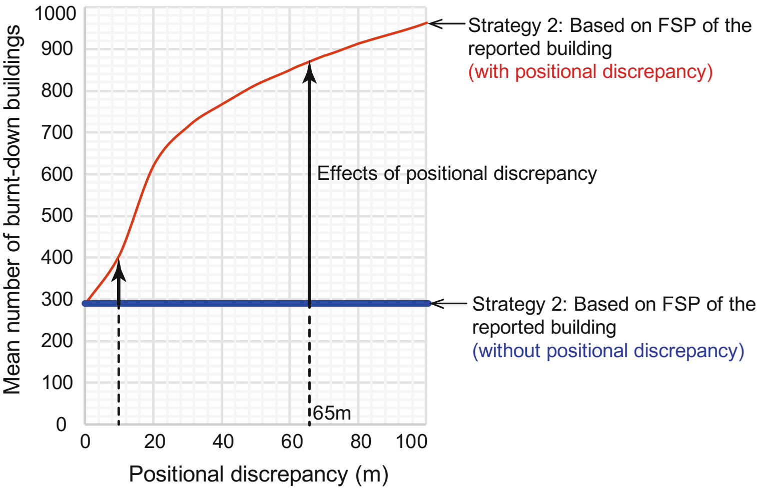


Fig. 12 Degree of positional discrepancy and the number of burnt-down buildings by strategy 2 based on FSP

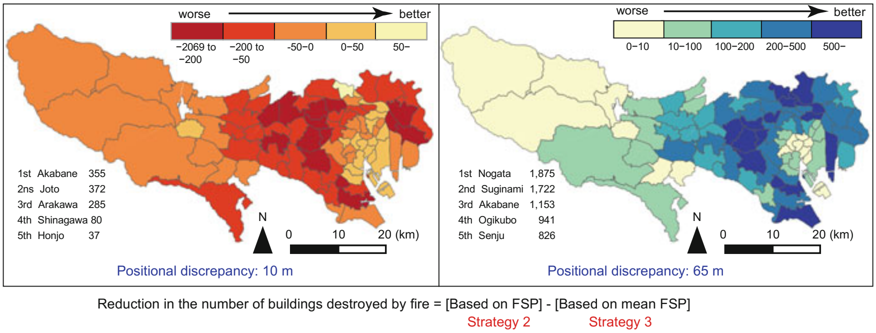


Fig. 13 Spatial distribution of the reduction in the number of buildings destroyed by fire when mean FSP (75 m) is used

Figure 13 shows the spatial distribution of the reduction in the number of buildings destroyed by fire when mean FSP (75 m) is used (results for discrepancies of 10 and 65 m). When the positional discrepancy is 10 m, the reduction in the number of buildings destroyed by fire is greater in most jurisdictions if firefighting each destination is determined based on the FSP (strategy 2) of the reported building rather than mean FSP (strategy 3). However, when the positional discrepancy is 65 m, the number of buildings destroyed by fire can be reduced in all jurisdictions by determining the firefighting destination based on the mean FSP (strategy 3).

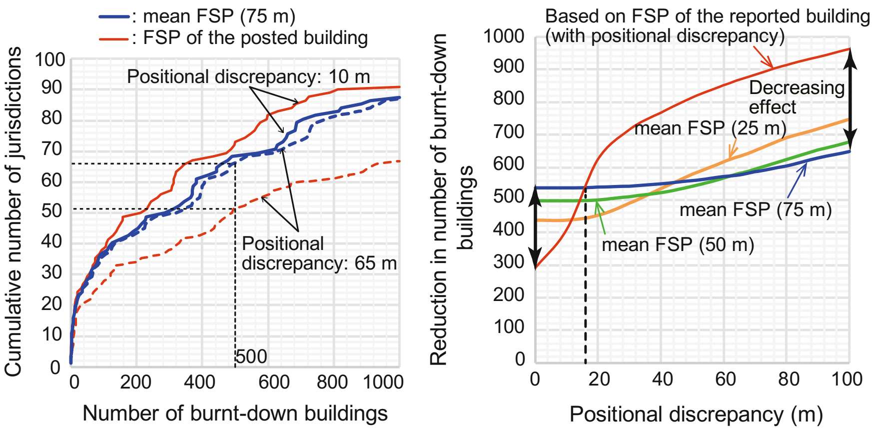


Fig. 14 Relationship between positional discrepancy and the number of burnt-down buildings

Even in the western area of the 23 wards, where the number of buildings destroyed by fire is particularly high, the number could be reduced by 1000 or more. Furthermore, there is a reduction in the percentage of jurisdictions where the mean number of buildings destroyed by fire is 500 or more, from 48.8% (40 jurisdictions) to 34.1% (28 jurisdictions) (Fig. 14, left panel).

Figure 14 (right panel) shows the relationship between the mean number of buildings destroyed by fire using mean FSP (25, 50, and 75 m) and the degree of positional discrepancy. When the positional discrepancy exceeds 15 m, the results of mobilization based on the FSP of the reported building and based on mean FSP (75 m) are reversed. In other words, excluding situations in which the location of the reported building is certain, the greatest reduction in the number of buildings destroyed by fire can be expected when the firefighting destination is determined based on the mean FSP.

It should also be noted that, even when the positional discrepancy is of the order of 100 m, if the firefighting destination is determined based on mean FSP, the number of buildings destroyed by fire will be approximately half compared to using the FSP of the reported building. However, the number of buildings destroyed by fire is approximately double in comparison to when there is no positional discrepancy. These results indicate that it is necessary to establish a method for obtaining accurate positional information on burning buildings.

5 Summary and Conclusions

In this study, we constructed a large-scale fire-spread simulation system for multiple simultaneous fires that occur in the aftermath of a large earthquake, which can be used for a DSS for fighting multiple fires in urban areas. The simulation describes the fire-spread characteristics from individual buildings taking into account, for example, the direction of fire-spread according to the fire resistance levels of buildings.

We defined two fire-spread indices: the Fire-Spread Potential (FSP), which is the total number of buildings destroyed by fire when a fire is left to take its own course; and the Burn-Down Potential (BDP), which is the probability that a building will burn down, taking into account not only an outbreak of fire within the building itself but also fire-spreading from surrounding buildings. We then carried out fire-spread simulations targeting all buildings in the Tokyo Metropolitan Area while assuming that seismic waves arrive at a uniform speed of 30 cm/s in the engineering bedrock, and we estimated the FSP and BDP of each building. The estimation results for FSP revealed that a mean of 300 buildings or more could be destroyed due to fire from a single building. In addition, the BDP estimation results revealed that approximately 50% of buildings in the Tokyo Metropolitan Area have a BDP that is 10 or more times higher than their fire outbreak probability.

We then examined a method for determining firefighting destination based on FSP as a technique for reducing the number of buildings destroyed by fire. When firefighters combat fires in random order, the percentage of jurisdictions in which the mean number of buildings destroyed by fire exceeds 500 is 64.6% (53 jurisdictions). In contrast, if firefighters fought blazes in the order of building-level FSP, this percentage would be reduced to 13.4% (11 jurisdictions).

Meanwhile, when the reported building differs from the building that is actually on fire, a difference of 300 or more arises in the mean number of buildings destroyed by fire in some jurisdictions. Therefore, we examined a method for determining firefighting destinations based on the mean FSP within a certain distance from the reported building. This showed that when the positional discrepancy between the reported building and the burning building exceeds 15 m, the number of buildings destroyed by fire could be reduced if the firefighting destination is determined based on mean FSP.

However, even if firefighters combat fires based on FSP, it is possible that they will be unable to prevent a fire from spreading if they arrive late at the scene due to road closures or congestion. Using the fire-spread simulation model constructed in this chapter, it is possible to analyze the process of fire-spread. Therefore, in our future work, we intend to analyze the success or failure of fire-spread prevention by modeling the movement of firefighters and analyzing simultaneously the time taken to move and the process of fire-spread (Claes et al. 2011; Ertugay and Duzgun 2006; Li et al. 2009; Wang and Zlatanova 2016).

Furthermore, by using the information on the process of fire-spread to discover the specific fire-spread routes (critical paths) that have a large influence on the number of buildings destroyed by fire, we intend to investigate methods of supporting more effective and efficient firefighting operations.

Acknowledgements This chapter is part of the research outcomes funded by Core Research for Evolutionary Science and Technology (CREST) and Japan Science and Technology Agency (JST) to whom the authors wish to express their sincere thanks.

References

Claes, R., Holvoet, T., & Weyns, D. (2011). A decentralized approach for anticipatory vehicle routing using delegate multiagent systems. *IEEE Transactions on Intelligent Transportation Systems, 12*(2), 364–373.

Ertugay, K., & Duzgun, S. (2006) Integrating physical accessibility of emergency establishments into earthquake risk assessment. *Proceedings Geohazards, Engineering Conferences International*, ECI Digital Archives (http://dc.engconfintl.org/geohazards/45).

Fire Chiefs' Association of Japan. (2015). Firefighting equipment information (vehicles). http://www.fcaj.gr.jp/info/. Accessed November 9, 2016 (in Japanese).

Fujii, K., & Itoigawa, E. (2005). A study on the strategy of firefighting based on information collecting activities by the fire department in case of post-earthquake fire. *Journal of Social Safety Science, 7,* 351–359. (in Japanese).

Fujimoto, K., & Midorikawa, S. (2005). Empirical method for estimating J.M.A. instrumental seismic intensity from ground motion parameters using strong motion records during recent major earthquakes. *Journal of Social Safety Science, 7,* 241–246.

Himoto, K., & Tanaka, T. (2006). Development of a physics-based urban fire-spread model. *Journal of Environmental Engineering, 607,* 15–22.

Hirokawa, N., & Osaragi, T. (2016). Earthquake disaster simulation system: Integration of models for building collapse, road blockage, and fire-spread. *Journal of Disaster Research, 11*(2), 175–187.

Iwami, T. et al. (2006). *Development of evaluation method for fire-spread in urban areas* (pp. 1–66). Report of Building Research Institute 145. Ibaraki: Building Research Institute.

Kato, T., Hong, C., Yalkun, Y., Yamaguchi, M., & Natori, A. (2006). A method for the integrated earthquake fire risk evaluation based on the single building fire probability applying to any different map-scale. *Journal of Social Safety Science, 8,* 279–288.

Li, M., Zhang, Y., & Wang, W. (2009). Analysis of congestion points based on probe car data. In *Proceedings of the 12th International IEEE Conference on Intelligent Transportation Systems*, St. Louis.

Midorikawa, S., Matsuoka, M., & Sakugawa, K. (1994). Site effects on strong motion records observed during the 1987 Chiba-Ken-Toho-Oki. In *Proceedings of 9th Japan Earthquake Engineering Symposium.*

Osaragi, T., Niwa, I., & Hirokawa, N. (2016). Development of web application for disaster-information collection and its demonstration experiment. In V. Wohlgemuth, F. Fuchs-Kittowski, & J. Wittmann (Eds.), *Advances and new trends in environmental informatics* (pp. 63–73). Switzerland: Springer International Publishing.

Sasaki, K., & Sekizawa, A. (2014). Risk assessment of fire-spread potential for a densely built-up area using a simulation model of fire-spread and fire-fighting. *Bulletin of Japan Association for Fire Science and Engineering, 64*(3), 29–37. (in Japanese).

Si, H., & Midorikawa, S. (1999). New attenuation relationships for peak ground acceleration and velocity considering effects of fault type and site condition. *Journal of Structural and Construction Engineering, 523,* 63–70.

Tokyo Fire Department. (1997). *Provision and elucidation of new factor of fire and fire-spread behavior considering inland earthquake*. Fire Prevention Council (in Japanese): Report of Fire Prevention Council. Tokyo.

Tokyo Fire Department. (2001). *Development and application of evaluation method for preventing ability of earthquake fire*. Fire Prevention Council (in Japanese): Report of Fire Prevention Council. Tokyo.

Tokyo Fire Department. (2005). *Provision and elucidation of risk factor after large earthquake in civilization*. Fire Prevention Council (in Japanese): Report of Fire Prevention Council. Tokyo.

Tokyo Fire Department. (2013). *Measurement of fire hazard level at the time of earthquake in Tokyo* (8th). http://www.tfd.metro.tokyo.jp/hp-bousaika/enshoukiken/no08/. Accessed November 9, 2016 (in Japanese).

Tokyo Metropolitan Government. (2013). *Measurement of fire hazard level at the time of earthquake in Tokyo* (7th). http://www.toshiseibi.metro.tokyo.jp/bosai/chousa_6/home.htm. Accessed November 9, 2016 (in Japanese).

Wang, Z., & Zlatanova, S. (2016). Multi-agent based path planning for first responders among moving obstacles. *Computers, Environment and Urban Systems, 56,* 48–58.

Chapter 6
Developing the Well-Located Land Index to Establish Smart Human Settlements for the Ekurhuleni Municipality, South Africa

Baleseng T. Mokoena, Walter Musakwa and Thembani Moyo

Abstract Since the dawn of democracy in 1994, the spatial form of South African cities has shown minimal change. Spatial segregation and fragmentation in cities still persist, particularly in Ekurhuleni, despite numerous and well-formulated policy documents such as the National Development Plan (NDP) and 'Breaking New Ground' that call for spatial transformation and integration. This is mainly because there are inadequate tools to assist planners in identifying strategically located land and weak implementation mechanisms. Consequently this study outlines a Planning Support System (PSS) called the Well-Located Index (WLLI) which uses a Geographic Information System (GIS) and the Analytical Hierarchy Process (AHP) to assist planners in identifying, quantifying and visualising well-located land in Ekurhuleni. The study also demonstrates that the WLLI PSS is an invaluable tool in advancing evidence-based decision making that will nurture sustainable and smart cities in South Africa. The WLLI will facilitate targeting smart and well-located land as well as provide the Ekurhuleni Metropolitan Municipality with clear guidelines on where to place future development if the legacy of spatial segregation is to be reversed.

Keywords GIS-MCDA · Well-located · Smart cities · South Africa · Land · Housing

---

B.T. Mokoena (✉) · W. Musakwa
Department of Town and Regional Planning, University of Johannesburg,
Cnr Siemert and Beit Streets, Doornfontein, South Africa
e-mail: baleseng.mokoena@ekurhuleni.gov.za; balesengmokoena211@gmail.com

W. Musakwa
e-mail: musakwarup@gmail.com; wmusakwa@uj.ac.za

T. Moyo
Department of Quality and Operations Management, University of Johannesburg,
Bunting Road Campus, Johannesburg, South Africa
e-mail: thembanijoel@gmail.com

S. Geertman et al. (eds.), *Planning Support Science for Smarter Urban Futures*, Lecture Notes in Geoinformation and Cartography,
DOI 10.1007/978-3-319-57819-4_6

1 Introduction

> *Yet, if we examine closely this system of compartments, we will at least be able to reveal the lines of force it implies.* (Fanon 1967, p. 29)

Under the colonial and apartheid eras, the South African spatial form was redesigned and segregated to serve the economic interests of a minority of people across the country (Dubow 2014; Harrison et al. 2008; Marais and Krige 1999; Fanon 1961; Republic of South Africa 2004, 2011). The Natives Land Act of 1913, for example, caused displacement and dispossession and provided a platform for the ongoing segregation of people based on race. Subsequently, between 1936 and 1951, black people started migrating into cities and this number grew from 17.3% to 27.2% (Dubow 2014). Between 1936 and 1946, in Johannesburg for example, the population grew by 60% which meant that black people started outnumbering white people for the very first time (Dubow 2014).

It then became the mandate of the then Government to slow down the urbanisation process through legislation such as the Group Areas Act of 1950 (Act No. 41 of 1950) and the pass laws that created impermanence within urban areas. These laws also dictated where black people could live (Dubow 2014; Mokoena and Musakwa 2016; Turok and Borel-Saladin 2014; Harrison 2003; Zuma 2013). When these restrictions were finally removed in 1994 when South Africa gained independence, cities saw an influx of more black people most of whom lived in informal settlements because of poverty and a lack of adequate housing opportunities to accommodate the different housing needs (Ross 2010; Mokoena and Musakwa 2016). According to recent statistics published in the Community Survey Report, South Africa today has a population of 55.6 million people, with the Gauteng province being the smallest province but the most populated at 13.4 million people (Stats SA 2016).

In the quest to address the housing backlog in 1994 the democratic Government sought to build houses for South Africans across the country and subsequently found themselves continuing what the Apartheid Government had started (Harrison 2003; Smith 2003). The Department of Housing continued to build on cheap land on the periphery of city centres (Huchzermeyer 2003) which perpetuated the apartheid legacy. Current policies and legislation such as the National Development Plan seek to reverse segregated spatial planning through developing smart and sustainable human settlements in well-located areas in South African cities. However, many cities, including Ekurhuleni, do not have a stepwise and objective Planning Support System (PSS) nor guidelines or a framework that clearly define what ‘well-located land’ for establishing human settlements means. Therefore the aim of this book chapter is to define and develop the well-located land index

(WLLI) PSS for the City of Ekurhuleni using Geographic Information Systems (GIS) and Multi-Criteria Decision Making (MCDM).

The rest of the chapter is structured as follows: the next section chronicles housing policy and legislation in South Africa, followed by a literature review on PSSs and a brief on the Erkuhuleni study area. The methodology, results and discussion, the challenges and the conclusion are then discussed.

2 Housing Policy and Legislation in South Africa

The Constitution of South Africa in 1996 established a bill of rights that was based on the socio-economic needs of the citizens (Socio-Economic Rights Institute 2011). Section 26 of the constitution of South Africa outlined in the previous section, that '*everyone has the right to have access to adequate housing*' and therefore the state recognised the urgent need to realise the delivery of housing to impoverished South Africans within its financial means over the years (Republic of South Africa 1996). The Housing Act of 1997, which was followed by the National Housing Code (2000, revised in 2009), then laid out the principles that were defined in the Housing White Paper of 1994, which expanded on the role and function of all three spheres of government in the housing development process as well as the funding mechanisms that would be used for development (Socio-Economic Rights Institute 2011).

The Breaking New Ground (BNG) policy was established in 2004 after the realisation that, while the state had delivered 3.2 million fully subsidised houses, there was a desperate need to look at how settlements were designed and where they were located (Republic of South Africa 2004). For example, Fig. 1 shows a settlement built in the 1950s in Soweto in Johannesburg which was designed in a monotonous way and followed a one-size-fits-all approach. Figure 2 is an aerial photograph of Diepsloot in Johannesburg taken in 2009 which shows the same monotonous design, the only difference being the manifestation of rapid urbanisation in the form of formal and informal backyard dwellings in Gauteng post 1994. It is also important to mention that these two townships are located on the periphery of the city. For this reason, the BNG policy advocates that settlements be built on well-located land with mixed housing opportunities. The National Development Plan of 2011 and the Spatial Planning and Land Use Management Act of 2013 uphold this by further emphasizing the need for better located human settlements for the lower income group which must spatially transform the apartheid legacy of South Africa and spatially target development in the right places Republic of South Africa 2013. The National Development Plan further states that "*where people live and work matters*" (Republic of South Africa 2011, p. 260).

Fig. 1 Soweto (Johannesburg) in the 1950s. *Source* http://affordablehousinginstitute.org/blogs/us/2006/11/advanceing_the_b.html

Fig. 2 Diepsloot (Johannesburg) in 2009. *Source* Presentation by guest lecturer at Witwatersrand University, Vearey 2015. A City of Migrants: Migration, urbanization and health in Johannesburg

3 Planning Support Systems

Tools to enable the spatial targeting of human settlement development must therefore be developed in order to have scientific methods that enable urban planners to implement spatial transformation in South Africa and other cities in the Global South. Modern age urban planning complexities have thus led to the introduction of PSS which seek to assist planners to shape the development of their city and assist them in making decisions on land identification. Pelzer (2016) defines PSS as being digital tools, which aim to facilitate planning strategies. Whilst Jiang et al. (2003, p. 1) describes PSS as "*spatial decision making systems with particular application for planning, which involves a wide range of professionals with diverse backgrounds and the general public concerned.*" PSS accordingly can be described as planning tools, which facilitate collaborative planning by focusing on specific steps of the planning process and improving the strategic capacity of these plans (Pelzer 2016; Te Brömmelstroet 2016a, b).

Although the term 'planning support system' was originally proposed by Harris (1989), most advances have only taken place recently with the introduction of new technologies which facilitate and simplify the visualization of big data. Consequently, PSS now act as both a communication support and information processing support to address spatial urban complexities (Pelzer 2016). Similarly with the emergence of smart cities in the age of digital information and communications technologies, PSS enable urban planners to collect, manage, analyse and store information more efficiently than before which enables planners to create cities that are suitable for all.

Given how urban development is premised on a balance of three environments namely, political, physical and economic, computer-based support systems developed by scholars, planners and the community promise to yield benefits to both planning policies and to the lives of the community (Geertman and Stillwell 2009). This would go a long way towards bridging the gap between interpreting and analysing spatial data, as the construction of computer simulated models leads to planning becoming more efficient as it takes less time to generate results and analysis. Pelzer (2016) also notes that PSS can lead to better informed plans or decisions, consensus, learning about other stakeholders, better communication and collaboration. It is because of these benefits that PSS have been applied the world over. Long et al. (2011) developed a PSS on urban containment planning which borrows ideas of Uniform Analysis Zones (UAZs) from the PSS What If? proposed by Klosterman (1999). Likewise, an urban strategy PSS was developed in Utrecht, Netherlands for environmental and traffic models (Pelzer 2016). Other PSS have been developed for land use management and transportation systems (Forgie 2011; Inada et al. 2014), environmental management (Ababaei et al.2014; Ayoub et al. 2006) and other urban issues (Te Brömmelstroet 2016a, b).

Te Brommelstroet (2013) has also brought further insights on PSS by describing them as a means of providing insight that should not be judged on the amount of big data they can process, as they are developed to provide enlightenment to the planning process. He advocates that planners should set out to operationalize the performance of PSS, as two terms become key, 'relevance' and 'specificity', which are dependent on the study area. Scholars are then confronted with the imperative to either develop new ground breaking planning outcomes that reflect novelty (leading to the introduction of new technologies) or to develop cohesive PSS that are simple to incorporate into the daily lives of planners. Nonetheless, regardless of which path scholars take, the potential merits of continuously developing PSS will lead to a growth in knowledge systems that govern the three key factors of PSS, information; communication; and analysis (Te Brömmelstroet 2013).

Over the years, scholars have developed computer-based support systems, which are either focused on user-friendliness or planning qualities. Much of the research on PSS implementation focuses on understanding and improving the user-friendliness of the instruments (Te Brömmelstroet 2013; Long et al. 2011). In the South African context, the development of a PSS to guide and inform development of housing requires a model that is user-friendly, interactive and able to allow the end-user to easily modify and interpret the results. The introduction of geospatial analysis platforms in conjunction with planning policies (namely the Spatial Planning and Land Use Management Act 16 of 2013, SPLUMA) and the housing Atlas (Council for Scientific and Industrial Research 2008) has enhanced how PSS are formulated. Nonetheless, though the potential merits of implementing PSS are vast, most African cities are still to integrate them into their daily practice, as most do not have the required mechanisms to do so.

4 Study Area

The Ekurhuleni Metropolitan Municipality (EMM) area consists of an amalgamation of nine towns that incorporate former black townships (Fig. 3). EMM is located within the Gauteng Province and is located next to the City Johannesburg and City of Tshwane (Fig. 3). The EMM was historically known as East Rand and it consists of major towns such as Kempton Park, Benoni, Germiston, and Alberton (Bonner et al. 2012). Each town or Central Business District (CBD) comprises suburbs, industrial areas and townships with a surface area of 1975 km^2 and a population of 3,178,870 inhabitants (City of Ekurhuleni 2015). It has a very strong manufacturing and industrial sector and is the transportation hub of South Africa as it has the busiest airport in Africa (OR Tambo International Airport) and has branded itself as an 'Aerotropolis' (City of Ekurhuleni 2015). However, the city also has 119 informal settlements with an estimated population of 164,000 households in need of adequate housing (City of Ekurhuleni 2014).

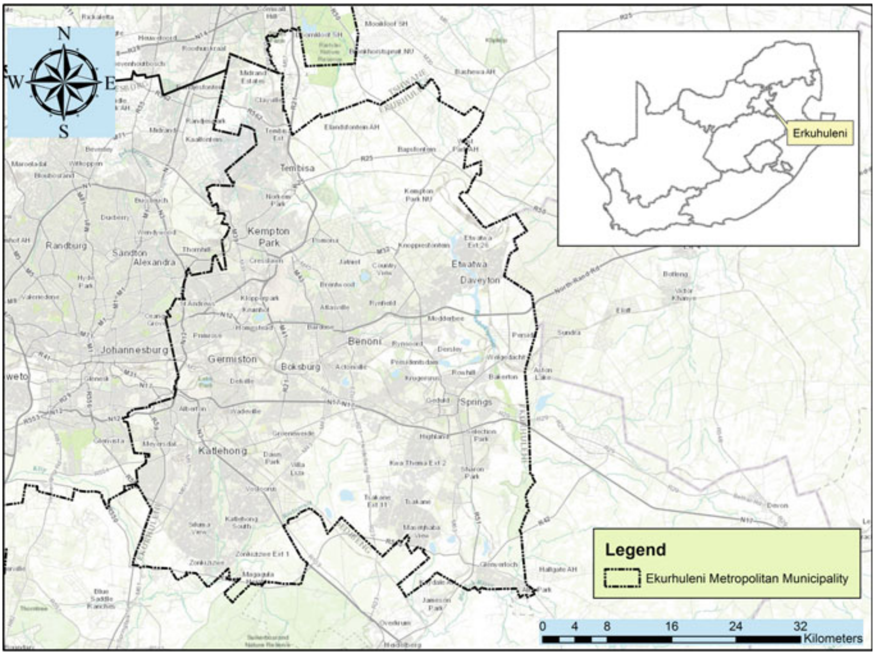


Fig. 3 Location of Ekurhuleni

5 Methodology

This section provides a step-by-step approach on how the WLLI for EMM was developed. It is a GIS-MCDA approach that is consistent with smart city approaches and theories as defined by Ching and Ferreira (2015). Hence the process was consultative, participatory, anticipatory and collaborative. This approach also improves user acceptance and a sense of ownership.

5.1 Criteria Identification and Assigning Weights

Criteria identification for developing the WLLI was carried out through a participatory planning workshop. Urban planning, housing, environmental and GIS professionals from the EMM and academics where invited for the workshop. Selection of the criteria was mainly guided by literature on human settlements, smart cities, national policies such as the National Development Plan (NDP) and the needs of the EMM (UN-Habitat 2010; National Research Council 2009; NEAT GIS Protocols 2010). The criteria was condensed to 13 (Table 1) so as to reduce complexity and redundancy. Similarly, the criteria had to be logically sound and consistently relate

Table 1 Criteria to identify well-located land in EMM

Criteria	Weight (%)	Rank
Dolomite	20.2	1
Mining	17.8	2
Bus Rapid transit bus stations	13.3	3
Train stations (Gautrain)	10.4	4
Train stations (Metro)	9.5	5
Priority areas	8.5	6
Airport	5.7	7
Elevation (Slope)	4.5	8
Major Towns	2.7	9
Soil Texture	2.2	10
Roads	2.1	11
Proximity to rivers	1.6	12
Proximity to informal settlements	1.6	13

Table 2 Pairwise matrix preferences

How important is A relative to B	Preference index assigned
Roads	2.1%
Equally important	1
Moderately more important	3
Strongly more important	5
Very strongly more important	7
Overwhelmingly more important	9
Values in between	2; 4; 6; 8

to the objective of identifying well-located land in EMM. Discussions in the workshop also ensured that criteria are realistic, smart, transparent and simple (Saaty 1990).

Upon agreeing on the number of criteria the participants engaged in a Group Analytical Hierarchy Process (GAHP) for weighting each criterion using a pairwise comparison matrix for the 13 criteria (Malczewski 2006a, b; Satty 1980). The pairwise comparison matrix rates how critical one criterion is relative to another based on a 1–9 scale (Table 2).

The professionals at the workshops were given a template of 78 pairwise comparisons of the 13 criteria to fill. This template was run using the GAHP calculator by Goepel (2014). To ensure that results were reliable the participants filled out the pairwise matrix over three days. The matrices of the professionals were than captured using the GAHP calculator software to create an overall weighting matrix which involves synthesizing each of the professional's judgments and merging the resulting priorities using a geometric mean (Malczewski and Rinner 2015). Such an approach is considered superior to the group consensus-reaching model since it alleviates the group of the need for a moderator, who may be biased, through the use of an automatic feedback mechanism

(Grošelj et al. 2015). A consistency ratio of 0.023 for the pairwise matrix was realized indicating that there were no logical inconsistencies in the matrix.

5.2 Assigning Criteria Rule Sets and Mapping

This section involved collecting spatial data for the criteria and assigning rule sets. The spatial data were mostly collected from the EMM, Council of Geosciences and the National Geospatial Inspectorate. The data were then stored and processed in a geodatabase. Subsequently rule-sets for each criterion were identified from literature (Frank et al. 2010; Musakwa et al. 2017; NEAT GIS Protocols 2010). For example, Frank et al. (2010) discusses the factors affecting walking distances, and NEAT GIS Protocols (2010) also discusses minimum walking distance to bus stations; subsequently, these standards influenced development of the rule sets for the WLLI.

Consequently, using the rule sets maps for each, criteria were categorized using a suitability scale of 1–4, where 4 is very well-located (highly suitable), 3 moderately-located (moderately suitable), 2 marginally well-located (marginally suitable) and 1 not well-located (unsuitable) (Table 3). From the criteria and the rule sets one can then define very well-located land for establishing smart human settlements in cities. Such well-located land is within three kilometres of public transit facilities and transportation infrastructure, does not possess dolomite, is at least 5–15 km from the negative impacts of mines and the airport, is close (<10 km) to major towns and cities and lastly, is earmarked for future developmental and investment projects commonly referred to as priority areas in the EMM. Proximity to towns in this study was used to imply proximity to employment opportunities as well as other essential services such as education and hospitals (Table 3).

5.3 Computing the Well-Located Land Index

To generate the WLLI, the Weighted Linear Combination (WLC) in ArcGIS software was utilized where S_l the total score of the well-locatedness for a land unit is calculated using the following equation:

$$S_l = \sum_{i=1}^{n} W_i P_i \qquad (1)$$

where W_i of each criterion is calculated using the GAHP, P_i represents value of each criterion based on corresponding standards and n is the number of criteria. The WLC was selected because it is risk averse (Van Niekerk et al. 2016). The WLLI was reclassified to a range of 0–100 where 0 is not well-located and 100

Table 3 Criteria and rule sets to identify well-located land in EMM

Criteria	Very well-located	Moderately well-located	Marginally well-located	Not well-located
Dolomite	Areas without dolomite	N/A	N/A	Areas with Dolomite
Proximity to mines	>15 km	10–15 km	5–9 km	<5 km
Proximity to bus rapid transit bus stations	<1 km	1–2 km	2, 1–3 km	>3 km
Proximity to train stations (Gautrain)	<2 km	2–4 km	4, 1–6 km	>6 km
Proximity to train stations (Metro)	<1 km	1–2 km	2, 1–3 km	>3 km
Proximity to priority areas	<1 km	1–2 km	2, 1–3 km	>3 km
Proximity to the airport	>15 km	10–15 km	5–9 km	<5 km
Elevation (Slope)	1200–2000 m	200–400 m	401–1200 m or 2001–2500 m	Sea level, <200 m or N2500 m
Major towns	<5 km	5–10 km	10, 1–15 km	>15 km
Soil texture	Sandy and well drained soils	Clay soils	Silty or silty clay	Peat or muck
Roads	<1 km	1–2 km	2, 1–3 km	>3 km
Proximity to rivers	>3 km	2,1–3 km	1–2 km	<1 km
Proximity to informal settlements	<2 km	2–4 km	4, 1–6 km	>6 km

very well-located land. Field validation visits were also carried out to determine the accuracy of the WLLI.

6 Results and Discussion

Figures 4 and 5 show the WLLI for Ekurhuleni on a scale of 0–100, where 0–30 is defined as not well-located (unsuitable), 31–50 as marginally well-located (marginally suitable), 51–70 moderately well-located (moderately suitable and 71–100 as very well-located (highly suitable). Table 4 shows the percentage areas of the well-located land in EMM.

Only 30% of the land in EMM is very well-located with another 31% marginally well-located, whilst 23% is marginally well located and 17% not well-located or unsuitable. From Figs. 4 and 5 it is clear that the highly suitable and well-located land is located in and around the major CBDs and activity corridors in Ekurhuleni such as Benoni, Kempton Park, Springs, Daveyton, OR Tambo international airport, Alberton and Germiston.

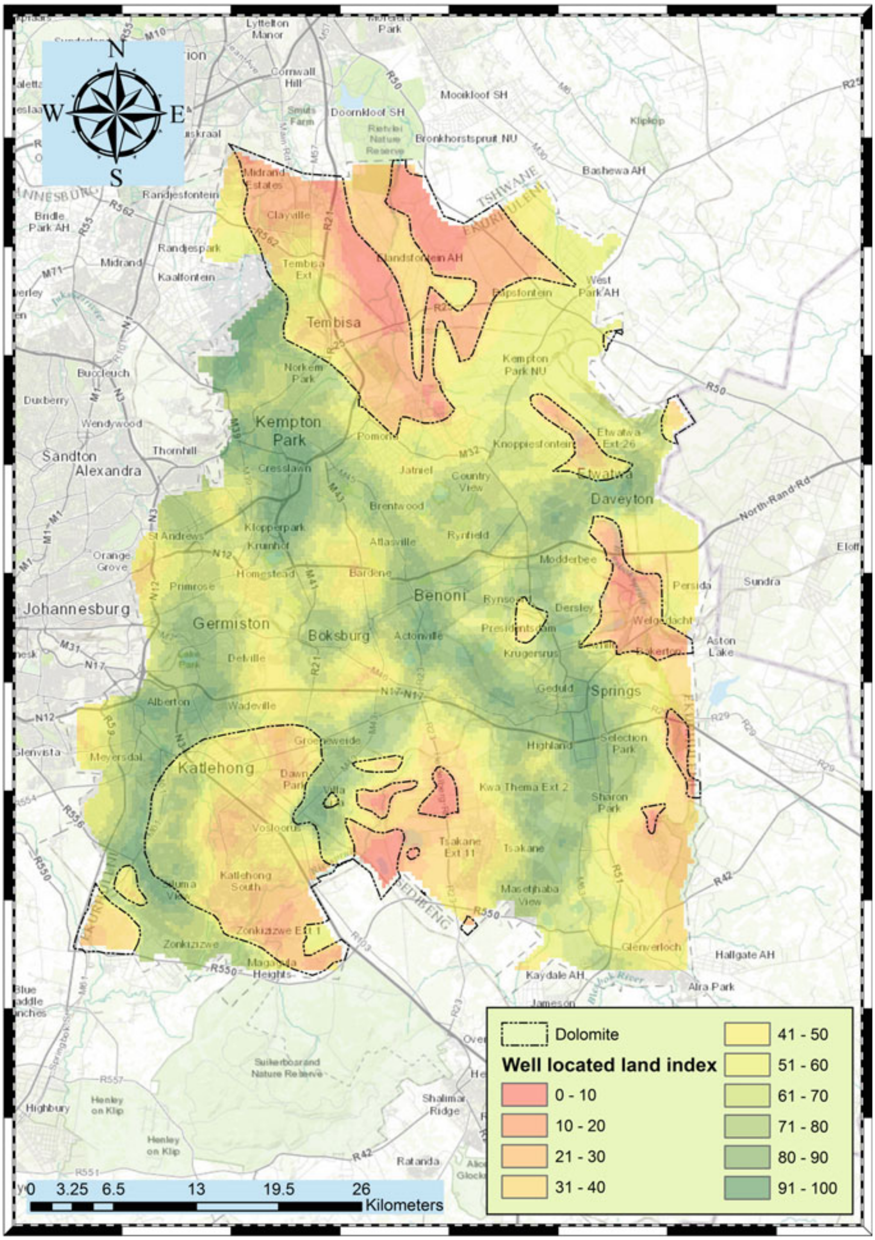


Fig. 4 The well-located land index for Ekurhuleni

To achieve its status as a smart city, the EMM can utilize the WLLI PSS to facilitate evidence-based decision-making by identifying land in the very well-located areas or to target for infill development of human settlements as well as

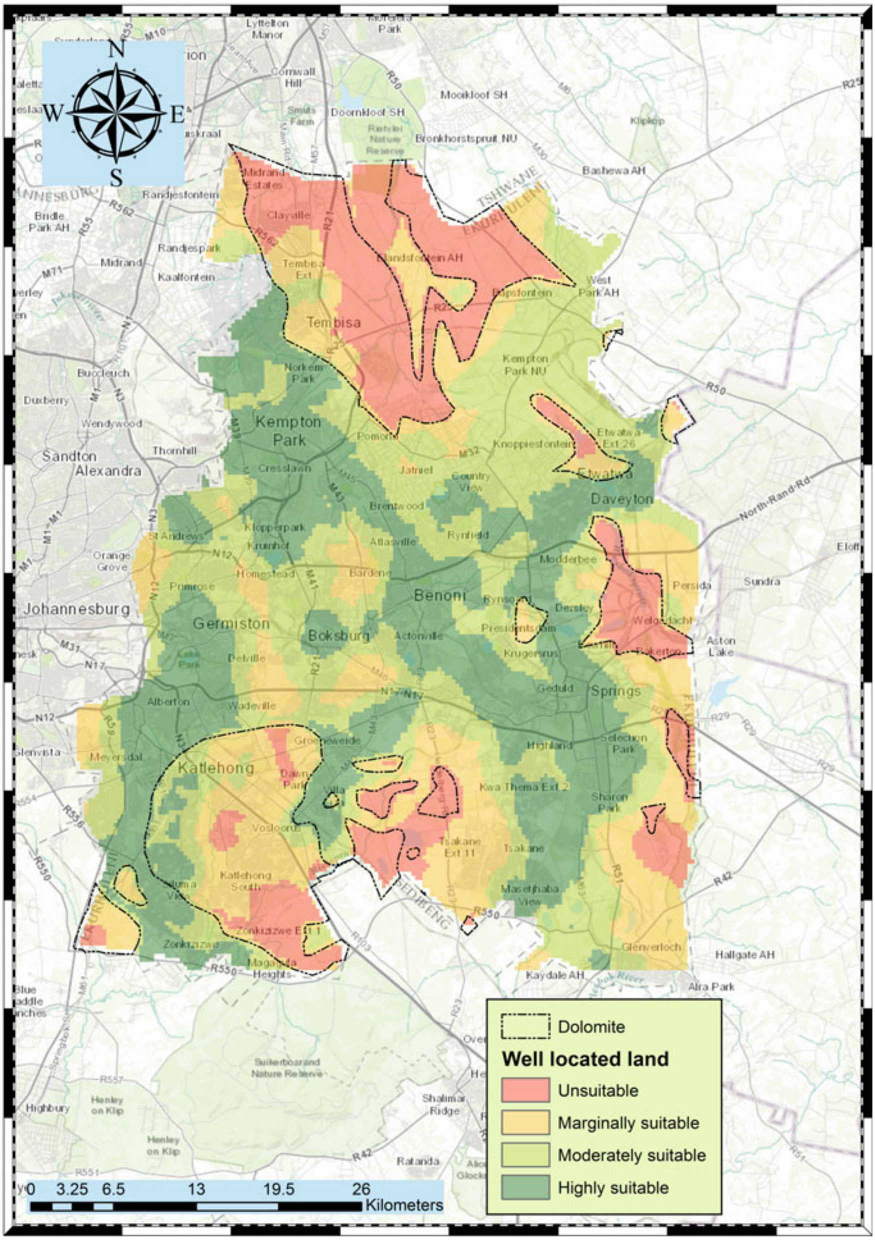


Fig. 5 Suitability classes of well-located land in Ekurhuleni

identifying areas where people in informal settlements can be resettled. These well-located areas have to be targeted, as they are highly accessible, already contain infrastructure and services as well as supporting land uses (Musakwa et al. 2017).

Table 4 Land suitability classes in Ekurhuleni

Land suitability class	Well-located index value	Percentage area	Area (km^2)
Not well-located	0–30	17	329.56
Marginally well-located	31–50	23	449.80
Moderately well located	−51 to 70	31	608.63
Very well-located	71–100	30	587.01
Total		100	1975

Continued development in these well-located areas in EMM will most likely lead to further densification and congestion which can eventually lead to inability to promote sustainability and smart cities. The question, therefore, becomes, can more growth in these areas be sustained or should growth be channelled elsewhere? (Musakwa et al. 2017). Perhaps a serious paradigm shift is required that promotes high-rise and high-density buildings as opposed to owning a land parcel.

Areas that are unsuitable and not well-located lie in the upper northern, southern and eastern areas of EMM in places such as Tembisa and Kathlehong. These not well-located areas are mostly on dolomitic areas and this is consistent with the weighted criterion since dolomite had greater influence. These areas are traditionally townships mostly populated by low-income groups and far from places of economic opportunities. It is very difficult to develop on these unsuitable sites as the presence of dolomite increases construction costs and the risk of subsidence and damage to infrastructure. Interestingly, large populations inhabit these areas and it is not necessarily smart because of the risk; in future, it is advisable for the EMM not to promote housing development for the low income families in areas that have dolomite due to the cost implications. However, should this be unavoidable, the rational design approach can be implemented.

From Fig. 5, it is clear that the moderately well-located land in Ekurhuleni is mostly located adjacent to the well-located land. This shows that suitability gradually declines as one moves away from the well-located sites that almost form a concentric pattern. Likewise, the not so well-located areas are further away from the very well-located areas. This is consistent in South African cities as a result of the apartheid segregation policies. What is more worrying is that 22 years after independence, broadly the same spatial pattern still exists. This casts doubts on the smartness and the seriousness of the current planning system in reversing the apartheid planning. The WLLI PSS is a tool that planners in EMM can use to highlight the inequalities that still exist and propose smarter ways to curb them. At present there is no PSS and scientifically structured system at the EMM, hence the WLLI PSS is a step in the right direction in streamlining decision making. From the weighting criteria workshop it also emerged that there is a strong need for a smart PSS in land identification, as the current systems are ad hoc, fragmented and not consistent. Possible reasons for the EMM not being able to devise a GIS-MCDA system for land addition are lack of skills, general unwillingness and fear amongst planners in South Africa to utilize GIS, lack of political will and a champion to develop a PSS.

It is crucial to note that the above statistics and maps as are only indicative of where to target areas for establishing smart human settlements. The WLLI therefore provides a structured and scientific procedure of identifying land for future development unlike the current ad hoc systems. With the WLLI, undesirable and disastrous consequences of the Reconstruction and Development Program (RDP), as carried out in the EMM that created human settlements far away from infrastructure, economic opportunities and services, can be avoided. The WLLI is a strong reminder to planners and politicians alike that little or nothing is ultimately gained if justice turns out to be purely symbolic and leaves people poorer, or even worse off (CDE 2008).

Accordingly, the WLLI is crucial to complement the political aspect of reversing apartheid planning as it makes sure that land targeted is suitable for human settlements, leads to spatial integration, densification, and does not perpetuate poverty as well as enabling access to opportunities (Musakwa et al. 2017). In light of this, the WLLI can be viewed not only as a technical tool but an enabler that ensures that mistakes of the past in land identification and settlement creation are not repeated while ensuring that the potential of urban areas is maximised when people, jobs, livelihood opportunities and services are aligned (Integrated Urban Development Framework 2014).

7 Challenges and Lessons Learned

A major challenge that hampers use of GIS in municipalities is the fear and often unwillingness of planners in South African municipalities of using GIS. This is partly because of lack of skills as well as a dearth in urban planning schools of PSS curricula and this may ultimately derail smart city initiatives. Similarly, it also appears that there is lack of political will to actively promote smart cities and GIS-MCDA and PSS in cities possibly because municipalities are concerned more about service delivery issues, particularly in informal settlements. Nevertheless, it is important to note that employing the WLLI, PSS and other smart city approaches will lead to better service delivery.

Lack of financial resources, costs of developing GIS datasets and technical challenges such as computer networks and servers were also identified as impediments to the use of PSS in South African cities (Musakwa et al. 2017). Another challenge identified at the workshops is the continued and often religious reference to planning law, policies and documents such as the Spatial Planning and Land Use Management Act (SPLUMA). As a result, planners rarely refer to literature and other best practices that can assists in delivering smart cities and service delivery. There are also implementation bottlenecks caused by this incessant reference to a multitude of laws and regulations so that in the end very little is done and innovation and smart city initiatives are stifled. South Africa is not short of policies but it is weak in implementation and innovation mechanisms which often hamper smart city initiatives. There is also a misconception that smart cities largely involve use of information and communications technologies (ICT). Ching and Ferreira (2015) point out that investing in the future, collaborations, partnerships, learning, relearning and adapting are essential cogs in the success of smart city initiatives. Perhaps these cogs need to be established in cities such as EMM for the success of smart city initiatives.

8 Conclusion

Identification of land to develop human settlements and to resettle people from informal settlements is a perennial challenge in Ekurhuleni and other South African cities. Similarly, prior to the WLLI, there was no consistent, objective and structured way of identifying well-located land in Ekurhuleni. Moreover, a definition did not exist that defines well-located land. The study has developed a working definition of well-located land as land that is close to public transit facilities and transportation infrastructure, towns and cities, is land that does not possess physical constraints and that is earmarked for development and investment by local or national government.

Based on the criteria for well-located land, the study used GIS-MCDA to develop a well-located index that was visualised in ArcGIS to identify land that is smart and well-located to establish human settlements. The WLLI therefore is a tool that may assist planners in streamlining decision making as well as making evidence-based decisions that can lead to attaining smart city status and reversing spatial planning brought about by the legacy of apartheid. However, challenges such as lack of skills hamper the successful implementation and utilization of GIS-MCDA, PSS and promotion of smart city approaches. Ultimately further training is required on GIS-MCDA, PSS and smart cities to ensure that planners are equipped with the knowledge and skills to create better cities that respond to the needs of its citizens.

Acknowledgements We thank the professionals at Ekurhuleni who participated in the criteria-weighting workshop. We also thank Rhona Logan for her editorial comments.

References

Ababaei, B., Sohrabi, T., & Mirzaei, F. (2014). Development and application of a planning support system to assess strategies related to land and water resources for adaptation to climate change. *Climate Risk Management, 6,* 39–50.

Ayoub, N., Wang, K., Kagiyama, T., Seki, H., & Naka, Y. (2006). A planning support system for biomass-based power generation. In Marquardt, W. & Pantelides C. (Eds.), *Computer Aided Chemical Engineering* (Vol. 21, pp. 1899–1904). Elsevier.

Bonner, P., Nieftagodien, N., & Mathabatha, S. (2012). *Ekurhuleni: The making of an urban region*. Johannesburg: Wits University Press.

Centre for Development and Enterprise (CDE). (2008). *Land reform in South Africa: Getting back on track*. Johannesburg: CDE.

Ching, T.-Y., & Ferreira, J. (2015). Smart cities: Concepts, perceptions and lessons for planners. In Geertman, S., Ferreira, J. Jr., Goodspeed, R. & Stillwell, J. (Eds.), *Planning Support Systems and Smart Cities* (pp. 145–168). Cham: Springer International Publishing.

City of Ekurhuleni. (2014). *Human settlement plan 2016–2021*. Benoni: City of Ekurhuleni.

City of Ekurhuleni. (2015). *RSDF*. (Online) http://www.ekurhuleni.gov.za/rsdf-1. Accessed February 27, 2016.

Dubow, S. (2014). *Apartheid: 1948–1994* (1st ed.). New York: Oxford University Press.

Fanon, F. (1967). *The Wretched of the Earth, with a Preface by Jean-Paul Sartre*. Constance Farrington trans.

Forgie, V. (2011). Making planning support systems matter: Improving the use of planning support systems for integrated land use and transport strategy-making. *Environmental Modelling and Software, 26*(12), 1772–1773.

Frank, L. D., Greenwald, M. J., Winkelman, S., Chapman, J., & Kavage, S. (2010). Carbonless footprints: Promoting health and climate stabilization through active transportation. *Preventive Medicine, 50*(SUPPL.), S99–S105.

Geertman, S., & Stillwell, J. (Eds.). (2009). *Planning support systems best practice and new methods* (Vol. 95). Springer Science & Business Media.

Goepel, K. (2014). *Pairwise comparison AHP*. (Online) *priorities*. http://pmsg.com/academic/ahp_calc.php. Accessed May 24, 2016.

Grošelj, P., Stirn, L. Z., Ayrilmis, N., & Kuzman, M. K. (2015). Comparison of some aggregation techniques using group analytic hierarchy process. *Expert Systems with Applications, 42*(4), 2198–2204.

Harris, B. (1989). Beyond geographic information systems. *Journal of the American Planning Association, 55*(1), 85–90.

Harrison, P. (2003). Fragmentation and globalisation as the new meta-narrative. In P. Harrison, M. Huchzermeyer, & M. Makekiso (Eds.), *Confronting fragmenetation: Housing and urban developement in a democratising Society* (pp. 13–25). Cape Town: University of Cape Town Press.

Harrison, P., Todes, A., & Watson, V. (2008). *Planning and transformation: learning from the post-apartheid experience*. Landon and New York: Routledge.

Huchzermeyer, M. (2003). Addressing segregation through housing policy and finance. In P. Harrison, M. Huchzermeyer, & M. Mayekiso (Eds.), *Confronting fragmentation* (pp. 211–227). Cape Town: University of Cape Town Press.

Inada, Y., Izumi, S., Koga, M., & Matsubara, S. (2014). Development of planning support system for welfare urban design—optimal route finding for wheelchair users. *Procedia Environmental Sciences, 22,* 61–69.

Integrated Urban Development Framework (2014). http://www.dta.gov.za/cgta/index.php/iudf/1212-integrated-urban-development-framework-iudf-2014-15?path

Jiang, B., Huang, B., & Vasek, V. (2003). Geovisualisation for planning support systems. In S. Geertman & J. Stillwell (Eds.), *Planning support systems in practice. Advances in spatial science* (pp. 177–191). Berlin: Springer-Verlag.

Klosterman, R. E. (1999). The what if? Collaborative planning support system. *Environment and planning B: Planning and Design*, *26*(3), 393–408.

Long, Y., Shen, Z., & Mao, Q. (2011). An urban containment planning support system for Beijing. *Computers, Environment and Urban Systems, 35,* 297–307.

Malczewski, J. (2006a). Ordered weighted averaging with fuzzy quantifiers: GIS-based multicriteria evaluation for land-use suitability analysis. *International Journal of Applied Earth Observation and Geoinformation, 8*(4), 270–277.

Malczewski, J. (2006b). GIS-based multicriteria decision analysis: A survey of the literature. *International Journal of Geographical Information Science, 20*(7), 703–726.

Malczewski, J., & Rinner, C. (2015). *Multicriteria decision analysis in geographic information science*. New York, NY, USA: Springer.

Marais, L., & Krige, S. (1999). Post-apartheid housing policy and initiatives in South Africa: Reflections on the Bloemfontein-Botshabelo-Thaba 'Nchu Region. *Urban Forum, 10*(2), 115–136.

Mokoena, B. T., & Musakwa, W. (2016). *Mobile GIS: A tool for informal settlement upgrading to improve intergrated human settlements in Ekurhuleni, South Africa*. Prague: ISPRS.

Musakwa, W., Tshesane, M. R., & Kangethe, M. (2017). The strategically located land index support system for human settlements land reform in South Africa. *Cities, 60,* 91–101.

National Research Council. (2009). *Driving and the built environment: The effects of compact development on motorised travel, energy use and CO2 emissions*. Washington, DC: National Academy of Sciences.

NEAT GIS Protocols. (2010). *Neighbourhood environment for active transport geographic information systems version 5.1, Design for health.net*. New York: Cornell University.

Pelzer, P. (2016). Usefulness of planning support systems: A conceptual framework and an empirical illustration. *Transportation research part A: Policy and practice*, doi:10.1016/j.tra.2016.06.019

Republic of South Africa. (1996). *Constitution of the Republic of South Africa, 1996*. http://www.gov.za/documents/constitution-republic-south-africa-1996

Republic of South Africa. (2004). "*Breaking new ground*"*: A comprehensive plan for the development of sustainable human settlements.* Retrieved December 29, 2015 from http://www.thehda.co.za/uploads/files/BREAKING_NEW_GROUND_DOC_copy-2_1.pdf

Republic of South Africa. (2011). *National development plan: Vision of 2030—Chapter 8.* Pretoria: Government Printers. Retrieved January 30, 2016 from http://www.gov.za/sites/www.gov.za/files/devplan_ch8_0.pdf

Republic of South Africa. (2013). *Spatial planning and land use management Act 16 of 2013.* Pretoria: Goverenment Printers. Retrieved December 28, 2015 from http://www.ruraldevelopment.gov.za/publications/booklet/file/2357-spatial-planning-and-land-use-management-act-no-16-of-2013-booklet

Ross, F. C. (2010). I long to live in a house. In H. Hacksley (Ed.), *Raw life, new hope: Decency, housing and everyday life in a post-apartheid community* (pp. 18–49). Claremont: UCT Press.

Satty, T. (1980). *The analytic hierarchical process*. New York: McGraw-Hill.

Saaty, T. L. (1990). How to make a decision: The analytic hierarchy process. *European Journal of Operational Research, 48*(1), 9–26.

Smith, D. M. (2003). Urban fragmenetaion, inequlaity and social justice: Ethnical perspectives. In P. Harrison, M. Huchzermeyer, & M. Mayekiso (Eds.), *Confronting fragmentation: Housing and urban development in a democratising society* (pp. 26–39). Cape Town: University of Cape Town.

Socio-Economic Rights Institute. (2011). *A resources guide to housing in South Africa 1994–2010: Legislation, policy, programmes and practice*. Johannesburg: Socio-Ecenomic Rights Institute of South Africa.

Stats, S. A. (2016). *Community survey report*. Pretoria: Statistics South Africa.

Te Brömmelstroet, M. (2013). Performance of planning support systems. *Computers, Environment and Urban Systems, 41,* 299–308.

Te Brömmelstroet, M. (2016a). PSS are more user-friendly, but are they also increasingly useful? *Transportation Research Part A: Policy and Practice.* doi:10.1016/j.tra.2016.08.009

Te Brömmelstroet, M. (2016b). Towards a pragmatic research agenda for the PSS domain. *Transportation Research Part A: Policy and Practice*. doi:10.1016/j.tra.2016.05.011

Turok, I., & Borel-Saladin, J. (2014). Is urbanisation in South Africa on a sustainable trajectory? *Development Southern Africa, 31*(5), 675–691.

UN-Habitat. (2010). *State of the World's cities 2010/2011 Bridging the urban divide*. London: EarthScan.

Van Niekerk, A., Du Plessis, D., Boonzaaier, I., Spocter, M., Ferreira, S., Loots, L., et al. (2016). Development of a multi-criteria spatial planning support system for growth potential modelling in the Western cape, South Africa. *Land Use Policy, 50,* 179–193.

Vearey, J. (2015). http://www.migration.org.za/entry/299/call-for-workshop-applicantsmigration-urbanisation-and-health-i

Zuma, N. (2013). *Rural-urban migration in South Africa*. Haikou: Economic Policy Forum.

Chapter 7
Designing with Data for Urban Resilience

Nano Langenheim, Marcus White, Jack Barton and Serryn Eagleson

Abstract The growing availability of spatial data heralds extensive opportunities for urban planning and design. Planning for resilience and enabling positive design outcomes requires transliterate methods of working with data and instigation of systems which can be quickly and iteratively adapted to complex multiple criteria and across multiple geographies. As such, planning support systems are critical to assist decision-makers navigate increasingly large repositories of (big) data, and develop evidence-based, replicable methodologies and easily communicated scenarios that can inform both the planning process and increase community buy-in for behavioural augmentation. To do this, we need to bring together data and information sets in a dynamic way, from disparate and vastly divergent disciplines and sources. This chapter will present a series of exemplars for environmental analysis, predictive modelling and planning support systems, particularly, the Australian Urban Research Infrastructure Network (AURIN): a federated data platform supporting urban research, design and policy formulation.

Keywords Interdisciplinary · Agent based pedestrian modeling · Community consultation · Data access

---

N. Langenheim (✉)
Monash University, Melbourne, Australia
e-mail: Nano.Langenheim@monash.edu

M. White · J. Barton · S. Eagleson
University of Melbourne, Melbourne, Australia
e-mail: mrwhite@unimelb.edu.au

J. Barton
e-mail: jack.barton@unimelb.edu.au

S. Eagleson
e-mail: serrynle@unimelb.edu.au

S. Geertman et al. (eds.), *Planning Support Science for Smarter Urban Futures*, Lecture Notes in Geoinformation and Cartography,
DOI 10.1007/978-3-319-57819-4_7

1 Introduction

Smart urban futures is a concept that covers a myriad of considerations; not only reducing climatic vulnerabilities of the built environment but also optimizing and diversifying the social, economic and structural systems that make our cities liveable (Gleeson 2008; Leichenko 2011).

Considering the theme of this book, this chapter will present two case-studies structuring environmental analysis, predictive modelling and planning support systems.

In the Australian context, we present the challenges of both naturally occurring environmental considerations; climatic, hydraulic and vegetation structure, and how this effects Australian cities' ability to support alternative constructed green and built environments.

This is followed by an outline of the complexities of urban densification alongside changing climatic conditions and the need for flexible and responsive urban forest design strategies which can simultaneously integrate environmental, economic and social systems and the increasingly accurate and rich data sets being developed in these fields.

We will then present a series of exemplars that investigate a reprioritisation of urban design factors, testing the potential for newly available data to directly inform design decision making. The case studies have been supported in part by the Australian Urban Research Infrastructure Network (AURIN) e-infrastructure, and have been extended to locally-specific applications. These case studies will examine:

- Urban forest design scenarios for Elwood in response to two possible hydraulically altered futures, with consideration to the wider Elster Creek catchment and the interaction of vegetation with the water table.
- Bringing together "PedCatch", the novel animated pedestrian accessibility modelling tool used to rapidly test proximity to services, with topographical data to assess calculate street steepness, to improve accessibility to primary schools.

The chapter concludes by presenting a consolidated model for decision-support regarding the above processes, how these can be harnessed to promote health and well-being by increasing the capacity of the built environment for walkability, and in the longer term, risk reduction and increased urban resilience.

1.1 The Concept of Resilience

Resilience is the capacity of individuals, communities, businesses and systems within a city to survive, adapt and grow, not just as a response to shocks (such as heat, fires and floods), but also to the stresses that weaken the fabric of a city on a day-to-day or cyclical basis (Rockefeller Foundation 2016). Resilience as a planning movement is broadly focused on the adaptability of existing urban settlements to changing current and future conditions; environmental, social, behavioural and economic (Boon 2014; Gleeson 2008; Ulmer et al. 2016). However, planning for and implementing the sometimes-competing concerns for resilience in the complex, limited and multifunctional real-estate of the street is a challenging and often 'wicked' problem (Conklin 2005).

1.2 Urban Reprioritisation

Over the past half century, the design of streets has been focused on optimisation of vehicle movement and minimisation of traffic congestion which has, unsurprisingly, lead to more comfortable streets for motorists and streets resilient to increasing vehicle use and ownership (DeRobertis et al. 2014).

Due to changing population health conditions and attitudes towards active transport, thermal comfort concerns in a changing climate, regularity of drought and flooding, and social needs, the priorities of streets are in many cases changing (NACTO 2013).

Reducing the car dominance of streets and increasing other street uses can conflict. For example, an intervention increasing a streets resilience to the environmental impact of overland storm water flow by slowing and filtering storm water through open, street edge retention trenches might contribute to hampering the same streets capacity to be adapted to increased cycle traffic or provide safe waiting zones for public transport users.

1.3 Increasingly Accurate and Rich Data Sets Being Developed

Designing for resilience in response to wicked problems requires a combination of data which is 'fit for use' and decision support tools (Batty 2016). An effective decision support system facilitates evidence-based design in support of smart urban planning.

Data is being generated at an unprecedented rate. Different disciplines are rapidly generating constant feeds of data at high volume, velocity, veracity and variety—commonly referred to as 'big data'. The veracity of data is an important aspect in evidence-based design (Kitchin 2014), enabling designers to assess the quality of the data to support decision-making, allowing for accountability (Wilkinson et al. 2016). Traditional, localised 'small data' repositories are also gaining more visibility and scalability in the context of open data policies and linked data protocols (Kitchin and Lauriault 2015). With these measures in place, is it possible to create a framework for replicable research, scenario testing and consensus building between multiple stakeholder groups? Importantly, a cohort of domain experts can assist in interpreting the data and revealing meaning for other stakeholders.

2 AURIN with Emerging Spatio-Temporal Digital Modelling

With the aforementioned complex, competing and interlinked variables alongside the growing complications of urban densification and changing climatic conditions, there is a growing need for flexible and responsive urban design strategies which can simultaneously integrate multiple data sets, competing design elements as well responding to social systems.

In this chapter, we put forward an integrated approach to a consolidated model for decision-support, bringing together the federated data platform of AURIN, with emerging spatio-temporal digital modelling technologies.

AURIN is a federated data platform supporting urban research, design and policy formulation (Pettit et al. 2015). The AURIN platform facilitates access to open and securitised data services combined over 100 analytical and visualisation tools in a cloud-based portal (Sinnott et al. 2014). As such, AURIN forms a suite of spatial decision support resources that can be tailored to support decision making. In this chapter, we will present two case studies showing how a range of site-specific data can be connected to environmental modelling and proximity/walkability analysis—both these case studies are pertinent to the concept of urban resilience: for both designing environments that are prepared for extreme weather events and also for promoting healthy, robust communities that are best placed to cope with stresses (McCormack et al. 2008; Sarkar et al. 2015; Ulmer et al. 2016).

3 Case Study 1: Urban Forest for Climate Change in Elwood

The Australian climate with its naturally strong variation caused by the changes in the cycle of the El Niño–Southern Oscillation and the Indian Ocean Diopole coupled with complex soil conditions and a consistently low rainfall, have resulted in some unusual and highly specialised eco-evolutionary plant adaptations (Eamus 2006).

The difference and value of Australian vegetation has been recognised and celebrated in planning policies, design and street planting, most recognisably in the work of the Griffins in the 1930s, with a style reflecting the City Beautiful approach, blending exotics and natives for textural effect (Wilson 1993) and reaching a height of popularity in the 1970s and 80s reflecting the growing interest in native flora and formation of the Society for Growing Australian Native Plants

(Gray 1993). During this period many local councils adopted indigenous tree planting strategies (White and Langenheim 2014), however, use of native species in public spaces has declined over the past decade due to suitability issues for urban conditions (Dobbs et al. 2013).

Often, it is the same mechanisms that make indigenous and native tree species resilient to a challenging climate that can make them difficult to manage or perceived as dangerous in higher density urban environments (Kirkpatrick et al. 2012). Climate survival mechanisms such as rapid growth and early decline in the case of many Acacia species, limb drop and bark shedding in the case of some Eucalyptus species, and regeneration through exposure to smoke or fire are not traits that lend themselves well to the needs of urban vegetation. Expectations of urban trees include: longevity, stable branch attachments, predictable form or architecture, minimum production of leaf litter and deciduous habit to maximise winter solar access (Kirkpatrick et al. 2012).

Few Australian native species fit these 'behavioural' expectations of urban trees unless selectively bred or genetically cloned (Holliday and Watton 1980). While these genetically selected forms may have more predictable form, the use of a narrow gene pool reduces the overall resilience of the urban forest to pest or pathogen attack.

Ecologically and culturally it is important to continue to include a proportion of native species in urban forests (Threlfall et al. 2016). However, harnessing the resilient capabilities of native vegetation means embracing some of the more challenging aspects such as large fruit, year-round leaf drop and less predictable mature tree architectures. Substantial changes in public expectations of urban tree 'behaviour' and more integrated specialised urban forest management strategies are needed and require integrated modelling of scenarios for both urban forest planning, environmental impact and community consultation and acceptance (Dobbs et al. 2014).

3.1 Climate Change Considerations

Both natural and urban forests are highly susceptible to even minor changes in climate and water balance. While natural vegetation communities have always been dynamic compositions, with individual species changing geographic occurrence or frequency according to climatic niche, the trees of urban forests are often artificially maintained for historic or cultural reasons (Shears 2009).

Climate change modelling suggests increases in heat wave duration, intensity alongside reduction in annual rainfall (BOM 2013). Even native tree species, already adapted to this variability are expected to have geographic migrations in response to future conditions (Mitchell et al. 2014) and the continued inclusion of a number of introduced species which struggled to survive the recent Millennium drought in Victorian urban forests is under question unless additional water resources can be supplied (Shears 2009).

3.2 Interoperability of Spatial Data Across Environmental and Political Boundaries

An increasing number of national environmental data platforms have been developed over the past decade geared towards environmental modelling of hydrology such as: the Bureau of Meteorology's Geofabric, an equivalent to a roadmap for streams and rivers and associated catchments across Australia; the Department of Environment, Land, Water and Planning (DELWP) Biodiversity Interactive Map (formerly the Department of Environment and Primary Industries; BIM) which contains the 1750s modelled vegetation classes based on pre-European settlement climatic, hydrology and geological conditions; and the Atlas of Living Australia, a data repository for occurrence records of all living things, where data can be overlaid with climatic biomes, or cleaned and used in the Biodiversity and Climate Change Virtual Laboratory (BCCVL) to model the spatial and climatic distributions of a specific species. These are just a selection of publicly accessible environmental spatial data repository and analysis portals, which can be used in conjunction with the political or health related data available through AURIN.

While design and planning have traditionally been engaged primarily with political or health data at a spatial level, integration of spatial environmental data with these political and social data sets is increasingly necessary for assessing the impacts of natural systems on built systems and vice versa.

Commonalities of data formats and geographic terminology allow transdisciplinary and diverse uses of spatial data from walkability of neighbourhoods to planning for sea level rise under different climatic conditions.

3.3 Elwood

In 2012 Melbourne Water (2012) released the document *Planning for Sea Level Rise* which assessed developed areas prone to future tidal inundation in the Port Phillip and Western Port Region, given a predicted increase of 0.8 m in the 100 year flood level by the year 2100. The current 100 year flood level is 1.6 m Australian Height Datum (AHD) and future predictions would see this rise to 2.4 m.

One of the most vulnerable areas within the Port Philip Region is the coastal suburb of Elwood, located at the base of the catchment of the Elster Creek. Elwood is already prone to flooding from overland flow from adjacent upper catchment suburbs during extreme rainfall events and a sea level rise of 0.8 m would render Elwood susceptible to both tidal and storm water flooding in the future (Fig. 1 broad scale and Fig. 2 local scale).

Making Elwood adaptable or resilient to these future conditions will require strategic integrated thinking from multiple disciplines and management bodies working across large-scale environmental data such as catchments, soil profiles,

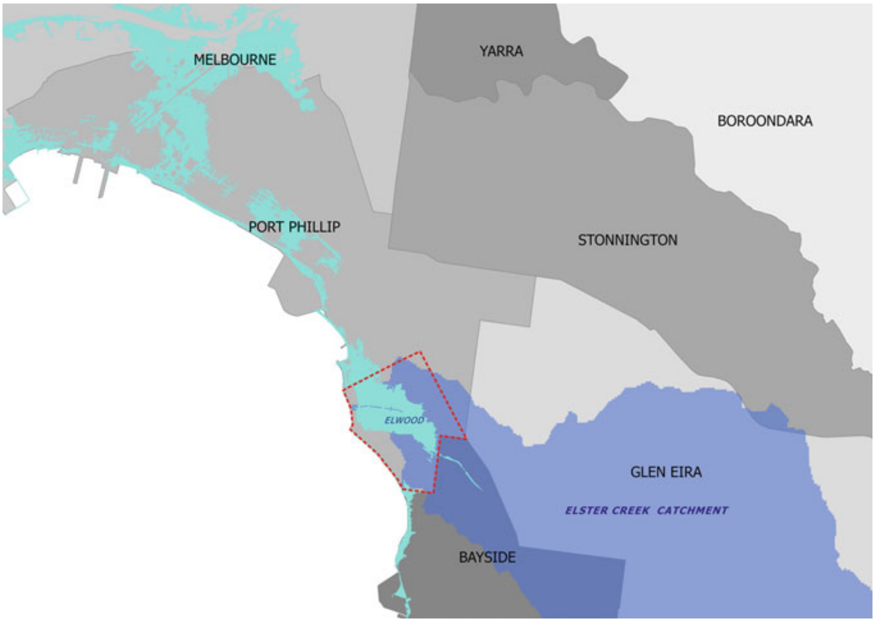


Fig. 1 Melbourne Water 2100, predicted 100 year flood level over Victoria's south east coast

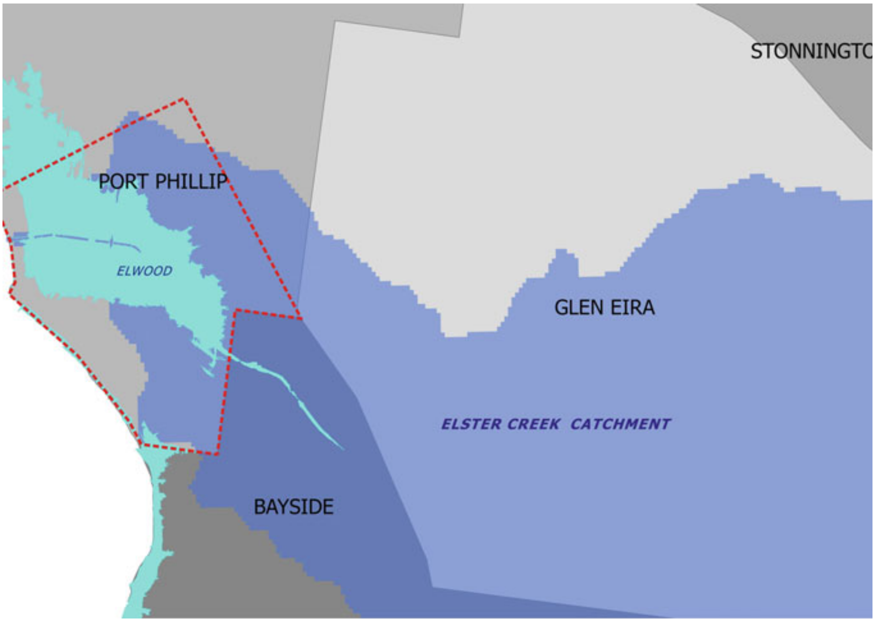


Fig. 2 Detail of the Elwood area at the base of the Elster creek catchment which extends over four LGA boundaries

political and economic data of employment, transport and land development and health data. Interventions will need to span both the public and private realm of the entire Elster Creek catchment and extend south east into the three adjacent Local Government Areas (LGAs) of Glen Eira, Kingston and Bayside. Some of the broader issues likely to impact Elwood in the future were the subject of an interdisciplinary research project undertaken by the CRC for Water Sensitive Cities in 2016 (Rogers et al. 2016).

3.4 Designing Urban Forests for Resilience

Urban forests, while generally considered to be publicly managed trees technically, can also include all vegetation strata, trees to ground cover, on both public and private land. There are however considerable barriers to control, protection or data collection of private landscapes to enable a quantifiable inclusion of either their impact or possible contribution to ecosystem services (Parmehr et al. 2016). Australian native plant survival was modelled by Mitchell et al. (2014) to have a threshold of 98% of the climatic extremes of their occurrence. In climate change scenarios of increased heat and CO_2 and decreased or more erratic water availability, there is likely to be a number of plant species ‘migrations’ where some species will no longer grow in certain areas and other traditionally warmer climate species might take their place.

In Elwood the defining survival factors for the urban forest could be a requirement for increased salt tolerance through sea water incursion into a rising water table, tolerance to prolonged inundation but possibly also periods of extended drought and heat.

This project explores replacement, planning and management strategies for the urban forest of Elwood as an integrated public and private space strategy spanning the multiple LGAs contributing to the Elster Creek catchment.

Surface water catchment data was extracted from the Bureau of Meteorology’ Geofabric version 3 and was coupled with the Department of Environment, Land, Water and Planning (DELPW); Interactive Biodiversity Map (BIM) data of the modelled 1,750 ecological vegetation classes (EVS)s alongside the recent mapping of aquifer and salt dependant vegetation communities, overlaid with Melbourne Water datasets of 1–5 m contours and building footprints for the suburb of Elwood accessed through the AURIN portal.

3.5 The Existing Urban Forest of Elwood

In Melbourne, urban forests can represent an increase in canopy cover compared with the previously existing natural conditions, particularly where development replaces open woodland, grassland or swamp ecological vegetation communities as is suggested by the BIM 1750s modelling data for Elwood Victoria (Presland 2008).

Despite poor conditions for tree growth, the existing street trees of Elwood are some of Melbourne's best specimens, possibly due to the better than average soil conditions, its location in the average annual rainfall distribution zone of 600–750 mm per year and its location at the base of a shallow valley, receiving additional stormwater runoff as a resource.

The urban forest design scenarios for Elwood are in response to two possible hydraulically altered futures:

(A) increased heatwaves and periods of drought and flash flooding (reduced water budget—decreased annual inflow with increased occurrence of the 100 year flood) (Melbourne Water 2013); or

(B) periods of prolonged and possibly saline flooding (sea level rise scenario) (Fig. 3).

Australia has been at the forefront of Water Sensitive Urban Design (WSUD) policy, technology and built design work for several decades (Fletcher et al. 2013). Pipeless or reduced dependence on piped stormwater infrastructure aims to reduce stormwater flow rates and to filter out pollution through soil profiles before it reaches receiving water bodies. WSUD has been very successful at protecting receiving waters, however where underground aquifers are open and close to the surface, complications of rising water tables and surface water/groundwater interaction can make this type of infrastructure unfeasible (Melbourne Water 2013).

Here, the aquifer boundaries and height from surface are extracted from the Southern Rural Water dataset which was recently used in the 'Visualising Victoria's Groundwater' three-dimensional web access model. These were overlaid with the

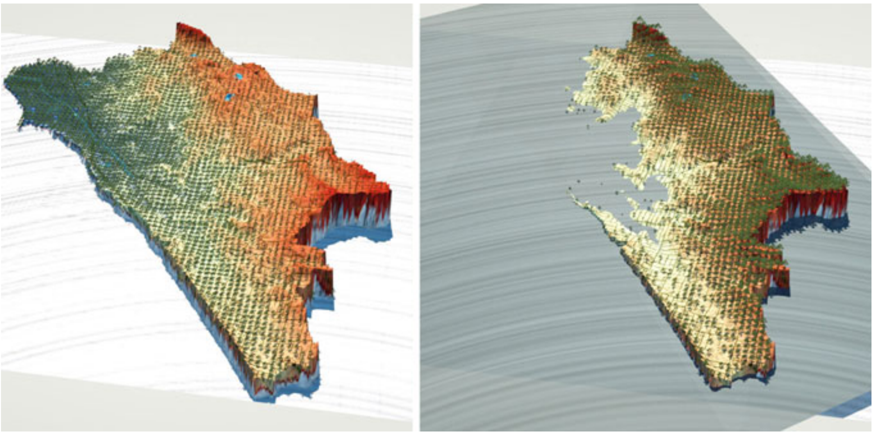


Fig. 3 Scenario A (*left*), where trees at the base of the catchment are the healthiest as they have the highest water budget and scenario B (*right*) where trees die off due to prolonged periods of possibly saline conditions

Fig. 4 Trees in the flood zone remain healthy while outside the flood zone they decline

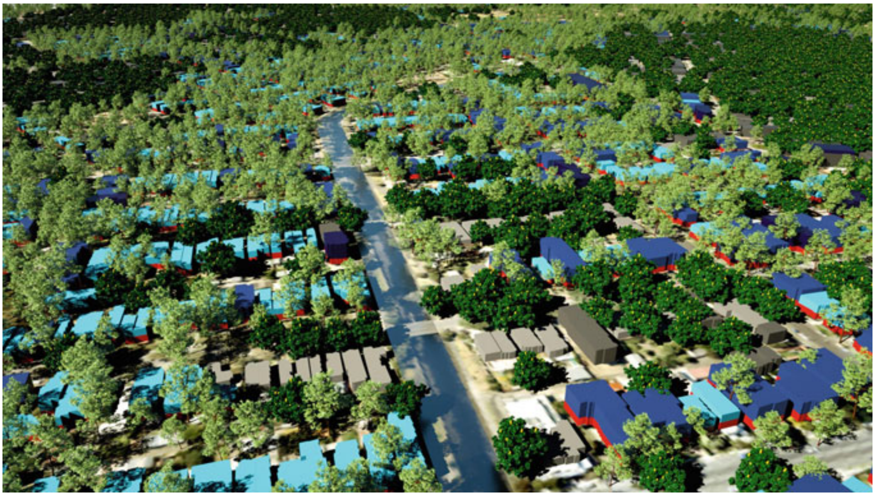


Fig. 5 Trees outside the flood zone are replaced with ground water utilizing species to ensure survival during drought

catchment boundaries from BOM's Geofabric both of which can be visualised in the AURIN portal against the tree inventory data.

In scenario A, the existing urban forest *within* the flood zone remains healthy while trees beyond the flood zone decline or are replaced by groundwater utilizing species (see Figs. 4 and 5—blue buildings are affected by flood).

In scenario B, where periods of prolonged flooding might occur, existing trees in the flood zone would decline due to anaerobic soil conditions (Fig. 6). Few species

Fig. 6 Existing trees in the flood zone die in the event of prolonged flood

Fig. 7 Fast growing replacement species in the flood zone—can be harvested in the case of repeat flood event

are adapted to both flood and drought and those that are have other traits which make them unsuitable for urban conditions, so in this scenario an unusual tree management strategy is modelled. As flooding to the 100 year level is expected to increase in the future and occur more frequently, flood zone trees are replaced with fast growing, short lifespan trees such as Acacia species which can be harvested and used for mulch in the event of death (Fig. 7).

4 Case Study 2: Inclusive Accessibility to Primary Schools

4.1 Walkable Access Leads to Healthier and More Resilient Communities

For the Australian population's health, it is critically important to increase the level of physical activity of the country's citizens, particularly its younger population which has seen a steady decline in active transport used by children to go to and from school and growing incidences of childhood obesity in recent decades (Olds et al. 2010; Schlossberg et al. 2006; Van der Ploeg et al. 2008). Children walking to school is critical for an active and healthy community with not only health, but environmental and social benefits (Giles-Corti et al. 2011).

The probability of children walking to school increases where children live in well-connected-neighbourhoods with good pedestrian accessibility or "Ped-shed" ratings (Giles-Corti et al. 2011; Owen et al. 2004). It is therefore important for urban designers to carefully consider school siting and street design in school neighbourhoods to encourage children to walk to school (Giles-Corti et al. 2011; Owen et al. 2004, 2007) in addition to traffic volume and perceived safety (Bell et al. 2005; Giles-Corti et al. 2011).

Accessibility is important for people with all levels of mobility and members of the disability community have a right to realise their potential for autonomous movement in the community, and this should be facilitated to the greatest possible extent (United Nations 2006). Strategies for urban design that consider physical barriers such as steep inclines are needed to maximise accessibility for people with mobility impairments. Gradient or steepness of streets can also impact upon parents with younger children in prams and children cycling to school.

In addition to health and social inclusion benefits of increasing walking and cycling to schools, there are also numerous co-benefits such as reduced car and oil dependence (Newman et al. 2009) as well as the reduction of energy use, travel costs and pollution (Jarrett et al. 2012; McDonald et al. 2016).

4.2 Measuring Access and Proximity: Pedestrian Catchment Modelling

Modelling walking proximity to services has traditionally been limited (Sander et al. 2010), to 'Euclidean buffers' or 'circular catchments' (as-the-crow-flies distance from destinations) being a commonly adopted approach (Andersen and Landex 2009). Here, a circle with a given radius is mapped, representing a theoretical catchment for a chosen walking time from a destination. For example, a 400 or 800 m radius may be drawn to indicate an approximation of five or ten minutes' walk to the central node. This Euclidean buffer method has been used since the early 1900s (Fig. 8), and is still common practice despite receiving criticism for not

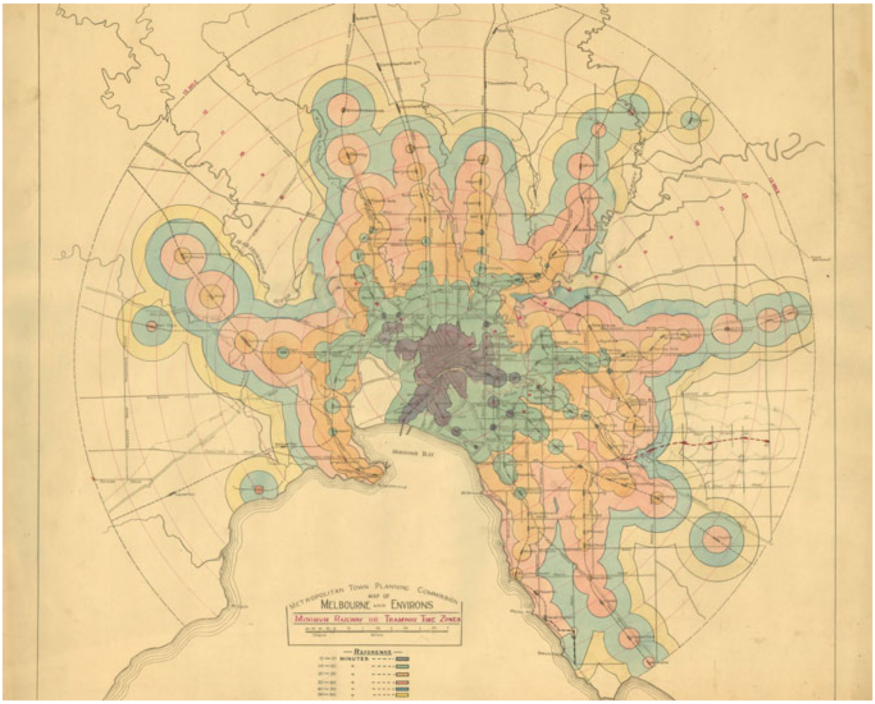


Fig. 8 Map by Melbourne and Metropolitan Tramways Board showing hand drawn public transport catchments using the Euclidean buffer approach to accessibility modelling (between 1910 and 1922 *Source* State Library of Victoria)

accounting for street networks, barriers to walkability such as steep inclines, and its tendency to overestimate catchment areas (Pikora et al. 2001).

Development of proprietary GIS software such as ESRI ArcGIS™ with the Network-Analyst™ plugin, makes a dramatic improvement on accessibility catchment modelling (Andersen and Landex 2009) with the vector distance based Service Area Approach (often referred to as pedsheds) and Network Buffer Approach. These methods calculate vector distances travelled for each path from a central node and, using the shoelace formula (Gauss's area formula), create a convex hull catchment shape or network offset buffer catchment shape respectively of known area (Steiniger and Hunter 2013).

This method can produce more accurate and useful accessibility analysis but can be prohibitively expensive, requiring high-end GIS software.

4.3 *The PedCatch Platform*

Due to improvements in both software and hardware, Agent-Based Modelling (ABM) is increasingly used for assessing human movement (Yang and Diez-Roux

2013). PedCatch was a simple agent-based-catchment analysis model used to animate and calculate the ratio of the pedestrian network area to the area of a Euclidian buffer (White 2007). The simple agents moved at average human walking speeds, navigating the street network from a central node (for example, railway stations or schools) to assess existing catchments for 5 and 10 min walking distances. The tool was later rewritten with Badland et al. (2013) to work with web-based GIS road centre line vector data from the AURIN portal. Here the impact of waiting time at traffic lights through an additional crossing wait time variable was added.

An updated version of PedCatch was then released in 2016 (http://pedcatch.com) which can use open-source (OpenStreetMap) network data in addition to data from the AURIN portal, can filter out major busy roads and freeways to exclude non-pedestrian trafficable roads, and can also calculate street steepness using elevation data such as NASA's Shuttle Radar Topography Mission (SRTM) or Land Victoria's State Digital Map Base topographic data (White and Kimm 2016).

4.4 Application on Kensington Primary School

To test the effectiveness of accessibility modelling utilising these data sets and design tools, we conducted an accessibility improvement study for Kensington Primary School, a primary school in an inner Melbourne suburb.

The workflow involved accessing road network data sets via AURIN and loading them into the PedCatch web-based tool. The location was set (this can be done by either searching for a specific location or by zooming and panning to the desired location followed by a right mouse click) and detailed start points were set (entry gates). Gradient (steepness) thresholds were set—for this example we used 1:14 gradient (possible to traverse in wheel chair with hand rails or ride up on a pushbike), walking speed was set to 1.3 m per second, and a catchment time limit was set to 10 min.

The simulation was then run, showing animated agents (pedestrians) navigating through the street network to analyse how far it was possible to travel out from the school within the specified time limit of 10 min (Fig. 9). The results of the simulation demonstrate the difference in catchment area between the old circular catchment method and the agent based simulation which was, as expected, considerably smaller in area (Fig. 10). Due to the steep railway underpass and steep embankments to the south-west and west of the school, many potential pathways were beyond the specified gradient threshold (shown red) and thus pedestrian agents did not traverse these streets. The impact of topographic barriers was clearly identifiable (Figs. 10 and 11).

Based on the topographic accessibility barriers, small urban interventions were proposed including a small pedestrian link to the north-west of the site, re-grading the underpass beneath the railway to be wheelchair accessible to the north-east of the site, and lengthening the existing ramp to the south-west of the site to be wheelchair accessible (Fig. 11).

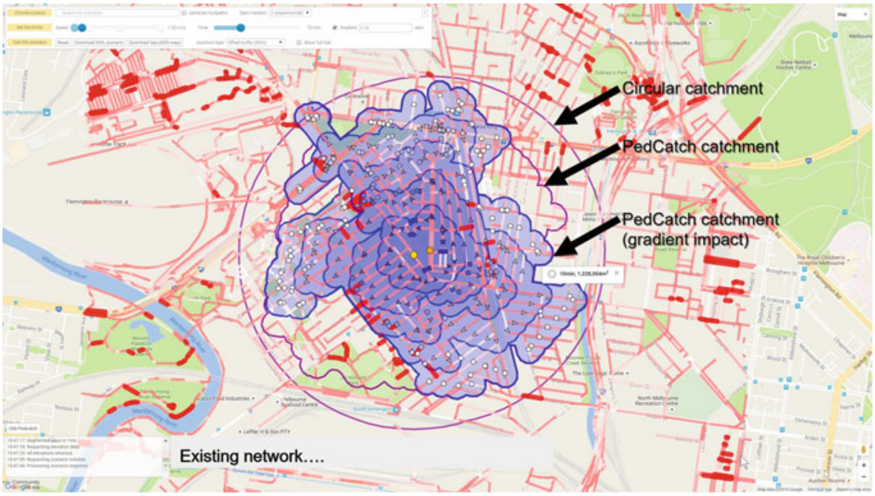


Fig. 9 PedCatch screen grab of simulation calculating catchment area for Kensington Primary School showing circular catchment area, PedCatch (pedestrians navigating through streets) catchment, and PedCatch with impacted by topographic barriers

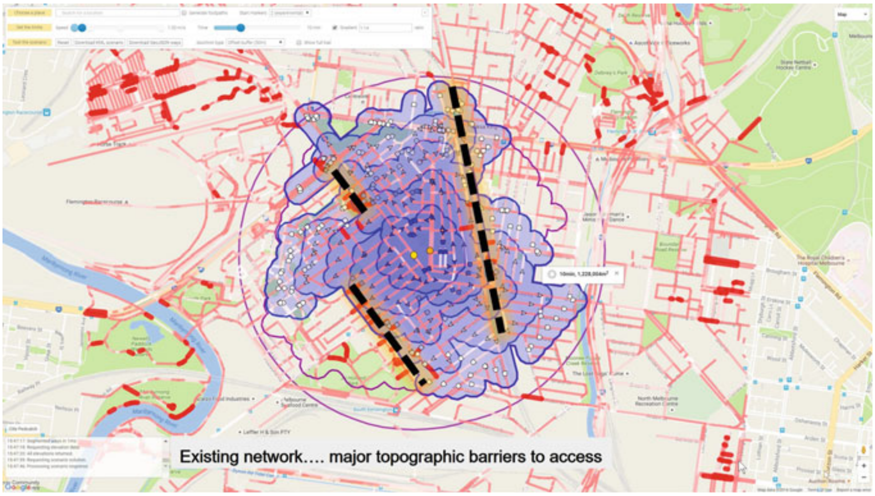


Fig. 10 PedCatch screen grab of simulation with dashed lines over major topographic barriers: steep embankments to the north-west and south-west of the site and the railway line to the east of the site

To test these proposed interventions, the pedestrian network data was downloaded and edited using the open-source GIS program QGIS using its inbuilt vector editing tools. The new network was then updated in PedCatch and the simulation was re-run (Fig. 12).

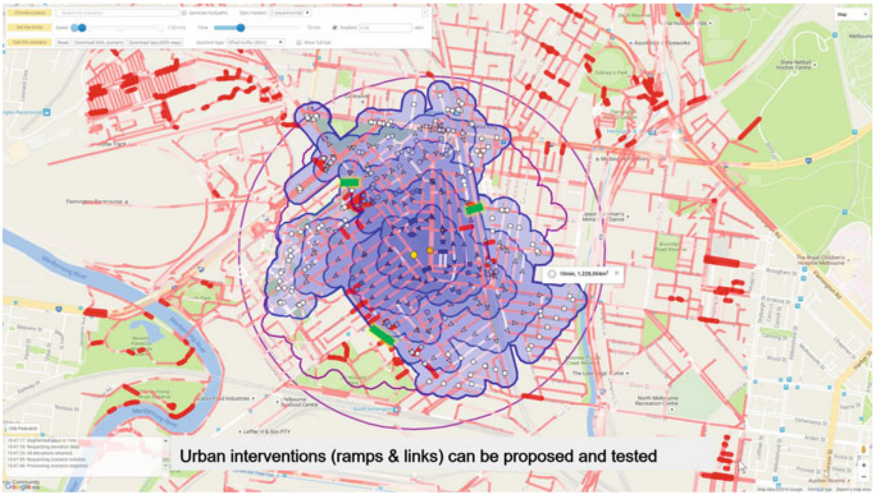


Fig. 11 Potential accessibility improvements to pedestrian network though minor urban interventions (edited network vectors) highlighted in *green*

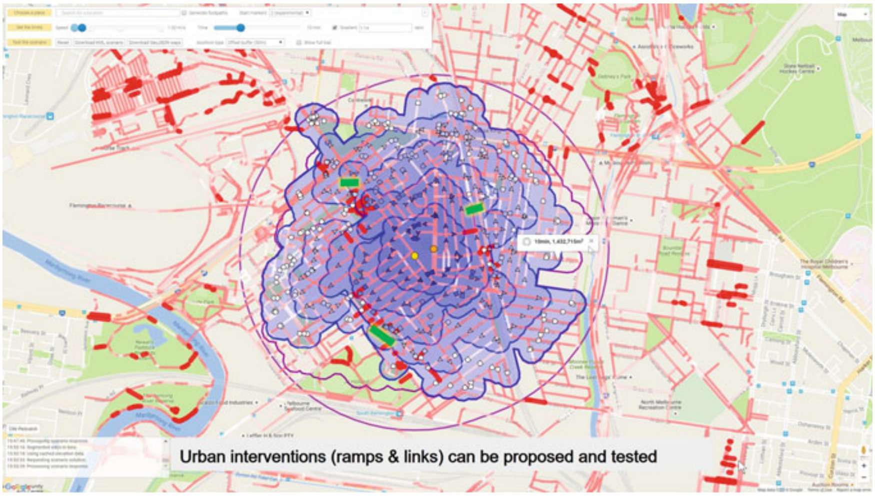


Fig. 12 PedCatch screen grab of simulation re-run with edited pedestrian network vectors, showing increased catchment area

The simulation of the proposed access modifications to the street network clearly demonstrated that by introducing these minor improvements, an additional 320 homes could be made accessible (Fig. 13).

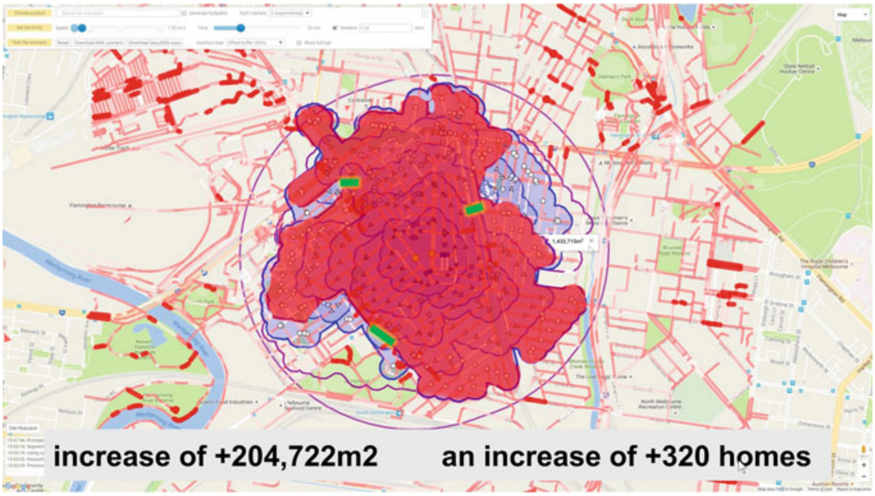


Fig. 13 Visual catchment area overlay comparing the existing catchment (*coloured red*) versus the potential catchment (*coloured mauve*) showing dramatic increase in catchment area and potential homes within this area

5 Discussion

In the first case study, we discussed the use of datasets from the water management bodies; Melbourne Water and Southern Rural Water, combining these with climate change and sea level rise projections and data extraction from satellite imagery to graphically model scenarios for Elwood's urban forest. The modelled scenarios demonstrate an integrated private and public realm approach as well as a vision which works across the political boundaries of several LGAs.

Accessing and visualising datasets which straddle diverse discipline areas within a single platform allowed us to integrate complex environmental and social conditions into a decision-making process. The resulting 'what if' visualisations for a possible future urban forest of Elwood are not a design determined by the datasets used in the process but they are quantifiably informed by them and the process can therefore become an adjustable framework for stakeholder engagement and negotiation.

In the second case study, we described the potential of designing with integrated street network, traffic and topographic data. Using datasets from AURIN combined with the pedestrian catchment modelling tool PedCatch, we could analyse existing urban conditions, graphically identify issues and then test potential urban design improvements. The simple primary school accessibility study illustrates the benefits of combing datasets for urban design decision-making helping local governments to prioritise infrastructure improvement spending to facilitate active and resilient transport for the school's parents and pupils.

The study also suggests the potential benefits of combining safety related data sets such as visual connectivity (visibility graph analysis), on-site carparking and numbers of driveways, and traffic incidences. The study also suggests benefits of combining spatio-temporal heat data, tree shade data as well as street pollution (pm10 and pm2.5) data.

6 Conclusion

The classic definition of a decision support system (Batty 2016; Geertman et al. 2013) entails an architecture that accommodates 'a system of systems' facilitating customisation and flexibility fit for a specific purpose. The current state-of-the-art enables decision-makers and researchers to have increasing ease of access to specialised datasets. Combining data across multiple domains helps inform the planning and design process on many levels. Transparent methodologies incorporating sharable data repositories encourage replicability and iterative improvements in outcomes. This collaborative, data-driven process is well matched to support the development of more resilient environments. In the case studies presented, the interplay between vegetation type, tree canopy, topography, walkability and agent behaviour has been modelled and serves to act as a method for articulating scenarios and outcomes in an evidence-based way. Combined with a site-specific approach, stakeholders can be engaged in an informed way. This interaction is critical in achieving a shared understanding of the risks and threats faced by a locality and presents the opportunity to build consensus and influence passive and active behavioural changes over the long term. With these mechanisms in place, we have the capacity to build longitudinal studies that can quantitatively measure the impact of a policy or design intervention at the local level. Given the long-term nature of managing community response to stresses relating to climate change, and concurrently encouraging healthy, thriving and resilient communities, both site-specific applications and replicable methodologies presented in this chapter are critical in building a communal knowledge and evidence base.

Acknowledgements The PedCatch tool has been built on prior work funded by the Australian Urban Research Infrastructure Network (AURIN) and The Australian National Data Service (ANDS). The current project is a University of Melbourne Disability Research Initiative funded by Melbourne Networked Society Institute (MNSI) and Melbourne Social Equity Institute (MSEI).

The Elwood project was developed through PhD candidature in the Department of Architecture, Monash University and forms part of the wider research into Elwood and its catchment undertaken by the Co-operative Research Centre for Water Sensitive Cities' D5.1 program.

References

Andersen, J., & Landex, A. (2009). GIS-based approaches to catchment area analyses of mass transit. In *ESRI Users Group Conference* (pp. 1–13). ESRI.

Badland, H., White, M., MacAulay, G., Eagleson, S., Mavoa, S., Pettit, C., et al. (2013). Using simple agent-based modeling to inform and enhance neighborhood walkability. *International Journal of Health Geographics, 12*(1), 58.

Batty, M. (2016). Urban resilience: How cities need to adapt to unanticipated and sudden change. In E. Pate-Cornell, W. B. Rouse, C. M. Vest (Eds.), *Perspectives on complex global challenges: Education, energy, healthcare, security and resilience* (pp. 169–171). New York: Wiley.

Bell, A., Garrard, J., & Swinburn, B. (2005). Active transport to work in Australia: Is it all downhill from here? *Asia-Pacific Journal of Public Health/Asia-Pacific Academic Consortium for Public Health, 18*(1), 62–68.

BOM. (2013). *2013 shaping up to be one of Australia's hottest years on record*. Bureau of Meteorology. Accessed July 11, 2016 from http://www.bom.gov.au/climate/updates/articles/a003-2013-temperature.shtml#july-update

Boon, H. J. (2014). Disaster resilience in a flood-impacted rural Australian town. *Natural Hazards*, *71*(1), 683–701.

Conklin, J. (2005). *Dialogue mapping: Building shared understanding of wicked problems*. New York: Wiley.

Derobertis, M., Eells, J., Kott, J., & Lee, R. W. (2014). Changing the paradigm of traffic impact studies: How typical traffic studies inhibit sustainable transportation. *ITE Journal*, *84*(5), 30.

Dobbs, C., Kendal, D., & Nitschke, C. (2013). The effects of land tenure and land use on the urban forest structure and composition of Melbourne. *Urban Forestry & Urban Greening, 12,* 417–425.

Dobbs, C., Kendal, D., & Nitschke, C. R. (2014). Multiple ecosystem services and disservices of the urban forest establishing their connections with landscape structure and sociodemographics. *Ecological Indicators, 43,* 44–55.

Eamus, D. (2006). *Ecohydrology: Vegetation function, water and resource management*. Melbourne : CSIRO Publishing.

Fletcher, T., Andrieu, H., & Hamel, P. (2013). Understanding, management and modelling of urban hydrology and its consequences for receiving waters: A state of the art. *Advances in Water Resources, 51,* 261–279.

Geertman, S., Toppen, F., & Stillwell, J. (Eds.). (2013). *Planning support systems for sustainable urban development.* Berlin, Heidelberg: Springer: Imprint: Springer.

Giles-Corti, B., Wood, G., Pikora, T., Learnihan, V., Bulsara, M., Van Niel, K., et al. (2011). School site and the potential to walk to school: The impact of street connectivity and traffic exposure in school neighborhoods. *Health & place, 17*(2), 545–550.

Gleeson, B. (2008). Critical commentary. Waking from the dream: An Australian perspective on urban resilience. *Urban Studies*, *45*(13), 2653–2668.

Gray, M. (1993). *Flora of Melbourne*. Hyland House.

Holliday, I., & Watton, G. (1980). *A gardener's guide to eucalypts* (pp. 94–95). Rigby Publishers.

Jarrett, J., Woodcock, J., Griffiths, U. K., Chalabi, Z., Edwards, P., Roberts, I., et al. (2012). Effect of increasing active travel in urban England and Wales on costs to the National Health Service. *The Lancet, 379*(9832), 2198–2205.

Kirkpatrick, J., Davison, A., & Daniels, G. (2012). Resident attitudes towards trees influence the planting and removal of different types of trees in eastern Australian cities. *Landscape and Urban Planning, 107*(2), 147–158.

Kitchin, R. (2014). The real-time city? Big data and smart urbanism. *GeoJournal, 79*(1), 1–14.

Kitchin, R., & Lauriault, T. P. (2015). Small data in the era of big data. *GeoJournal, 80*(4), 463–475.

Leichenko, R. (2011). Climate change and urban resilience. *Current Opinion in Environmental Sustainability*, *3*(3), 164–168.

McCormack, G. R., Giles-Corti, B., & Bulsara, M. (2008). The relationship between destination proximity, destination mix and physical activity behaviors. *Preventive Medicine*, *46*(1), 33–40.

McDonald, N. C., Steiner, R. L., Palmer, W. M., Bullock, A. N., Sisiopiku, V. P., & Lytle, B. F. (2016). Costs of school transportation: quantifying the fiscal impacts of encouraging walking and bicycling for school travel. *Transportation, 43*(1), 159–175.

Melbourne Water. (2012). *Planning for sea level rise—Guidelines*. Melbourne: Melbourne Water.

Melbourne Water. (2013). *Stormwater strategy: A Melbourne Water strategy for managing rural and urban runoff*. Melbourne: Melbourne Water.

Mitchell, P. J., O'Grady, A. P., Hayes, K. R., & Pinkard, E. A. (2014). Exposure of trees to drought-induced die-off is defined by a common climatic threshold across different vegetation types. *Ecology and Evolution, 4*(7), 1088–1101.

NACTO. (2013). *Urban street design guide.* Washington, DC : Island Press/Center for Resource Economics : Imprint: Island Press.

Newman, P., Beatley, T., & Boyer, H. (2009). *Resilient cities: Responding to peak oil and climate change*. Island Press.

Olds, T. S., Tomkinson, G. R., Ferrar, K. E., & Maher, C. A. (2010). Trends in the prevalence of childhood overweight and obesity in Australia between 1985 and 2008. *International Journal of Obesity, 34*(1), 57–66.

Owen, N., Cerin, E., Leslie, E., Coffee, N., Frank, L. D., Bauman, A. E., et al. (2007). Neighborhood walkability and the walking behavior of Australian adults. *American Journal of Preventive Medicine, 33*(5), 387–395.

Owen, N., Humpel, N., Leslie, E., Bauman, A., & Sallis, J. F. (2004). Understanding environmental influences on walking: Review and research agenda. *American Journal of Preventive Medicine, 27*(1), 67–76.

Parmehr, E. G., Amati, M., Taylor, E. J., & Livesley, S. J. (2016). Original article: Estimation of urban tree canopy cover using random point sampling and remote sensing methods. *Urban Forestry & Urban Greening, 20,* 160–171.

Pettit, C.J., Barton, J., Goldie, X., Sinnott, R., Stimson, R., & Kvan, T. (2015). The Australian urban intelligence network supporting smart cities. In S. Geertman, J. Stillwell, J. Ferreira, J. Goodspeed (Eds.), *Planning Support Systems and Smart Cities* (pp. 243–259). Lecture Notes in Geoinformation and Cartography. Cham: Springer International Publishing.

Pikora, T., Giles-Corti, B., & Donovan, R. (2001). How far will people walk to facilities in their local neighbourhoods? In *Australia: Walking the 21st Century, International Conference, 2001, Perth, Western Australia* (Vol. 3).

Presland, G. (2008). *The place for a village: How nature has shaped the city of Melbourne.* Melbourne: Museum Victoria Publishing.

Rockefeller Foundation. (2016). The role of foundations: Rockefeller Foundation. *Public Health Reviews, 37*(1), 32.

Rogers, B., Bertram, N., Gunn, A., Löwe, R., Murphy, C., Pasman, R., et al. (2016). An interdisciplinary approach to identify adaptation strategies that enhance flood resilience and urban liveability. In *IWA World Water Congress & Exhibition*.

Sander, H., Ghosh, D., van Riper, D., & Manson, S. M. (2010). How do you measure distance in spatial models? An example using open-space valuation. *Environment and Planning B: Planning and Design, 37*(5), 874–894.

Sarkar, C., Webster, C., Pryor, M., Tang, D., Melbourne, S., Zhang X., & Jianzheng, L. (2015). Exploring associations between urban green, street design and walking: Results from the greater London boroughs. *Landscape and Urban Planning*, *143*, 112–125.

Schlossberg, M., Greene, J., Phillips, P. P., Johnson, B., & Parker, B. (2006). School trips: effects of urban form and distance on travel mode. *Journal of the American Planning Association, 72* (3), 337–346.

Shears, I. (2009). City of Melbourne: An urban greening perspective. In *Proceedings of Conference on The 10th National Street Tree Symposium, TreeNet, Adelaide, Australia* (pp. 55–61).

Sinnott, R. O. C., Bayliss, A., Bromage, G., Galang, G., Grazioli, P., Greenwood, G., et al. (2014). The Australia urban research gateway. *Concurrency and Computation: Practice and Experience, 27*(2), 358–375.

Steiniger, S., & Hunter, A. J. (2013). *A user manual to perform home range analysis and estimation with OpenJUMP HoRAE*.

Threlfall, C. G., Williams, N. S., Hahs, A. K., & Livesley, S. J. (2016). Approaches to urban vegetation management and the impacts on urban bird and bat assemblages. *Landscape and Urban Planning, 153,* 28–39.

Ulmer, J. M., Wolf, K. L., Backman, D. R., Tretheway, R. L., Blain, C. J. A., O'Neil-Dunne, J. P. M., & Frank L. D. (2016). Multiple health benefits of urban tree canopy: The mounting evidence for a green prescription. *Health & Place*, *42*, 54–62.

United Nations. (2006). *UN Convention on the Rights of Persons with Disabilities*. Department of Public Information. http://www.un.org/disabilities/convention/conventionfull.shtml

Van der Ploeg, H. P., Merom, D., Corpuz, G., & Bauman, A. E. (2008). Trends in Australian children traveling to school 1971–2003: Burning petrol or carbohydrates? *Preventive Medicine, 46*(1), 60–62.

White, M. (2007). The plan is an inadequate tool for planning: Enhancing the urban design process through the use of 3D+ digital tools directed towards sustainability. In *Forum on the Application of Sustainable Theory to Urban Development Practice Proceedings*.

White, M., & Kimm, G. (2016). *PedCatch*. http://www.pedcatch.com

White, M., & Langenheim, N. (2014). Impact assessment of street trees in the City of Melbourne using temporal high polygon 3D canopy modelling. In *7th International Urban Design Conference Designing Productive Cities*. Adelaide, Australia.

Wilkinson, M. D., et al. (2016). The FAIR Guiding Principles for scientific data management and stewardship. *Scientific Data*, 3.

Wilson, W. H. (1993). *The city beautiful movement*. Baltimore, USA: Johns Hopkins University Press.

Yang, Y., & Diez-Roux, A. V. (2013). Using an agent-based model to simulate children's active travel to school. *International Journal of Behavioral Nutrition and Physical Activity, 10* (10.1186), 1479–5868.

Chapter 8
Geodesign, Resilience and the Future of Former Mega-Event Sites

Jennifer Minner

Abstract Mega-event sites can yield valuable information for urban planning and they provide a remarkable set of cases to study sustainability, resilience and the urban management of public spaces. This chapter examines concepts of resilience and the application of geodesign tools in the context of design and heritage conservation at former international exposition sites. Evaluation of two geodesign tools are derived from a university urban design workshop and a sponsored research project. Resilience is defined in terms of the ability for public spaces to retain a sense of place and history through preservation of historic resources and other cultural assets. The former mega-event sites can also contribute to the resilience of surrounding communities. Design and planning for these spaces requires interdisciplinary planning that responds to changing social and economic conditions and environmental imperatives. Geodesign tools, such as 3D modeling and scenario planning tools, have the potential to aid in this process. However, additional effort is needed to further develop this capacity, especially in terms of bridging different forms of intelligence about architecture, geography and landscape into a unified 3D GIS platform.

Keywords Geodesign · Mega-events · Resilience · Heritage conservation · Historic preservation · 3D GIS · Mega-projects · Scenario planning

1 Introduction

Both expressions of popular enthusiasm and skepticism are represented in the media coverage of mega-events such as international expositions and the Olympic Games. Scholarly literature on these mega-events fits within a larger research trajectory on the planning and management of mega-projects (Flyvbjerg 2014). Within the mega-projects literature, there is an extensive and growing number of articles about the history of mega-events, their project management and planning, impacts

---

J. Minner (✉)
Department of City and Regional Planning, Cornell University, Ithaca, NY, USA
e-mail: j.minner@cornell.edu

S. Geertman et al. (eds.), *Planning Support Science for Smarter Urban Futures*, Lecture Notes in Geoinformation and Cartography,
DOI 10.1007/978-3-319-57819-4_8

of the events and their performance (Clark et al. 2016; Flyvbjerg 2014). The relatively substantial set of international exposition sites can yield important information for urban planning and management (Azzali 2016; Deng et al. 2014). These sites provide a remarkable set of cases for inquiry into sustainability, resilience and urban management of mega-event sites and the public and private spaces created and maintained over time. Lacking in the literature of mega-events is research on public spaces long after an international exposition has passed and issues in the management and stewardship of these places over time. Furthermore, while international expositions have been showcases of cutting edge-technology, the question of how technology can be used to plan for the future of former international exposition sites has received little attention. This chapter aims to encourage inquiry into geodesign tools and critically assess them according to their usefulness in urban design, preservation and resilience planning at the site of former mega-events.

This chapter fits within the rubric of Planning Support Science. The chapter represents observations from research funded through a U.S. National Parks Services' National Center for Preservation Technology and Training. The research was also initially informed by an urban design workshop at Cornell University that undertook comparative research on four former international exposition sites in North America between 2014 and 2016. The former exposition sites included in the research projects were as follows: the 1962 Century 21 Expo in Seattle, Washington; the site of the 1939–40 and 1964–65 world's fairs in New York City; the site of HemisFair '68 in San Antonio, Texas; and the Expo '67 site in Montreal, Québec. These four international exposition sites are around fifty years old and have a mix of heritage values and issues related to sustainability and urban management. Most pertinent to this book, two of the sites, HemisFair Park in San Antonio and Flushing Meadows Corona Park in New York City, provided a testbed for design, preservation and planning efforts including the use of technologies that include Geographic Information Systems (GIS), 3D modeling, and a scenario planning tool.

This chapter focuses on the questions: What geodesign tools are useful in efforts to examine resilience and heritage conservation at former mega-event sites? What are their strengths and shortcomings? The technologies tested in this research included a freely available scenario planning tool called Envision Tomorrow and the 3D modeling tool, CityEngine. In addition, ArcGIS was used extensively. An array of other design tools, including Photoshop, Google Earth, and SketchUp, and specialized architectural 3D modeling tools, as well as GIS data sources, such as the 3D Warehouse, and local and federal GIS portals were incorporated into this research.

The next section provides an overview of three intersecting areas of literature—mega-event sites, geodesign, and resilience. A following section details the methodology used in a graduate-level workshop and in a related sponsored research project and how the results of those efforts were used in the analysis presented in this chapter. Thereafter, an analysis of geodesign tools and their outcomes with regard to geodesign and resilience is presented. The chapter concludes with a discussion of observations, including the value of publicly available data and the need for higher performance geodesign tools for managing and planning for public spaces that have entwined heritage, design and planning, and management needs.

2 Mega-Events, Geodesign and Resilience

The former sites of international expositions provide units of analysis that are comparable. They vary in size but are uniformly at the scale of the district or neighborhood. Geodesign is especially relevant at this scale, as detailed information about abiotic and biotic environmental systems can be gathered alongside detailed social information (Steiner 2008; Steinitz 2012). In a white paper, Miller (2012) describes geodesign as specifically including 'science-based,' 'values-based' and 'integral design.' The paper describes the use of scientific knowledge, as well as social values, to design in a way that is holistic, and that this provides a "*framework for exploring issues from an interdisciplinary point of view and resolving conflicts between alternative value sets*" (Miller 2012, p. 18). Ervin (2016) writes about the definition of the term: "*Perhaps it would be more comprehensive (though less concise) to say, instead of 'geodesign': 'systems-oriented-planning-and-design-for-large-complex-projects-by-interdisciplinary-teams-and-public-participation-using-computers-and-other-digital-devices-and-representations-together-with-Geographic Information Systems (GIS)-Computer Aided Design (CAD)-Building Information Models (BIM)-and-other-algorithmic-techniques-including-timely-simulation and-impact-assessments' (!); but since this is a mouthful, a community of academics, researchers, planners, designers, computer scientists, policy-makers and others (geodesigners?) have, for only a few years now, been shortening that to 'geodesign'*" (p. 12).

The concept of geodesign has been heavily promoted by ESRI as a means of understanding the value of technology in uniting design and geography (McElvaney 2012; Steinitz 2012; Wilson 2015). The focus on geodesign seems to stem from observations that designers do not use GIS to the extent that the GIS industry and some scholars would hope, using instead other kinds of graphic illustration and architecture specific tools (Ervin and Flaxman 2015).

As awareness of the potential severe effects of climate change has grown, geodesign has been promoted as a tool for resilience (Gerlinger 2014). Resilience is a concept fundamental to disaster preparedness efforts around the world and has a growing literature within urban planning (Beatley 2009; Berke and Stevens 2016). The United Nations Office for Disaster Risk Reduction defines resilience as: "*The ability of a system, community or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions*" (United Nationals office of Disaster Risk Reduction 2007). Land-use planning offers systematic methods to plan for recovery from hazards (Berke and Stevens 2016). This set of methods can be described in four steps: "*(1) generating planning intelligence regarding hazard risks and vulnerability of the local population; (2) setting goals and objectives for reducing risk and vulnerability, (3) adopting policies and programs to achieve the goals and objectives; and (4) monitoring and evaluating the results, making revisions to policies and programs over time as necessary*" (Berke and Stevens 2016, p. 284).

Berke and Stevens emphasize how participatory planning is integral to this four step process. Geodesign tools can be useful for all four steps and in participatory processes, but geodesign tools are particularly relevant to gathering, storing, analyzing, and sharing planning intelligence; designing and assessing alternatives; and in evaluation and monitoring efforts.

Butler et al. (2016) elaborate on the gathering of planning intelligence as the foundation for the design of alternatives in the planning process. They write of comprehensive vulnerability assessments that go beyond basic hazard identification and that "*characterize likely hazard impacts on exposed assets and resources of value*" (Butler et al. 2016, p. 321). Among these potential assets are the historic resources that serve both social and economic functions within a community (Appler and Rumbach 2016). Historic resources contribute to resilience because they help to "*preserve a community's shared identity and reinforce connections between neighbors and the larger community*" (Appler and Rumbach 2016, p. 93). Resilience can also be directly extended to historic resources and their ability to 'bounce back' and retain their historical and cultural significance in the face of change. Cultural landscapes, a term increasingly used in heritage conservation (Longstreth 2008; Minner and Chusid 2016) and that can be applied to former international exposition sites, can be said to be resilient if their historical imprints can be retained in the face of change. Furthermore, a site's cultural resources can contribute to the ability for a community as a whole to recover from natural and man-made threats, by maintaining a sense of place in the face of change (Appler and Rumbach 2016). The historic resources or cultural assets of a site provide continuity through the retention of valued community landmarks, which can contribute to the identity and coherence of public spaces (Lynch 1960, 1972).

The research efforts described in the following sections focus on the evaluation of geodesign tools for the urban management of public spaces and planning where urban design, heritage conservation, and resilience intersect. In this research, historic resources are considered primary assets in design, planning, and maintenance of the sites. Geodesign tools were tested by faculty researchers and students for their usefulness in collecting, maintaining and applying information about historic resources as assets. In addition, as the historic resources are considered assets for the resilience of public spaces and the community's that utilize them, then geodesign tools should be useful in assessing the vulnerability of assets to natural hazards. In addition, a useful geodesign toolset should aid in the creation of alternatives or scenarios in design, planning and conservation. Geodesign tools, when applied to former mega-event sites should support the four step process and in the formation of informed designs and governance. The next section describes the methodology used to explore the use of two geodesign tools in this way, in the interest of building a "critical geodesign" literature, as suggested by Wilson (2015).

3 Research Methodology

An urban design workshop called “Sustainable Adaptation of Large Modern Footprints” was offered in the fall, 2014. The initial workshop concept centered on sustainability and encouraged students to compare four world’s fair sites in North America using a sustainability framework that focused their attention to the domains of economics, environment and equity. Table 1 provides information about the basic attributes of the sites. The workshop generated design, planning and preservation alternatives for two of the sites: Flushing Meadows Corona Park, in the borough of Queens in New York City, and HemisFair Park, in downtown San Antonio, Texas. Special care was taken to incorporate the conservation of historic resources and cultural landscape preservation into proposals. The application of geodesign tools at two sites (highlighted in grey in Table 1) are the focus of this chapter.

Independent of the workshop, but working with insights and results of the workshop, a team of faculty received funding from the National Center for Preservation Technology and Training to explore the use of a 3D GIS modeling tool called CityEngine at Flushing Meadows Corona Park. The platform was used to incorporate 3D models developed by students, professionals, and volunteered by the on-line community, along with 2D GIS data. The goal of that research project was to understand the extent to which CityEngine provided a valuable tool for park preservation and planning efforts.

This chapter represents the extension of both the workshop and sponsored research project, by triangulating the experiences and outcomes of the workshop and subsequent research project with the literature on mega-events, resilience and geodesign.

4 Analysis

In the urban design workshop, students discussed the value of historic resources, including those that date from prior international expositions on the site, as a palimpsest, in which traces of the fairs, as well as from previous and subsequent eras, are visibly manifest in the landscape. The workshop emphasized the retention of these visible traces of the past by either recognizing or re-envisioning them as useful parts of the landscape. At Flushing Meadows Corona Park, this approach took the form of proposals to reconstruct pathways from the 1939 and 1964 world’s fairs that had been removed in later landscaping efforts. Students also proposed creation of new water features using neglected fountains from earlier fairs. A largely abandoned and deteriorating New York State Pavilion was also proposed as a reinvigorated event space. At San Antonio’s HemisFair Park, design interventions focused on means of retaining the traces of the 1968 world’s fair and repurposing pavilions threatened with demolition with new uses.

Table 1 Four former world fair sites that were the focus of a design workshop (Case study sites for this chapter in grey)

	Flushing Meadows Corona Park	**HemisFair Park**	**Seattle Center**	**Parc Jean-Drapeau**
Fair	1964-1965 New York World's Fair	HemisFair	Century 21 Exposition	Expo '67
Location	Within Queens, a borough of New York City, USA	Within downtown San Antonio, Texas, USA	Near downtown Seattle, Washington, USA	Near Downtown, Montreal, Quebec, Canada
Original site size	646 acres	92 acres	74 acres	900 acres
Size of remaining public land after fair	897 acres	92 acres	74 acres	520 acres
Management agency	New York City Parks	HemisFair Park Area Redevelopment Corporation (501(c)3 nonprofit local government corporation)	Seattle Center (a department of the City of Seattle)	Société du parc Jean-Drapeau
Land ownership	City of New York	City of San Antonio, University of Texas at San Antonio, Federal Government	City of Seattle	City of Montreal

Before these design proposals were created, students gathered information or 'planning intelligence.' ArcGIS was used as a means of obtaining information from the New York City Parks Department and from a planning consulting firm that had previously created a geodatabase of major park features and surrounding areas for a 2008 framework plan (Quennell Rothschild and Partners & Smith-Miller + Hawkinson Architects 2008). GIS was a primary platform for the transfer of geographic information about HemisFair Park from the HemisFair Area

Redevelopment Corporation. Students also used ArcGIS to georeference maps of prior fairgrounds, in order to understand building retention and demolition since the fair and changes in land ownership patterns and impervious surfaces. The use of GIS also helped students to understand differences in the overall geography of the sites, including the position of the sites relative to the central business district of each metropolitan area and to compare sites in terms of historic and current sizes of the sites and demographic context. Thus, ArcGIS was a primary platform for gathering and combining detailed intelligence about the sites and analyzing them.

Flushing Meadows Corona Park and HemisFair Park received the most detailed treatment and development of design interventions, whereas sites in Seattle and Montreal were primarily analyzed for sustainability initiatives and compared to the other two. This chapter focuses on the results of the evaluation of two geodesign tools. Many other analyses were conducted, such as the comparative analysis of the sites, key infrastructure, geography and surrounding demographics of the sites. However, this chapter presents only observations about assessments of geodesign tools.

4.1 Assessing a 3D Asset Management and Geodesign Platform for Flushing Meadows Corona Park

The urban design workshop aimed at developing preservation and urban design interventions that combined both scientific data about the geography of the site and threats to it, with values-based discussion. For example, students learned about previous proposals for change within the park. A new soccer stadium had been proposed on the site, and critics had decried additional development within the park. There were concerns that additional impervious surfaces would reduce the park's function as "*a natural sponge for tidal surges and stormwater runoff*" (Munshi-South 2012, n.p.) that protects surrounding neighborhoods from severe flooding during storms. Students responded to these concerns with a proposal to reconstruct lost pathways, illustrating changes using ArcGIS and Photoshop. The research team later extended this work, bringing their proposal into 3D models produced in CityEngine.

In the workshop, students also learned about proposals to daylight the Flushing River, which had been piped in preparation for the 1939 international exposition. In the workshop, students steered clear of exploring daylighting of the river in detail, given that the piped river runs underneath historic fountains that are remnants of both the 1939 and 1964 world's fairs. Students were also acting in accordance with the direction of a park official who encouraged students to explore other priorities. Given the potential benefits of daylighting the river, the research team subsequently modeled a design scenario in which the river is daylighted, but the fair fountains remain in place and unaltered. The model was not highly detailed, but provided a vision of daylighting that did not disturb historic fountains from the fairs. This was a vision that detailed technical studies could explore in the future. A basic representation could be used to inspire future discussion about accomplishing a solution that both returns ecological functions to the site and preserves historic fabric.

The design workshop's sustainability framework focused students' attention on equity and they made connections between the legacy of the 1964 world's fair, which officially emphasized 'peace through understanding' and the sharing of cultures from around the world, and the ethnic diversity of park users and the surrounding community. Students observed that Flushing Meadows Corona Park is heavily used by communities of color. Immigrants from Latin America bring a multitude of variations on soccer (Correal 2015) and sports fields in the park are used by many ethnic groups from Latin America. In addition, the park is used as a social space for picnicking, a common site for weddings, and is the site of large Ecuadorian, Colombian, and Hispanic heritage celebrations (Ricourt and Danta 2002). Flushing Meadows is located in what researchers have called one of the most diverse areas on Earth (McGovern and Frazier 2015) and serves a vital function for residents of surrounding neighborhoods who have emigrated from or have ancestry linked to many different parts of the world.

CitiField and National Tennis Center stadia and large festivals in the park draw diverse crowds from around the region and internationally, yet the heavy use of the park by surrounding local residents has particular relevance to the discussion of resilience. The research team chose to illustrate this by layering a 3D model of the site with a 2D layer that depicts of the social vulnerability of surrounding neighborhoods (Fig. 1). In this case social vulnerability is described by the U.S. National Oceanic and Atmospheric Administration (NOAA) as: "*areas of high human vulnerability to hazards, is based on population attributes (e.g., age and poverty) and the built environment*" (U.S. National Oceanic and Atmospheric Administration 2016).

Just as Appler and Rumbach described the power of historic resources in resilience, the Park is a vital resource positioned for surrounding neighborhood residents to utilize. When studied at a closer level, it is also evident that parts of the surrounding neighborhoods with high levels of vulnerability are also cut off from easy access to the park, due to large, multi-lane highways that separate surrounding neighborhoods from the park on several sides. The issue of access and wayfinding is an important issue in equitable access to parks and has been taken up by the Design Trust for Public Space, a non-governmental organization in New York City (Design Trust for Public Space 2014).

NOAA's Sea Level Rise and Coastal Impacts Viewer (U.S. National Oceanic and Atmospheric Administration 2016) and underlying data were also referenced by the research team after the urban design workshop concluded. This included the use of CityEngine to integrate 2D GIS data on flood hazard risk, sea level rise and storm surge with 3D models of historic resources. The research team experimented in this way with the layering of scientific data and 3D visualizations as a tool to help orient decision makers and the public to architectural and landscape features that were vulnerable to flooding and inundation associated with climate change (Fig. 2).

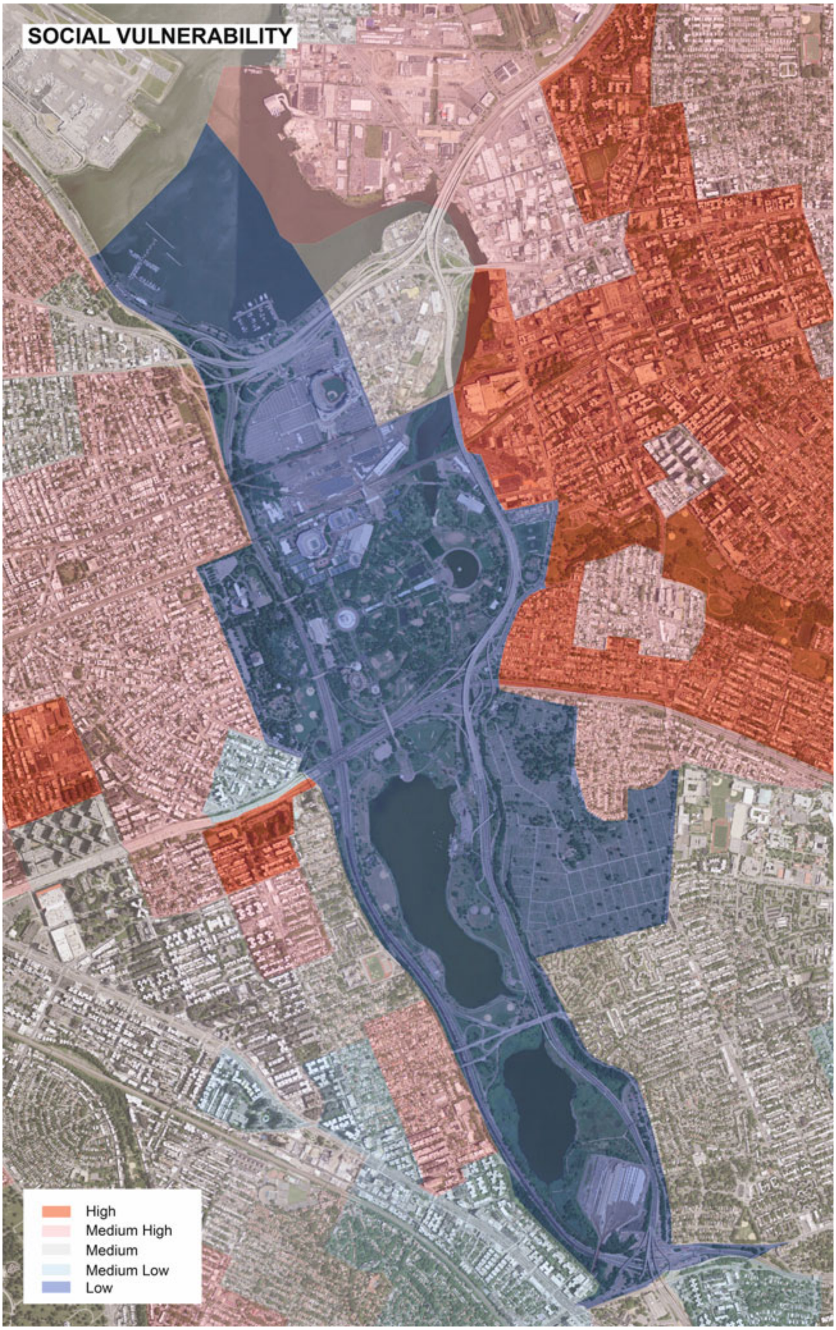


Fig. 1 Social vulnerability mapped to Flushing Meadows site (Map by Xiao Shi)

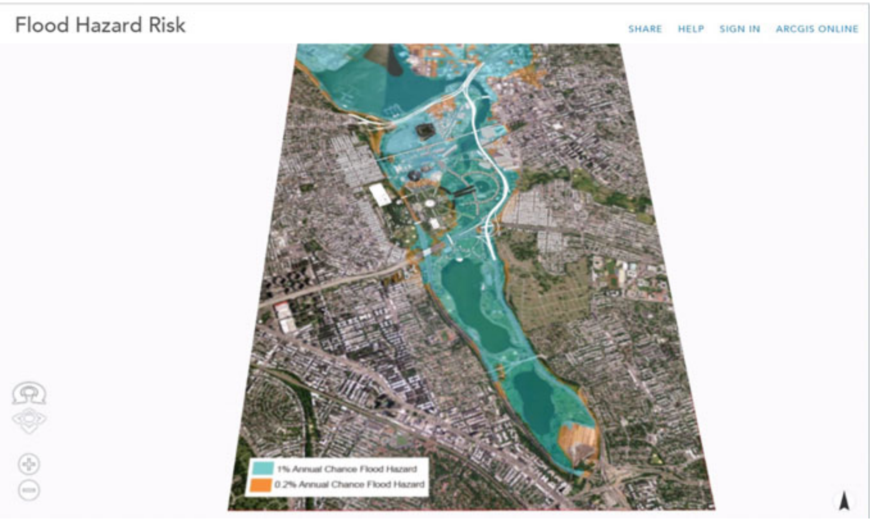


Fig. 2 Screenshot of CityEngine Web Viewer zoomed out to show flood hazards around Flushing Meadows Corona Park (Model produced by Xiao Shi and Yanlei Feng)

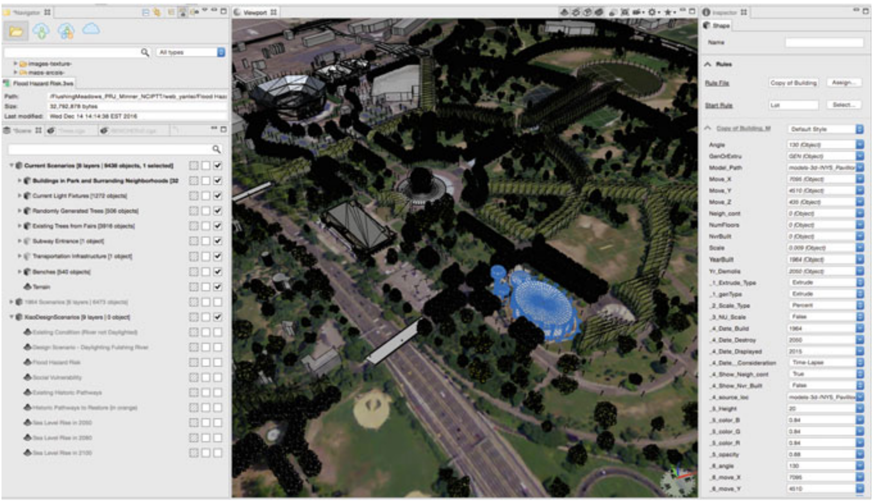


Fig. 3 Screenshot showing CityEngine interface and 3D buildings and landscape features

Detailed 3D modeling of building and landscapes in CityEngine (Fig. 3) proved to be quite time intensive to create. As the sponsored research project was specifically focused on Flushing Meadows Corona Park, it was modeled and analyzed to a greater extent than the other three international exposition sites. Significant resources would be needed replicate similar 3D modeling efforts for the other sites.

For Flushing Meadows Corona Park, the research team relied heavily upon existing data for modeling efforts and then performed a reconnaissance level survey to add information about landscape features. The research team benefited from readily available public data about buildings from PLUTO, New York City's land information system (The City of New York, Department of City Planning n.d.) and New York City's open GIS portal (The City of New York 2016). In addition, the team utilized 3D models from the 3D Warehouse (Trimble 2016), a website where models had been submitted by both professionals as well as amateur world's fair and sports enthusiasts. Contributors who modeled existing stadia and former fair pavilions as well as more esoteric aspects of former fair landscapes, such as whimsical 1964 world's fair light fixtures that were later removed. These public contributions alluded to the potential for volunteered geographic information (Sui et al. 2013; Minner et al. 2015) or citizen-science based initiatives (Bowser and Shanley 2013), which have been more commonly involved 2D GIS, rather than focused on 3D mapping.

The research team found some aspects of CityEngine to be useful, especially the ability to aggregate multiple 3D models from other architectural programs with 2D layers to create visualizations that are navigable 'web scenes'. In addition, there was the potential for sophisticated representations of landscapes in 3D. For instance, points representing the known location of individual trees, such as historic trees from the formal arrangements of the '39 and '64 world's fairs, could be represented with appropriate 3D models representing the species and height of the trees. Where there was more recent, naturalistic landscaping and where more precise information about individual trees was unknown, a mix of 3D models of various species were generated based on probabilities generated in particular areas. Both the detailed information about individual trees and information about areas that contained an estimated mix and number of trees could be maintained in CityEngine. In addition, the display of repeating features, such as historic benches or light standards could be easily generated. CityEngine provided a glimpse into a potentially valuable future asset management tool, where detailed information and representations of landscape features and building information could be maintained and compared.

However, major drawbacks were also identified. CityEngine is significantly different in operation from ArcGIS, but it requires ArcGIS for preparation of terrain and other data for importation into CityEngine. This means that users must be experienced and have expert-level troubleshooting abilities. The research team found that the use of CityEngine was not only time-consuming, but required significant computing resources, including a fast CPU speed, significant amounts of memory and disk space, and it had specific graphics card requirements. Limits in time and resources could be particularly problematic for an under-resourced management agency that wishes to use CityEngine to manage information about built and natural assets. Staff could not rely simply on prior knowledge of GIS, but would have to have both specialized knowledge of CityEngine and ArcGIS. The research team noted that it seemed unlikely that the City of New York Parks and Recreation Department would invest staff time and resources into learning and maintaining 3D applications unless there were major modifications in usability and better integration with GIS. This significantly tempered enthusiasm for CityEngine as a geodesign tool, along with discoveries about the limitations of the analytical tools built into the platform. For users of ArcGIS, the plethora of spatial analysis tools built into the system are expected; whereas many basic querying and analysis tasks in CityEngine were limited and often required learning a specialized language called CGA.

Consistent with findings by Koehl and Roussel (2015), the modeling of detailed buildings within CityEngine was found to be inefficient and difficult compared to other modeling tools such as SketchUp or specialized 3D modeling tools such as Rhino and Maya. While detailed models can be imported from other 3D modeling programs into CityEngine, it is not unusual to experience the loss of textures or other problems in important them. Detailed Building Information Models (BIM) cannot be imported, stored and analyzed in CityEngine. In this way, CityEngine does not appear to fully bridge the substantial gap between digital tools that support architectural design and detailed buildings models versus geodesign tools aimed at visualizing and analyzing geographic data (Minner and Chusid 2016). This is a serious problem if government agencies, large property managers, and other actors wish to fully capture detailed information about historic resources and model detailed scenarios. It is also a problem with special consequences for heritage conservation, as the field must draw from architectural expertise to propose detailed interventions for buildings, while also drawing upon geography to address context and larger scales such as whole districts or cultural landscapes.

A major component of geodesign is the fruitful comingling of information about social values and scientific data. To do this well for sites similar to Flushing Meadows Corona Park, the process must involve community engagement. Theoretically, the production of detailed models could be shared with the public online and at public meetings to enhance democratic deliberation about the future of the park. However, technical issues with CityEngine models, such as slowness in running online and limits in the size of information that could be loaded on the web viewer, meant online audiences would be likely to lose patience. Hence, they could be prevented from accessing detailed representations of the whole landscape. In person, the operation of a slow web viewer or desktop model would likely detract, rather than add to public workshops or charrettes. The use of existing web-based 2D GIS viewers, such as NOAA's Coastal Mapper, would be easier and probably just as effective at conveying data about the park, than sharing 3D scenes with the same 2D GIS layers from NOAA. In this case, the benefits of the 3D representation did not seem to outweigh the costs.

Technical challenges in the operation of the desktop version of CityEngine, meant that without improvements, it would be unlikely to bridge the differing demands of planners who need a robust set of analytical tools applied to a wider geographic scale and preservation architects who would need more detailed representations of individual historic resources. The more detailed the representation of the landscape in 3D, the more difficult it became to export models that depicted detailed architectural representations of buildings along with layers of scientific data about storm surge and sea level threats and vulnerability. Commenting tools embedded in the web viewer also remained quite basic. Finally, the research team felt that the ability to bring together different kinds of data both for and from community engagement processes, largely depends upon a team's commitment to sustained community conversation and maintaining a diverse and interdisciplinary management team.

Table 2 outlines observations about CityEngine as a geodesign tool for heritage-focused resilience planning processes. More development of CityEngine or of a similarly functioning geodesign tool is needed to fully bridge 2D and 3D GIS, fully support the layering of scientific data with value-based information, and serve both architectural and geographical sources of knowledge.

4.2 A Tool for Financial Feasibility and Resilience

For design efforts at HemisFair Park in San Antonio, students in the urban design workshop used a freely available tool called the Envision Tomorrow (ET) Prototype Builder, also known as the Return on Investment (ROI) tool (Fregonese Associates n.d.). The Prototype Builder tool can be used to estimate the costs associated with construction projects and the financial and sustainability outputs. The Prototype Builder tool consists of an Excel spreadsheet with macros that can be linked back to GIS using ET's Scenario Builder, which is used to aggregate the building prototypes into development types that can be 'painted' over larger areas. The output is then linked back to an Excel spreadsheet and it can be used to assess different scenarios for a single site up to an entire region.[1] The tool can be used without GIS, as a tool for generating a *pro forma* for development, as it was in this use case.

Students used the tool to explore the financial feasibility of repurposing remaining pavilions from the 1968 world's fair. In a recent master plan for the Park, the pavilions appeared likely to be demolished. Similar to the way 2D and 3D visualizations were used to elevate design proposals to address environmental aspects of resilience, the Prototype Builder was used as a means of examining potential costs associated with adaptive reuse of former fair pavilions. It was also used to estimate potential environmental benefits if green infrastructure was incorporated or social benefits such as the number of jobs created. The student team that employed the ET Prototype Builder benefited from the tool, but did not feel confident about estimates. The specialized nature of adaptive reuse and choices around detailed preservation treatments for individual buildings meant that accurate cost estimates would take significantly more research. However, students had positive comments about their exposure to ET as a geodesign tool. The simplicity and transparency of the Prototype Builder tool stood in contrast to CityEngine. The Prototype Builder was relatively easy for graduate students to operate and learn

---

[1] More information about the use of ET can be found in Minner (2015).

Table 2 Test of City Engine as a geodesign tool at Flushing Meadows Corona Park

Steps in resilience lanning from Berke and Stevens (2016)	Related-need in heritage-focused resilience planning	Evaluation/observations
Planning intelligence regarding hazard risks and vulnerability of historic resources (assets) and populations	Store information about the location and attributes of historic and cultural assets in order to produce a cultural resource inventory Information to include: detailed data about the character-defining features of buildings and cultural landscapes. Cultural landscapes include landscape features such as trees and other vegetation, pathways, lighting, and benches	CityEngine was initially conceptualized as a way of bringing together 3D architectural models, with 3D representations of vegetation and other landscape features. CityEngine is good at representing repeated features (e.g. benches, trees). Vegetation can be symbolized in 3D using points or rules if actual locations unknown Limitations in the number of features that can be displayed on web viewer and slowness of web viewer and desktop were challenges
	Map vulnerable populations in and around site	2D GIS layers are a primary means of acquiring and displaying population information. 2D layers can be imported into CityEngine
Setting goals and objectives for reducing risk and vulnerability	Support for deliberating about historic resources in relation to natural hazards Ability to query and conduct spatial analyses Ability to share basic information among stakeholders, public	2D layers showing natural hazard risks can be displayed Queries of spatial data not as easy to accomplish in CityEngine and fewer spatial tools than in 2D GIS Difficulty in exporting to web scenes
Adopting policies and programs to achieve the goals and objectives	Ability to visualize alternatives or scenarios for management of cultural assets	Multiple scenarios can be created; however, limitations in complexity and number of features that can be displayed in web viewer means complications for incorporation into online and in-person meetings
Monitoring and evaluating the results, making revisions to policies and programs over time as necessary	Ability to maintain detailed information about changes to buildings and landscape features over time	Specialized skill set needed in addition to 2D GIS skills Additional tools for detailed representing of architecture needed to unite architectural and geographical scales

from, whereas CityEngine proved to be too complex to incorporate into a semester-long design workshop.

At the scale of modeling the return of investment for individual buildings, ET does not have a visual component. However, it remains a vital geodesign tool with potential for informing resilience at former international exposition sites. The financial and sustainability indicators within the tool appear to have relevance for the wider set of mega-event sites. Greater accountability, transparency and accuracy in estimating costs is a major theme in the literature on mega-event sites (Flyvbjerg 2014). If geodesign tools are to fully support concepts of resilience, useable tools that incorporate financial feasibility and sustainability indicators in a way that is highly transparent and operable is essential.

5 Conclusions

This chapter highlights the value of former international exposition sites as a testbed for ongoing urban planning and urban management methods. In the examples, concepts of social or community resilience are examined in relation to preservation of historic resources and other kinds of cultural assets. Available geodesign tools were examined from experiences in gathering planning intelligence, the analysis of sites, and the creation and examination of multiple design scenarios.

Geodesign tools were useful up to a degree. However, there were several areas in which CityEngine fell short of expectations. Experiences suggested greater attention is needed to retaining the spatial analysis benefits of 2D GIS in 3D applications such as CityEngine and also the need to increase the user-friendliness of the application. Both the interests of heritage conservation and resilience could be advanced if the substantial gaps between architectural and geographic tools, and also between 2D and 3D GIS, were more successfully bridged. This will take additional development of CityEngine as an interoperable platform or the development of alternative platforms. Alternatively, different asset management and design tools can continue to be used by different disciplines, in which case landscape architects, preservation professionals and planners will continue to model the landscape through their own technological lenses. Regardless of technological developments, interdisciplinary teams that can unite environmental, social and economic knowledge are central to successful geodesign processes.

Envision Tomorrow's Prototype Builder tool, in contrast, was relatively easy to use, but served a different function. This tool supported examination of the financial feasibility of adapting buildings and estimating the outcomes of these efforts. The adaptation of former pavilions can be a key element to furthering sustainability and resilience efforts at former mega-event sites.

Publicly accessible and crowdsourced data were central to efforts to explore sustainability and resilience at former mega-event sites. Citizen-contributed 3D models were useful in producing 3D visualizations of Flushing Meadows Corona Park. Open data from local government sources was crucial, as was the willingness of local government and quasi-public agencies to share information. For the ability to elevate conversations about resilience, NOAA's scientific data on the environment was useful for the creation of visualizations of hazard risk, vulnerability and resilience. These are essential inputs for deliberating on the future of these important public spaces.

The former international exposition sites are just one type of many different kinds of mega-event and mega-project sites. One aspect that makes them stand out is their legacy as a public space and the cultural assets that remain on them. Resilience efforts at the scale of whole communities can benefit when an interdisciplinary and holistic approach is taken to maintaining the cultural assets on these sites.

Acknowledgements I would like to thank the research assistants for the NCPTT research project: Xiao Shi, Yanlei Feng, Nicolas Azel, Feiyang Sun, Geslin George, and Ethan Rhee. Thanks to all of the dedicated students in the urban design workshop and other research assistants: Brian Byrd, Michael Catsos, Hector Chang, Rashmi Gajare, Gabriel Halili, Irene Hung, Daniel McKenna-Foster, Christine Ma, Isaac Robb, Robert Rivera, Rachel Shindman, and Taru. I would also like to acknowledge members of the research advisory team: Thomas J. Campanella, Jeffrey Chusid, Andre Hafner, and Michael A. Tomlan.

This article was developed under a grant from the National Center for Preservation Technology and Training, a unit of the National Park Service. Its contents are solely the responsibility of the authors and do not necessarily represent the official position or policies of the National Park Service or the National Center for Preservation Technology and Training. The Workshop also received support from Cornell Engaged Learning and Research and the Department of City and Regional Planning within the College of Architecture Art and Planning.

References

Appler, D., & Rumbach, A. (2016). Building community resilience through historic preservation. *Journal of the American Planning Association, 82*(2), 92–112.

Azzali, S. (2016). Mega-events and urban planning: Doha as a case study. *Urban Design International, 22*(1), 3–12.

Beatley, T. (2009). *Planning for coastal resilience: Best practices for calamitous times*. Washington, DC: Island Press.

Berke, P. R., & Stevens, M. R. (2016). Land use planning for climate adaptation: Theory and practice. *Journal of Planning Education and Research, 36*(3), 283–289.

Bowser, A., & Shanley, L. (2013). *New visions in citizen science: Case study series* (Vol. 3). Washington DC: Commons Lab, Science and Technology Innovation Program. Woodrow Wilson International Center for Scholars. Accessed December 1, 2016 from http://www.wilsoncenter.org/publication/new-visions-citizen-science

Butler, W. H., Deyle, R. E., & Mutnansky, C. (2016). Low-regrets incrementalism: Land use planning adaptation to accelerating sea level rise in Florida's Coastal Communities. *Journal of Planning Education and Research*, *26*(3), 319–332.

Clark, J., Kearns, A., & Cleland, C. (2016). Spatial scale, time and process in mega-events: The complexity of host community perspectives on neighbourhood change. *Cities, 53,* 87–97.

Correal, A. (2015). A Flushing Meadows chronicler of soccer and immigration. *New York Times*, N.Y. Region section, June 12.

Deng, Y., Poon, S. W., & Chan, H. W. (2014). Synergising functional and environmental planning for mega-event led urban renewals and beyond: Lessons from the Expo 2010 Shanghai China. *International Planning Studies, 19*(3–4), 244–267.

Design Trust for Public Space. (2014). *The World's Park: Reconnecting a regional park with its neighbors*. Accessed December 23, 2016 from http://designtrust.org/projects/worlds-park/

Ervin, S. M. (2016). Technology in geodesign. *Landscape and Urban Planning*, *156*, 12–16.

Ervin, S., & Flaxman, M. (2015). A geodesign research agenda/map. Accessed December 23, 2016 from http://proceedings.esri.com/library/userconf/geodesign15/papers/geodesignFS_12.pdf

Flyvbjerg, B. (2014). *Mega-projects planning and management reader* (Vols. 1 and 2). Cheltenham, UK and Northampton, MA: Edward Elgar Publishing, Inc.

Fregonese Associates. (n.d.). *Prototype builder. Envision Tomorrow website*. Accessed December 23, 2016 from http://envisiontomorrow.org/enhanced-roi/

Gerlinger, J. (2014). *Empowering resilience with GIS* (Presentation). Accessed December 23, 2016 from http://resilient-cities.iclei.org/fileadmin/sites/resilient-cities/files/Resilient_Cities_2014/PPTs/07_Geringer.pdf

Koehl, M., & Roussel, F. (2015). Procedural modelling for reconstruction of historic monuments. In *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, *Volume II-5/W3, 2015 25th International CIPA Symposium 2015*, 31 August–04 September 2015, Taipei, Taiwan, pp. 137–144.

Longstreth, R. (Ed.). (2008). *Cultural landscapes: Balancing nature and heritage in preservation practice*. Minneapolis: University of Minnesota Press.

Lynch, K. (1960). *The image of the city*. Cambridge, MA: The MIT Press.

Lynch, K. (1972). *What time is this place?*. Cambridge, MA: The MIT Press.

McElvaney, S. (2012). *Geodesign: Case studies in regional and urban planning*. Redlands, CA: ESRI Press.

McGovern, B., & Frazier, J. W. (2015). Evolving ethnic settlements in Queens: Historical and current forces reshaping human geography. Focus on Geography. *Journal of the American Geographical Society, 58*(1), 11–26.

Miller, W. R. (2012). *Introducing geodesign: The concept*. Redlands, CA: ESRI. Accessed December 23, 2016 from http://www.esri.com/library/whitepapers/pdfs/introducing-geodesign.pdf

Minner, J. (2015). Recoding embedded assumptions in the adaptation of tools for sustainability planning, transparency, and participatory governance. In S. Geertman, J. Ferreira Jr., R. Goodspeed, & J. Stillwell (Eds.), *Planning support systems and smart cities* (pp. 409–425). Dordrecht: Springer International Publishing.

Minner, J., & Chusid, J. (2016). Time, architecture, and geography: Modeling the past and future of cultural landscapes. *APT Bulletin: The Journal of Preservation Technology, 47*(2–3), 49–58.

Minner, J., Roberts, A., Holleran, M., & Conrad, J. (2015). Capturing volunteered historical information: Lessons from development of a local government crowdsourcing tool. *International Journal of E-Planning Research, 4*(1), 19–41.

Munshi-South, J. (2012). Development will damage Flushing Meadows' role as marshy buffer against storm surge and coastal flooding. *Daily News*, December 3.

Quennell Rothschild and Partners & Smith-Miller + Hawkinson Architects. (2008). *Flushing Meadows Corona Park Strategic Framework Plan. City of New York Parks and Recreation Department*. Accessed December 23, 2016 from https://www.nycgovparks.org/parks/flushing-meadows-corona-park

Ricourt, M., & Danta, R. (2002). *Hispanas de Queens: Latino panethnicity in a New York City neighborhood*. Ithaca, NY: Cornell University Press.

Steiner, F. (2008). *The living landscape: An ecological approach to landscape planning*. Washington, DC: Island Press.

Steinitz, C. (2012) *A framework for geodesign: Changing geography by design*. Redlands, CA: Esri Press. http://www.esri.com/library/ebooks/GeoDesign.pdf

Sui, D., Elwood, S., & Goodchild, M. (Eds.). (2013). *Crowdsourcing geographic knowledge: Volunteered geographic information (VGI) in theory and practice*. Dordrecht: Springer.

The City of New York. (2016). *NYC OpenData*. Accessed December 23, 2016 from https://nycopendata.socrata.com/

The City of New York, Department of City Planning. (n.d.). *PLUTO and MapPLUTO. On New York City website*. Accessed December 23, 2016 from https://www1.nyc.gov/site/planning/data-maps/open-data/dwn-pluto-mappluto.page

Trimble. (2016). *3D Warehouse*. Accessed December 23, 2016 from https://3dwarehouse.sketchup.com/?hl=en

United Nations Office for Disaster Risk Reduction. (2007). *Definition for resilience on terminology page*. Accessed December 23, 2016 from https://www.unisdr.org/we/inform/terminology

United States National Oceanic and Atmospheric Administration. (2016). *Sea level rise and coastal flooding impacts viewer*. Accessed December 22, 2016 from https://coast.noaa.gov/slr/

Wilson, M. W. (2015). On the criticality of mapping practices: Geodesign as critical GIS? *Landscape and Urban Planning, 142,* 226–234.

Chapter 9
The Walkability Planning Support System: An Evidence-Based Tool to Design Healthy Communities

Claire Boulange, Chris Pettit and Billie Giles-Corti

Abstract A major challenge for all cities is to reconcile growth with cultural, social and environmental considerations, along with connecting urban design with opportunities for health and wellbeing. Planning Support Systems (PSSs) can facilitate future planning and foster collaboration between researchers and urban planners in promoting healthy built environments. The Walkability PSS was developed specially for that purpose. This chapter presents an evaluation of the Walkability PSS, a PSS for building planning scenarios and assessing their impacts on walking behaviours. The evaluation was conducted in collaboration with a group of local urban planners. The study results show that the Walkability PSS could support planners in several situations including testing and comparing planning scenarios for greenfield and brownfield areas, conducting consultation and/or workshops with various stakeholders and making decisions about the provision of new infrastructure.

Keywords Planning Support System · Walkability · Healthy cities · Participatory planning · Co-design

1 Introduction

Today, non-communicable diseases and conditions, such as heart disease or diabetes, are a significant problem in urban centres (World Health Organization 2010). Most of this heightened risk can be traced back to changes in physical activity

---

C. Boulange (✉) · B. Giles-Corti
Centre for Urban Research, Healthy Liveable Cities Research Group, RMIT University, Melbourne, Australia
e-mail: claire.boulange@rmit.edu.au

B. Giles-Corti
e-mail: billie.giles-corti@rmit.edu.au

C. Pettit
City Futures Research Centre, UNSW, Sydney, Australia
e-mail: c.pettit@unsw.edu.au

S. Geertman et al. (eds.), *Planning Support Science for Smarter Urban Futures*, Lecture Notes in Geoinformation and Cartography,
DOI 10.1007/978-3-319-57819-4_9

because of urbanization. In all major cities, promoting active modes of transport (i.e., cycling or walking) is an important policy area, with evidence of co-benefits across multiple sectors, such as health, transport and sustainability (Lowe et al. 2014). Furthermore, active modes of transport are seen as a promising means of increasing levels of physical activity and improving population health.

City planners face the challenge of building environments that promote active modes of transport on undeveloped land ('greenfield area') or on land that has been previously used and is subject to redevelopment ('brownfield area'). Given a growing body of evidence (Christian et al. 2011; Frank et al. 2006; Badland and Schofield 2005; Sallis et al. 2016), built environment interventions to increase the walkability of an area are generally well known. An intervention in this context is any modification to the built environment that is supportive of walking, i.e., a mix of land uses, enhanced pedestrian crossings, sidewalks wide enough to accommodate a range of pedestrian users safely or public space that exclude cars and encourage walking (Van Dyck et al. 2011).

However, there is still the complex task of getting the right mix of interventions. This requires the capacity to test, sketch, visualise and compare plans against urban performance indicators. While the planning process appears to be increasingly complex, decision-makers and city planners can now access more tools including Planning Support Systems (PSSs) especially designed for supporting them in developing evidence-based plans (Geertman and Stillwell 2004). While PSSs are increasingly available to planners, they are not being used routinely in practice and there is still a lack of tools aimed at facilitating health-oriented urban planning.

This chapter presents the evaluation of an operational health-oriented PSS, the Walkability PSS. It is a PSS built on the computer program CommunityViz 5.0, aimed to assist spatial planners in developing healthy and walkable communities by allowing them to test planning scenarios and assess their impacts on participation in walking.

The chapter begins with an examination of the potential role of PSSs for Health Impact Assessment (HIA) in the context of greenfield and brownfield developments. Next, the study design is outlined and the general development of the Walkability PSS is introduced. This is followed by an extensive report of the Walkability PSS evaluation study. Finally, conclusions from the evaluation study are discussed.

2 Health Impact Decision Support System: A Specific Type of PSS

A HIA is a technique that allows those responsible for planning decisions to make informed choices in order to maximise the health benefits of any proposed development and to minimise any negative impacts on health (Wong et al. 2011).

HIAs rely on scientific data, health expertise and public input to identify the potential health effects of proposed new laws, regulations, projects and programs (World Health Organization 1986). PSSs that are designed to facilitate HIA are also known as health impact decision support systems (Ulmer et al. 2015). They can be used within the context of health-oriented urban planning: in fact, they are built on urban models that can estimate outcomes related to both urban planning and population health (Ulmer et al. 2015).

For both greenfield and brownfield development, decision-makers prioritise investments that will generate economic, social and environmental benefits (State Government Victoria 2014), including positive outcomes for population health, such as increased participation in active modes of transport, decreased exposure to air pollution, reduced greenhouse gas emissions or decreased exposure to noise, and so on. Health-oriented PSSs can support this goal by integrating the HIA capacity with the ability to conduct problem diagnosis, data collection, mining and extraction, spatial and temporal analysis, data modelling, visualisation and display, scenario-building and projection, plan formulation and evaluation, report preparation and collaborative decision-making (Geertman and Stillwell 2004), prior to construction taking place.

3 Study Design: Phase One

The Walkability PSS was developed incrementally, starting as a multilevel logistic model, and evolving to a functional interactive tool.

In earlier work, transport data from metropolitan Melbourne were used to model the relationship between a range of built environment characteristics and participation in walking within the urban residential neighbourhood:

$$\text{Estimate of}\,\mathrm{P}(\mathrm{y_i} = 1|\mathrm{x_{i1,\cdots}x_{ip}}) = \frac{\mathrm{e}^{(\mathrm{a}+\mathrm{b_1\,X_{i1}}+\cdots+\mathrm{b_p\,X_{ip}})}}{1+\mathrm{e}^{(\mathrm{a}+\mathrm{b_1\,X_{i1}}+\cdots+\mathrm{b_p\,X_{ip}})}} \tag{1}$$

where $\mathrm{P(y = 1)}$ is the probability of the dependent variable y taking on the value 1 (y = 1), if a participant undertakes at least one or more walking trips; $\mathrm{x_k}$ (k = 1, 2, …, p) are the independent variables relating to the built environment and socio-demographic variables; a is the constant and $\mathrm{b_k}$ (k = 1, 2,…, p) are the estimated regression coefficients. In this model, the effect of each built environment variable $(\mathrm{x_k})$ is 'weighted' by its regression coefficient $(\mathrm{b_k})$ to measure the probability that the dependent variable y taking on the value 1 (y = 1), if a participant undertakes at least one or more walking trips.

The first task consisted of coupling the spatial variable and coefficients from the regression model into an interactive spatial interface. CommunityViz 5.0 was used for that purpose. CommunityViz 5.0 is a multipurpose type of PSS software with the capacity to set up custom interactive spatial interfaces and develop complex spatial models. Where data and evidence of associations are available, CommunityViz 5.0 can be enhanced to include models that relate built environment characteristics to specific outcomes such as participation in walking (Saelens et al. 2003), cardiovascular disease outcomes (Eichinger et al. 2015), energy use (Creutzig et al. 2015), greenhouse gases, and pollutant emissions (Wilkinson et al. 2007). CommunityViz 5.0 is designed to help people visualise, analyse and communicate geographic decisions. It is also capable generating results in near real-time. This makes the software helpful for testing and refining planning scenarios in a workshop situation.

CommunityViz 5.0 was programmed so that automatic calculations generate the built environment variables that were found to impact participation in walking. These built environment variables are fed into a logistic regression model, which estimates the probability of success that an individual participates in walking in the study area, as it is represented on the map display. This value is presented as a percentage in a dynamic chart which automatically updates as changes are made on the spatial layers or in the assumption bars.

Figure 1 presents the user interface. On the left side, the table of contents (outlined in blue) lists the spatial layers which can be manipulated using the 'sketch tools' (see Fig. 2). For example, users can add new points, resize polygons or change attributes in features. As soon as the spatial layers are edited, the indicator charts (outlined in green) update.

Multiple scenarios can be created and compared in terms of how they perform for supporting participation in walking.

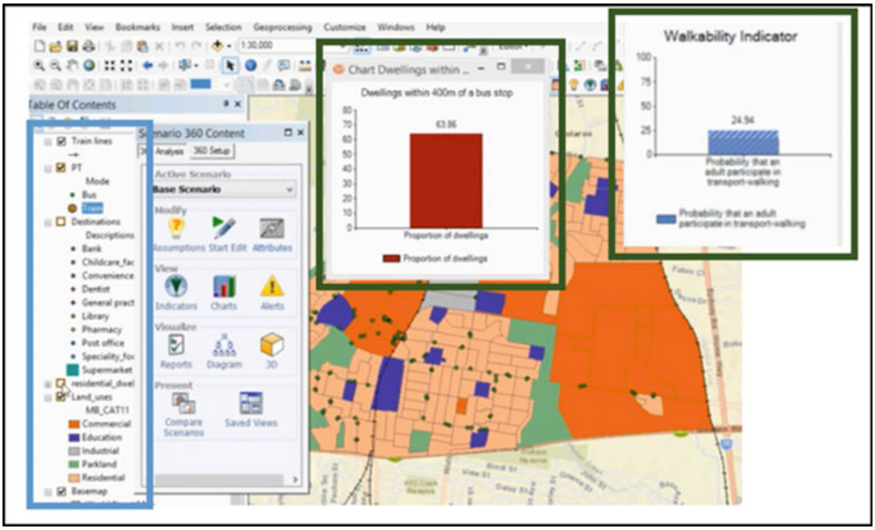


Fig. 1 Interface and indicators

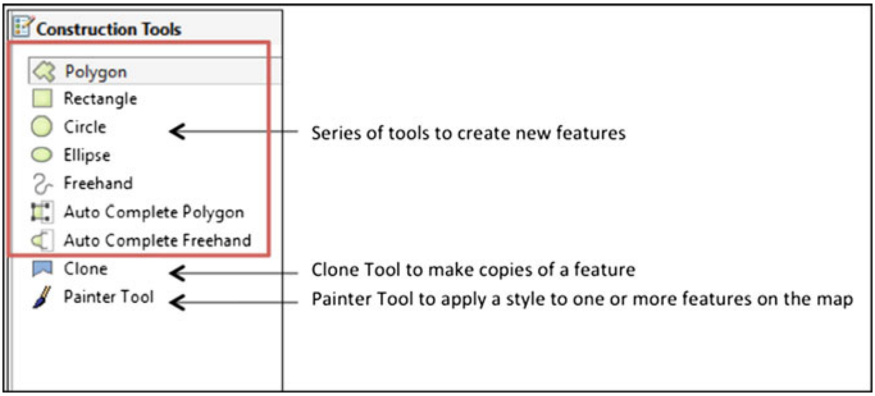


Fig. 2 Sketch tools for applying changes to the spatial layers and drawing scenarios

4 Study Design: Phase Two

One key objective of this research was to maximise the practical application of the Walkability PSS. Hence a participatory evaluation workshop was designed to document and understand the experiences of the Walkability PSS users, and any implications for future development. In the participatory evaluation workshop, the Walkability PSS was applied to the study area of Broadmeadows (Victoria, Australia) to be tested and reviewed by a group of professional city planners.

4.1 Evaluation Framework

The evaluation framework was adapted from previous studies that examined the Strengths, Weaknesses, Opportunities, and Threats (SWOT) of PSSs (Vonk et al. 2007) and the potential added values of PSSs in planning practice (Pelzer et al. 2015). Vonk et al. (2007) developed an evaluation framework to assess the ability of different PSSs to assist with various planning tasks by examining their main functions (Vonk et al. 2007). The study found that to be applicable, PSSs should be sufficiently dedicated to the demands of planning processes and users (Vonk et al. 2007). The work conducted by Pelzer and colleagues built on Vonk and colleagues' earlier studies (Vonk et al. 2005, 2007) by examining the degree of fit between PSS functions and planning tasks. Known as the 'task-technology fit' approach, it showed that the level of usefulness of PSSs may be measured by how much the PSS functions align with the planning tasks (Pelzer et al. 2015). For this Walkability PSS evaluation study, the framework was structured based on the Walkability PSS functions and its suitability for planning tasks. It also included an assessment of its degree of transparency.

4.2 Workshop Methods

A two-hour workshop was conducted in May 2016 with a group consisting of seven spatial planners (i.e., urban and transport planners) from the Metropolitan Planning Authority (MPA) in Melbourne and one State government adviser from the Victorian Department of Health and Human Services. The workshop was conducted at the MPA offices in Melbourne Central Business District, using a MapTable—a digital, touch-enabled screen in the form of a moveable table (Fig. 3). The MapTable was used because it is a piece of hardware especially designed to encourage a group of people to interact with the software CommunityViz 5.0 (Arciniegas et al. 2013). It allows them to sketch and test ideas together. Previous

Fig. 3 The MapTable used in the participatory workshop at the MPA

studies have shown that it is particularly suited to group processes (Pelzer et al. 2014, 2015; Hopkins et al. 2004).

The workshop opened with presentations, followed by hands-on experiments on the Walkability PSS and finished with group discussions. The hands-on experiments were conducted on the Walkability PSS operated on the MapTable using Broadmeadows, the study area. The hands-on experiments consisted of creating a new planning scenario, likely to support more walking, by using the sketch-tools and assumptions bars. Participants were invited to take control of the pointer, and to use the commands (i.e., sketch tools) themselves by tapping on the touch screen. If unsure, they were instructed to ask the workshop facilitator (first author of the present chapter) to apply the changes they wanted. A questionnaire was distributed at the end of the hands-on experiments and participants were asked to complete it prior to the start of the group discussions. The questionnaire was designed to collect the participants' views on the following questions:

- How do they rate the Walkability PSS in terms of the following functions: gathering information, storing and organizing data, visualizing information, supporting communication, analysing information and modelling outcomes (Vonk et al. 2007)?
- Is the Walkability PSS explained with sufficient transparency?
- For what planning tasks would the Walkability PSS be most useful?

The participants indicated the extent to which they agreed with statements reflecting capacity, usability and potential applications of the Walkability PSS. The responses were measured on a Likert scale from 1 to 5, with higher scores indicating greater agreement with the statement. The workshop ended with a group discussion aimed at reviewing the strengths and weaknesses of the Walkability PSS, potential uses, and how it could be improved to better support their practice and fit their needs. The participants' views on each question were recorded on large sheets of butcher's paper.

5 Results

5.1 Description of the Sample

At the time of the workshop, four of the seven participants were involved in both greenfield and brownfield projects, two were involved in greenfield projects and two were involved solely in brownfield projects. Three participants were using GIS techniques to prepare framework plans and one participant was using GIS techniques to prepare both framework plans (i.e., a plan that suggests strategies for future development) and implementation plans (i.e., a plan that has been approved and is being implemented).

Three participants were using data-driven techniques (i.e., the participants used data analytics techniques and technologies to drive their decision making) to prepare framework plans and three participants were using data-driven techniques to prepare both framework plans and implementation plans. The participants commented that they were using the Microsoft Excel spreadsheet program, the Access database management system, census datasets and GIS programs including MapInfo, QGIS and ArcGIS.

5.2 Findings from the Questionnaire: Practice Relevance of the Walkability PSS

The participants were asked about the practice relevance of the Walkability PSS (Table 1). Overall the participants agreed with the statements reflecting the functionality of the Walkability PSS, with responses to all six questions ranging from neutral to strongly agree. Most participants (75%) strongly agreed with the statement "the Walkability PSS is an effective tool to support communication of planning strategies," and "the Walkability PSS is an effective tool to model different planning scenarios". They (62.5%) also strongly agreed with the statements that: "the Walkability PSS is an effective tool to visualise a range of information"; "the Walkability PSS is an effective tool to analyse information (e.g., evaluate levels of planning performance against policy requirements)". Many of the participants (62.5%) also agreed with the statement "the Walkability PSS is an effective tool to store and organise spatial data". One half of the participants (50%) agreed with the statement: "the Walkability PSS is an effective tool to collect spatial information".

Table 1 Evaluation of the Walkability PSS functions (n = 7)

To what extent do you agree with the following?	Neutral (%)	Agree (%)	Strongly agree (%)
The Walkability PSS is an effective tool to collect spatial information	25.0	50.0	25.0
The Walkability PSS is an effective tool to store and organise spatial data	25.0	62.5	12.5
The Walkability PSS is an effective tool to visualise a range of information	12.5	25.0	62.5
The Walkability PSS is an effective tool to support communication of planning strategies	25.0	0.0	75.0
The Walkability PSS is an effective tool to analyse information (e.g., evaluate levels of planning performance against policy requirements)	0.0	37.5	62.5
The Walkability PSS is an effective tool to model different planning scenarios	0.0	25.0	75.0

5.3 Findings from the Questionnaire: Usability of the Walkability PSS

The participants' responses to the statements on the usability of the Walkability PSS are presented in Table 2. Findings showed that 100% of participants agreed or strongly agreed (62.5%) with the statement "I can understand the outputs and the relationships between the spatial representations and the indicators displayed in the PSS". One half (50%) agreed or strongly agreed (25%) about the statement "the implementation of the walkability PSS on a touch table makes it easy to use and supports the planning experience".

Two participants provided written comments about the MapTable; they commented that "touch screens in general take a bit of practice, but it wouldn't take long for users to be confident in its use", and that the MapTable "is good for round-table discussion and potentially for consultation, but for everyday planning the touch screen is not necessary".

5.4 Findings from the Questionnaire: Potential Applications of the Walkability PSS

Table 3 presents the participants' responses to the statements reflecting on the potential applications of the Walkability PSS. One-half of the participants (50%) strongly agreed that the Walkability PSS could support them with the tasks of problem definition (an additional 37.5% agreed with this statement) and 50% also agreed that the Walkability PSS could support consultation with other stakeholders and public as well as decision making. One participant saw little use of the Walkability PSS to support implementation while 37.5% agreed that the Walkability PSS could support the implementation task.

Table 2 Evaluation of the Walkability PSS usability (n = 7)

How usable is the Walkability PSS?	Neutral (%)	Agree (%)	Strongly Agree (%)
I can understand the outputs and the relationships between the spatial representations and the indicators displayed in the PSS	0.0	37.5	62.5
The implementation of the walkability PSS on a touch table makes it easy to use and supports the planning experience	50.0	25.0	25.0

Table 3 Evaluation of the Walkability PSS suitability (n = 7)

To what extent do you agree that the Walkability PSS could support your work with regard to:	Neutral (%)	Agree (%)	Strongly agree (%)
Problem definition (i.e., conducting an urban situation analysis, identifying low walkability levels)	12.5	37.5	50.0
Problem exploration and analysis (i.e., identifying causes of low walkability and opportunities to respond)	25.0	37.5	37.5
Consultation with other stakeholders and public (i.e., discussion, negotiation)	12.5	50.0	37.5
Decision making	12.5	50.0	37.5
Implementation (i.e., dissemination, initiating action)	25.0	37.5	25.0
Monitoring and evaluating effects of interventions	0.0	62.5	37.5

5.5 *Findings from the Group Discussion*

The group discussion captured the participants' views about the Walkability PSS in terms of strengths, weaknesses, potential application and areas for improvement.

Although a small group, the participants recognised many strengths in the Walkability PSS. The main strength identified was being the ability to create different scenarios, save and compare them. Another strength of the tool was seen to be the ability to review precinct structure plans throughout their development. There was general agreement that the use of the Walkability PSS by practitioners could improve the quality of the data and make a case for greater data collection in the future. The consensus was that the Walkability PSS was practice relevant and could be applied to planning projects focused on greenfield and brownfield areas.

During the hands-on experiments and the group discussion, the participants acknowledged the capacity of the Walkability PSS to demonstrate how walkability depends on a range of built environment variables, and there was general agreement that the Walkability PSS "shows the complex picture of the walkability problem". There was a unanimous view that a major strength was the ability to customise the current Walkability PSS by adding indicators to assess other outcomes and behaviours (not just walking).

The participants identified key additional features for the Walkability PSS that could help inform their practice. Relevant additional features were seen to be the inclusion of topographical data and slope analysis, i.e., the elevation profile of the pedestrian routes in the walkability model and the addition of a spatial layer representing tree cover. One participant suggested that the analytical framework could be applied to a smaller area with the inclusion of spatial layers representing amenities at a micro level, i.e., benches, footpath or trees.

When assessing the weaknesses of the Walkability PSS, there was a general agreement that the quality and robustness of the analysis strongly depended on the quality of the underlying data and evidence. Two participants suggested that the graphics performance and readability of the control panels could also be improved.

The participants identified a range of potential applications of the Walkability PSS. There was unanimity from the participants that the Walkability PSS could aid them with testing and comparing planning scenarios for greenfield and brownfield areas, and could be applied in consultation or workshops involving multiple sectors. There was also unanimity from the participants that the Walkability PSS could help them with making decisions about the provision of new infrastructure, for example, in deciding where to locate a new supermarket or a new train station.

One viewpoint (from a health department participant) was that the Walkability PSS could support service planning, i.e., health service planning. There was a general agreement that the use of the Walkability PSS could support a case for greater emphasis on social connection, health and wellbeing in the planning of greenfield and brownfield areas. Some participants also identified three planning questions where an analytical framework developed in the software CommunityViz 5.0 (beyond the question of walkability) could provide support:

- One viewpoint was that an interactive spatial simulation system like the Walkability PSS could aid public housing planning.
- Another participant suggested that a modified Walkability PSS would be useful to compare different service provision scenarios in high-density areas: e.g., in comparing a concentration of a range of services including retail, administration, education or health services in one location, i.e., create a 'hub' of services (scenario A) or scatter these services across the neighbourhood (scenario B).
- Finally, one participant suggested adding a model that considered regional accessibility and predicts driving outcomes.

6 Conclusions

Consistent with previous research on health-oriented PSS (Ulmer et al. 2015), this study demonstrated that empirical evidence can be integrated into a user-friendly PSS application. Findings from the workshop suggest that the Walkability PSS could support a range of planning tasks, i.e., testing and comparing planning scenarios for greenfield and brownfield areas, conducting consultation or workshops with multiple sectors. Further research could apply Pelzer's 'task-technology fit' (Pelzer et al. 2015) framework to assess the usefulness of the Walkability PSS for specific applications.

This study demonstrated that it is possible to develop a Walkability PSS where users can sketch planning scenarios and instantly 'see' what would be the potential impacts on people's health. The PSS could be further developed to include other health outcomes related to the built environment. However, the addition of more models would increase the complexity of the tool, the calculation speed and the preparation time in collecting the data. There is a dilemma in terms of the future development of simple yet credible health-oriented Walkability PSS. As Waddell (2011) observed, a balance should be maintained between transparency and validity in PSSs. He explains that transparency matters for building trust and facilitating adoption since "*models will not have credibility as tools for decision support in complex, conflict-laden domains such as land use, transportation and environmental planning, unless they can be explained with a sufficient degree of transparency*" (Waddell 2011, p. 213). However, he notes that over-simplification poses problem as it reduces precision, validity and eventually credibility.

The study contributed to the larger investigation on the practice-relevance of PSSs involving sketch planning capacities (Goodspeed 2016) and found that the Walkability PSS was seen as relevant and applicable in planning practices. In future research, more workshops will be held to collect data and effectively assess the areas for improvement and add-ons necessary to better meet the user needs.

The Walkability PSS was well received by the practitioners and the participatory workshop stimulated discussions between the participants. The workshop participants used the sketching tools and tested their ideas. Nevertheless, it is unclear whether the operation of the Walkability PSS on the MapTable itself was essential to support participation and engagement. Future research could shed more light on the role of this type of hardware by comparing participation and engagement with application on a desktop computer. It could be that if the 3D module was used, the real impact of the MapTable could become more evident. Certainly, the users found the tool engaging; however, it is unclear whether the novelty factor drove the engagement. Further research could provide added clarity to the practice-relevance of the Walkability PSS after the initial novelty has passed. The findings from this study suggest that the Walkability PSS could play an important role in research dissemination as a platform for researchers and practitioners (and potentially the community) to work together to review and design future precinct structure plans.

References

Arciniegas, G., Geertman, S., & de Kroes, J. (2013). Using MapTable® to learn about sustainable urban development. In S. Geertman, F. Toppen, & J. Stillwell (Eds.). *Planning support systems for sustainable urban development* Heodelberg: Springer-Verlag, pp. 167–186.

Badland, H., & Schofield, G. (2005). The built environment and transport-related physical activity: What we do and do not know. *Journal of Physical Activity and Health, 2*(4), 433–442.

Christian, H., Bull, F., Middleton, N., Knuiman, M., Divitini, M., Hooper, P., Amarasinghe, A., & Giles-Corti, B. (2011). How important is the land use mix measure in understanding walking behaviour? Results from the RESIDE study. *International Journal of Behavioral Nutrition and Physical Activity, 8*(55), doi:10.1186/1479-5868-1188-1155.

Creutzig, F., Baiocchi, G., Bierkandt, R., Pichler, P.-P., & Seto, K. C. (2015). Global typology of urban energy use and potentials for an urbanization mitigation wedge. *Proceedings of the National Academy of Sciences of the United States of America, 112*(20), 6283–6288.

Eichinger, M., Titze, S., Haditsch, B., Dorner, T. E., & Stronegger, W. J. (2015). How are physical activity behaviors and cardiovascular risk factors associated with characteristics of the built and social residential environment? *PLoS ONE, 10*(6), e0126010.

Frank, L. D., Sallis, J. F., Conway, T. L., Chapman, J. E., Saelens, B. E., & Bachman, W. (2006). Many pathways from land use to health: Associations between neighborhood walkability and active transportation, body mass index, and air quality. *Journal of the American Planning Association, 72*(1), 75–87.

Geertman, S., & Stillwell, J. (2004). Planning support systems: An inventory of current practice. *Computers, Environment and Urban Systems, 28*(4), 291–310.

Goodspeed, R. (2016). Sketching and learning: A planning support system field study. *Environment and Planning B: Planning and Design, 43*(3), 444–463.

Hopkins, L. D., Ramanathan, R., & Pallathucheril, V. G. (2004). Interface for a sketch-planning workbench. *Computers, Environment and Urban Systems, 28*(6), 653–666.

Lowe, M., Boulange, C., & Giles-Corti, B. (2014). Urban design and health: Progress to date and future challenges. *Health Promotion Journal of Australia, 25*(1), 14–18.

Pelzer, P., Arciniegas, G., Geertman, S., & Lenferink, S. (2015). Planning support systems and task-technology fit: A comparative case study. *Applied Spatial Analysis and Policy, 8*(2), 155–175.

Pelzer, P., Geertman, S., van der Heijden, R., & Rouwette, E. (2014). The added value of planning support systems: A practitioner's perspective. *Computers, Environment and Urban Systems, 48,* 16–27.

Saelens, B. E., Sallis, J. F., & Frank, L. D. (2003). Environmental correlates of walking and cycling: Findings from the transportation, urban design, and planning literatures. *Annals of Behavioral Medicine, 25*(2), 80–91.

Sallis, J. F., Cerin, E., Conway, T. L., Adams, M. A., Frank, L. D., Pratt, M., et al. (2016). Physical activity in relation to urban environments in 14 cities worldwide: A cross-sectional study. *The Lancet, 387*(10034), 2207–2217.

State Government Victoria (2014). *Plan Melbourne. Metropolitan planning strategy 2014*. Melbourne: State Government Victoria.

Ulmer, J. M., Chapman, J. E., Kershaw, S. E., Campbell, M., & Frank, L. D. (2015). Application of an evidence-based tool to evaluate health impacts of changes to the built environment. *Canadian Journal of Public Health*, 106(1 Suppl 1), eS26–34, doi:10.17269/cjph.106.4338.

Van Dyck, D., Cardon, G., Deforche, B., Owen, N., & De Bourdeaudhuij, I. (2011). Relationships between neighborhood walkability and adults' physical activity: How important is residential self-selection? *Health Place, 17*(4), 1011–1014.

Vonk, G., Geertman, S., & Schot, P. (2005). Bottlenecks blocking widespread usage of planning support systems. *Environment and planning A, 37*(5), 909–924.

Vonk, G., Geertman, S., & Schot, P. (2007). A SWOT analysis of planning support systems. *Environment and Planning A, 39*(7), 1699–1714.

Waddell, P. (2011). Integrated land use and transportation planning and modelling: Addressing challenges in research and practice. *Transport Reviews, 31*(2), 209–229.

Wilkinson, P., Smith, K. R., Beevers, S., Tonne, C., & Oreszczyn, T. (2007). Energy, energy efficiency, and the built environment. *The lancet, 370*(9593), 1175–1187.

Wong, F., Stevens, D., O'Connor-Duffany, K., Siegel, K., & Gao, Y. (2011). Community health environment scan survey (CHESS): A novel tool that captures the impact of the built environment on lifestyle factors. *Global Health Action, 4*, doi:10.3402/gha.v4i0.5276.

World Health Organization. (1986). *Ottawa charter for health promotion: First international conference on health promotion, Ottawa, 21 November 1986* (International Conference on Health Promotion). Geneva: World Health Organization.

World Health Organization. (2010). *Hidden cities: Unmasking and overcoming health inequities in urban settings*. Geneva: World Health Organization.

Chapter 10
A Dynamic Real-Time Navigation System for Urban Tourists

Kayoko Yamamoto and Shun Fujita

Abstract The present study aimed to design, develop, operate and evaluate a system that considers dynamic real-time situations to provide effective support for tourist activities both in normal conditions and in the event of disasters. The system was developed by integrating Web-GIS (Geographic Information Systems) , social media, recommendation systems and AR (Augmented Reality) terminals (smart glasses) into a single system, and operated in the center part of Yokohama City in Kanagawa Prefecture, Japan. The web-based system was operated for eight weeks, and the total number of users was 86. Additionally, a system using smart glasses was also operated for two days, and the total number of users was 34. Evaluation results clarified that it was possible to support user behavior both in normal conditions and in the event of disasters, and to efficiently and safety conduct navigation using smart glasses. Operation assuming disaster conditions showed that users who accessed the system via mobile information terminals increased, and actively used functions requiring location information.

Keywords Navigation system · Dynamic Real-Time · Web-based Geographical Information Systems (GIS) · Social media · Recommendation system · Augmented Reality (AR) · Smart glasses

1 Introduction

As many who visit sightseeing spots do not have a good sense of locality, they get to know the route to their destination by means of guidebooks using paper maps. However, carrying around maps is inconvenient, and because users must look up

---

K. Yamamoto (✉) · S. Fujita
Graduate School of Informatics and Engineering, University of Electro-Communications,
1-5-1 Chofugaoka, Chofu-Shi, Tokyo 182-8585, Japan
e-mail: k-yamamoto@is.uec.ac.jp

S. Fujita
e-mail: fujita@si.is.uec.ac.jp

S. Geertman et al. (eds.), *Planning Support Science for Smarter Urban Futures*, Lecture Notes in Geoinformation and Cartography,
DOI 10.1007/978-3-319-57819-4_10

the route to their destination by constantly checking their present location on the map, this time consuming process may reduce their desire to sightsee. Additionally, because many tourists do not have any knowledge about local disaster countermeasures including evacuation locations and support facility locations in the event of disasters, it will be extremely difficult for them to take necessary actions to evacuate. Additionally, in the event of disasters, although there are systems for supporting the evacuation of residents in the affected area, as these disaster countermeasure systems are not used in normal conditions, it will be difficult to suddenly use such systems when disasters actually occur. Therefore, a system that is used in normal conditions in addition to one that supports the evacuation in the event of disasters by means of the same method used for normal conditions is necessary. From what is mentioned above, users can sightsee more efficiently and safely than before, by means of the system using the information of the situation around their location for appropriate support of sightseeing and evacuation.

On the other hand, although navigation systems using mobile information terminals are often used in recent years, using a smartphone while walking is called "wexting", and can be dangerous as it makes it hard for users to grasp their own surroundings. In contrast, with navigation using AR (Augmented Reality) terminals (smart glasses) which are a type of wearable terminal, as information is displayed in front of users without any special effort on their part, it is easy to grasp their surroundings and can help them safely navigate. Additionally, with the spread of social media in recent years, information related to sightseeing and disasters are being submitted and updated on social media in real time. Therefore, gathering real-time information through social media, and reflecting this both in sightseeing support in normal conditions and evacuation support in the event of disasters is necessary to realize a more efficient and safe sightseeing environment than before. However, as detailedly described in the next section, the systems in consideration of all above-mentioned points have not yet been put into practical use.

Based on the circumstances mentioned above, in order to support sightseeing in normal conditions as well as evacuation in the event of disasters, the present study aims to design, develop, operate and evaluate a navigation system that can gather high real-time information and actively alter routes in urban sightseeing areas. In recent years, most countries are shifting from being the ubiquitous network society to being a cloud computing society in which various information tools can be used to connect to the internet. Therefore, a society is being realized in which anyone, anywhere, anytime can connect to the internet and easily use an information system, regardless of time and place, as long as there is an environment in which the internet is connected to, and the person is someone who has some kind of information terminal. Considering the above points, it is expected that this system will support both tour planning and disaster management planning in smarter urban futures, by connecting the real world with the virtual world.

The central part of Yokohama City in Kanagawa Prefecture, Japan was selected as the region of operation. The reason for this is that (1) there is a variety of sightseeing spots, as it is an urban sightseeing area, which enable recommendations of sightseeing spots to be made according to each user's preferences, and (2) because tourists and sightseeing spots are concentrated in a small area, a lot of information concerning sightseeing spots are transmitted and the obtainment of real-time information is made possible.

2 Related Work

The present study is related to (1) the study concerning the sightseeing support system (Kurata 2012; Sasaki et al. 2013; Fujitsuka et al. 2014; Ueda et al. 2015), (2) the study concerning the point-of-interests (POI) recommendation system (Noguera et al. 2012; Ye et al. 2011; Yuan et al. 2013; Chen et al. 2016), and (3) the study concerning social media GIS (Geographic Information Systems) (Yamada and Yamamoto 2013; Okuma and Yamamoto 2013; Murakoshi and Yamamoto 2014; Yamamoto and Fujita 2015). Among the preceding studies in related fields as listed above, (1) (2) (3) support the tour planning and accumulating, sharing and recommending sightseeing spot information for sightseeing activity support in normal conditions, and (3) accumulating and sharing disaster information for evacuation support in the event of disasters. However, these preceding studies do not go further than offering information to users by means of accumulating, sharing and recommending information, which is realistically not enough to support users' activities. Additionally, they do not support the users' activities for both sightseeing in normal conditions and evacuation in the event of disasters. In contrast to these preceding studies in related fields, the present study shows originality in developing a system, which supports sightseeing in normal conditions and evacuation in the event of disasters by means of navigation, by integrating SNS (Social Networking Services), Twitter, Web-GIS, recommendation systems and smart glasses.

3 System Design

3.1 System Configuration

The system of the present study is developed by integrating SNS, Twitter, Web-GIS, recommendation system and smart glasses, as shown in Fig. 1. With the support of both sightseeing and evacuation as the purpose of the present study, users' activities are supported by means of the navigation that can actively change routes. Concerning navigation, in the case of sightseeing, information of the route to a single sightseeing spot from user's present location as well as routes for touring a group of sightseeing spots is provided. Additionally, in the case of evacuation,

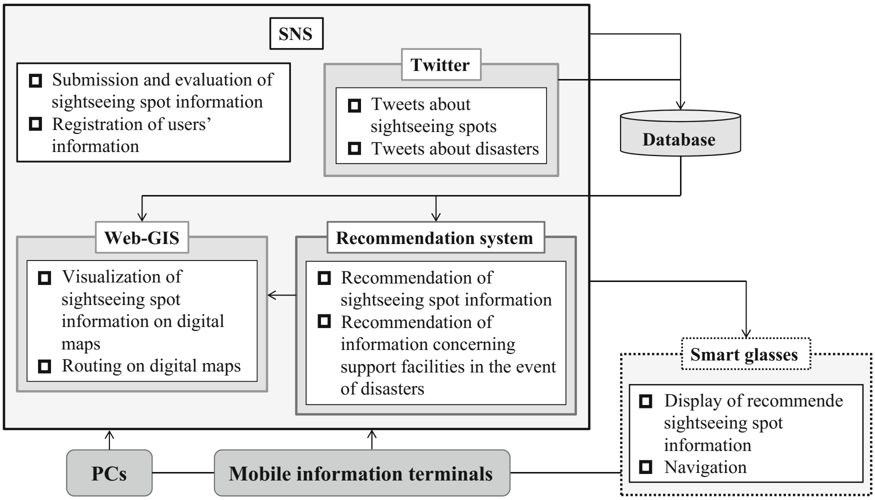


Fig. 1 System design of dynamic real-time navigation system

information including the closest evacuation locations from user's present location and routes to the support facility in the event of disasters is provided. Moreover, on Twitter and SNS which is originally developed, information of sightseeing spots including that of various events as well as disaster information of nearby areas will be obtained in real time, and the navigation route will change according to the information provided if necessary. By means of such a navigation system that focuses on obtaining real-time information, the efficient support of both sightseeing and evacuation is realized.

3.2 Targeted Information Terminals and User Assumption

This system is set with the assumption that it will be used from PCs, mobile information terminals and smart glasses. Because PCs are assumed to be used indoors, the submitting, viewing and recommending function of sightseeing spot information, registration function of activity history, support function for tour planning, and navigation functions in order to confirm routes, which are detailedly described in the next section, will all be available. Assuming mobile information terminals will be used indoors and outdoors, the submitting and viewing function of sightseeing spot information as well as the navigation function in order to visit sightseeing spots will be the main functions. However, because using mobile devices while walking can be dangerous, assuming the use of the smart glasses which displays information in front of the user as well, safe navigation will also be realized.

Additionally, regarding the submitting function of sightseeing spot information, the use method of those with knowledge concerning the region of operation and those without will be different. It is assumed that the former, in addition to submitting sightseeing spot information that they already know about, will make submissions concerning the evaluation of sightseeing spots using comment and tag functions. For the latter, it is assumed that they will visit sightseeing spots based on submitted information, and make submissions concerning the evaluation in the same manner as the former.

4 System Development

4.1 System Frontend

4.1.1 Functions for Sightseeing Support in Normal Conditions

In this section, the functions of this system for sightseeing support in normal conditions which are introduced in Sect. 4.3 are explained.

1. Submitting function of sightseeing spot information

By clicking on the “spot submissions” in the menu bar, users will be moved to the submitting page of sightseeing spot information. On the submitting page, users can submit sightseeing spot information by entering the name, description, images and location information of the sightseeing spot. The location information of the sightseeing spot can be entered by clicking the targeted location on the Web-GIS. Additionally, by clicking the “display past submitted locations”, users can confirm whether the same sightseeing spot information has been submitted in the past.

2. Viewing function of sightseeing spot information

Users can return to the homepage by clicking “home” in the menu bar, and view sightseeing spot information submitted in the past on the Web-GIS. Each sightseeing spot information is displayed with different color markers according to each category (food and drinks, shops, entertainment, event, landscape, art and recreation), and the category of each marker is explained in the image below the Web-GIS. When clicking the marker, a bubble containing the name and image of the sightseeing spot will be displayed. By clicking the bubble, users will be moved to the details page of the selected sightseeing spot which will enable them to check the detailed information.

In the details page of sightseeing spots, the comment and tag functions can be used. The comment function will enable communication between users as well as supplementation to be added to sightseeing spot information. Additionally, as detailedly described in the next section, Tweets related to sightseeing spots automatically obtained through Twitter in the backend of this system is also displayed in the comment section. These comments and Tweets are considered as real-time information of sightseeing spots. Regarding the tag function, the features of sightseeing spots can be freely added as tags by users. Users can use tags that have been registered in the past as well as the ones that have been newly registered. Moreover, by clicking tags that have already been added, additional importance can be placed on them. The most commonly used tag will be treated as the feature of the sightseeing spot when recommended. All tags belong to a category, and the category that the most-used tag of a sightseeing spot belongs to will also be the category in which the sightseeing spot belongs to. Additionally, by clicking on "start navigation from your present location", users can receive navigation to any sightseeing spot from their present location on the Web-GIS.

3. Registering function of activity history

By clicking on "history" in the menu bar, users will be moved to the activity history registration page. Activity history is made up of users' evaluation, budget and group of previously visited sightseeing spots within the region of operation. The numbers of sightseeing spots that can be registered are 2–5. Additionally, if the activity history is already registered, the confirmation screen of activity history will appear. On the confirmation screen of activity history, users can confirm the activity history registered in the past. The contents of activity history that will be displayed include the name, image and category of each sightseeing spot.

4. Support function of tour planning

By clicking "plans" in the menu bar, users will be moved to the tour planning page. Concerning the tour planning page, users can receive tour planning support from this system based on the registered activity history. First, concerning the tour planning, the budget and group, and the number of sightseeing spots that the users would like to visit must be entered and sent as conditions. Based on the conditions and activity history of each user, this system will recommend patterns made up by categories. Regarding each category in the pattern recommended, users can select and match sightseeing spots belonging to each category and create a tour plan. Additionally, in order to efficiently create a tour plan, the location information of sightseeing spots applied to each category will be actively displayed on the Web-GIS. If the tour plan is already made, users will be moved to the tour plan confirmation screen, and the name, image and category of sightseeing spots will be displayed according to the order on the sightseeing schedule. To send the displayed tour plan to the smart glasses, users must click the "setup the plan in smart glasses". By clicking the "start navigation", the navigation of the tour plan will start on the Web-GIS.

5. Navigation function

By clicking the "start navigation from present location" on the details page of sightseeing spot information or the "start navigation" on the tour plan confirmation screen, the first option will take the users to the navigation screen for single sightseeing spots, and the second will take them to the navigation screen for a group of sightseeing spots. Regarding navigation for single sightseeing spots, navigation will be conducted by displaying the present location and the route to the user's destination on the Web-GIS. Additionally, for navigation of a group of sightseeing spots, the navigation will be conducted by simultaneously displaying the present location and the route for a group of sightseeing spots.

6. Recommendation function of sightseeing spot information

Users will be moved to the recommendations page by clicking the "recommended" in the menu bar, and sightseeing spots with the most-used tags that are also registered as their preference information will be recommended. The information of the recommended sightseeing spots will be listed in tile form, and the content will include the name, description, image and category of each sightseeing spot.

4.1.2 Functions for Evacuation Support in Emergency Situations in the Event of Disasters

In this section, the functions of this system for evacuation support in emergency situations in the event of disasters are introduced.

1. Viewing function of support facilities in the event of disasters

Users can go to the homepage by clicking "home" in the menu bar, and view information of disaster support facilities (evacuation locations, evacuation sites, temporary accommodation, water supply points, and medical institutions), published by the disaster prevention map of Yokohama City as the region of operation, on the Web-GIS. The information of these disaster support facilities are differently marked according to the facility on the Web-GIS, and the type of marked facilities are explained below the image of the Web-GIS. When clicking the marker, a bubble with the name of the disaster support facility will be displayed. For more detailed information, users can click the bubble which will take them to the details page of the selected disaster support facility. The comment function can be used on the details page of disaster support facilities. The comment function enables communication between users and the supplementation of information concerning the disaster support facilities. Additionally, by clicking the "start navigation from present location", users can receive navigation from their present location to the selected disaster support facility on the Web-GIS.

2. Navigation function to the closest evacuation location

By clicking the "evacuation navigation" in the menu bar, users can move to the navigation page that shows the route to the closest evacuation location from their present location.

3. Search function of support facilities near users in the event of disasters

Users can go to the nearby disaster support facility page by clicking the "nearby disaster support facilities" in the menu bar, and disaster support facilities that are within 1 km from their present location will be recommended. The recommended disaster support facilities will be listed in tile form, and the name, facility type, and distance from the user's present location to the facility of each disaster support facility will be displayed.

4.2 System Backend

4.2.1 Information Obtained Through Twitter

In the present study, real-time information is gathered through Twitter in addition to the originally developed SNS. Twitter API 1.1 is used to obtain Tweets from Twitter. Tweets that are automatically obtained by this system in normal conditions are those submitted within 24 h that include the words "Minatomirai" or "#Minatomirai", and have been retweeted or added to favorites 5 times each. Taking the text out of each obtained Tweet, a search of letter strings by means of regular expressions will be conducted. The searched letter string is to be the names of all sightseeing spots submitted in this system, and if a matching letter string is found, this Tweet will be registered in the database as comment relating to the sightseeing spot matched by the letter string. In the event of disasters, Tweets including "#DynamicNavigation" in addition to having location information will be automatically obtained. This system obtains Tweets every minute, because the Twitter API has restricted the number of Tweet obtainment to 15 times in 15 min.

4.2.2 Calculation of the Similarity Ratio of Preferences Between Users

With the method of Fujitsuka et al. (2014) as a reference, SVM (Support Vector Machine) will be used for calculations of the preference similarity rate between users in the present study. SVM is one of the methods of machine learning, and it can also make models that discern different patterns in order to divide data into several classes. In the present study, users' activity history will be used as learning data, and budget/group and tags will be treated as features, while class will be divided into satisfactory class and dissatisfactory class. First, a user model based on his/her activity history will be made, the activity history of a different user will be applied to it, and the data will be divided into the satisfactory class or the dissatisfactory class. By comparing the aforementioned user model and the separation results, the ratio of matched satisfaction and dissatisfaction among the activity history will be set as the preference similarity rate between users. With reference to Fujitsuka et al. (2014), the present study will set those with a preference similarity rate of over 60.0% as users with similar preferences.

4.2.3 Making Recommendations

In normal conditions, this system will make recommendations for users in order to support the sightseeing spot recommendation based on their preference information as well as the tour planning based on their activity history. Concerning the former, tags registered as users' preference information and the most-used tags included in sightseeing spot information will be put together, and the matching sightseeing spot information will be recommended. Concerning the latter, calculations of the preference similarity rate between users will be made, and based on the activity history of users with similar preferences as well as their conditions, recommendation will be made using the pattern mining method. In particular, sightseeing spot information included in the activity history will first be converted to the category it belongs to, and the category group will be made. Then, all patterns from the category groups will be extracted. Next, as shown in Fig. 2, the closeness (degree of distance) will be solved for the extracted patterns considering the chronological order of the categories, and the closeness score of each pattern will be calculated by multiplying the support rate of patterns (appearance ratio). The pattern with the highest closeness score will be recommended to users. Additionally, in the event of disasters, based on the present location information of users, the closest evacuation

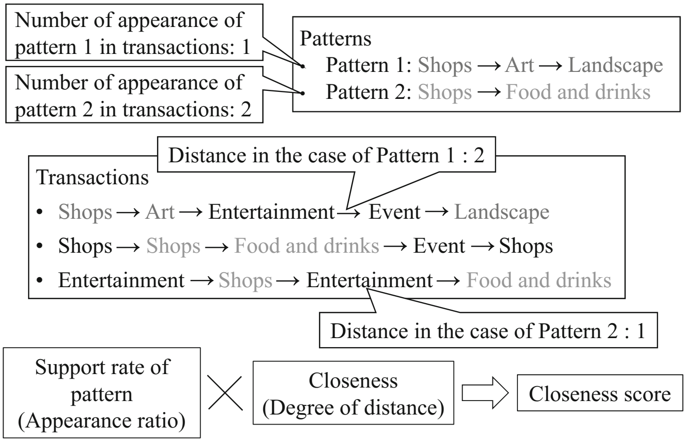


Fig. 2 Calculation method of closeness score

location and disaster support facilities within a certain distance from them will be recommended.

4.2.4 Change of Route

During navigation, by means of comments submitted on SNS and information automatically obtained through Twitter, routes will be changed when this system perceives higher information. Concerning normal conditions, when comments and Tweets concerning sightseeing spots are registered to this system, users receiving navigation will be notified whether they would like to visit these. If the user would like to visit the sightseeing spot, the route will change by adding it. Concerning disasters, if Tweets concerning the disaster which include the word "DynamicNavigation" and the location information are automatically obtained, the location information will be extracted from the Tweet, and it will be dealt as barrier information. Afterwards, by searching for new routes that arrive at the destination without going through the location shown in the extracted barrier information, the route will change.

4.2.5 Switching to the Emergency Mode

This system can be switched to emergency mode only by the administrator in the event of disasters. In this study, the authors play a role as an administrator. Concerning the switch to emergency mode, the administrator can either rewrite the text file within the system of the present study, or click the "switch to emergency mode" button which only appears on the home screen of the administrator. Additionally, the switch to normal mode from emergency mode can be done in the same way only by the administrator.

4.3 System Interface

The interface is optimized according to the user's PC screens (Fig. 3), mobile information terminal screens (Fig. 4), and smart glasses screens (Fig. 5), and administrator's screens. As mentioned in Sect. 3.2, users can properly choose the three types of information terminals such as PCs, mobile information terminals and smart glasses. In the menu bar of the user's PC screens (Fig. 3), the main functions of this system for sightseeing support in normal conditions, which are introduced in Sect. 4.1.1, are shown. Though the mobile information terminal screens (Fig. 4) is

観光支援システム

システム概要

本システムは研究目的で構築されており、

横浜市みなとみらい周辺において、平常時には観光回遊支援を、災害時には避　支援を行います。

主な利用方法としては以下の4つになります

・観光情報の投稿

・観光の計画立て

・ルートのナビゲーション

・観光スポットの推薦

※ 初めにプロフィールと履歴の登録をお願い致します。

最近の更新情報

- 日本洋服業発祥顕彰碑
- 元町オザワ洋装店
- 赤レンガ倉庫
- ヨコハマ・グッズショップ横濱001
- 横浜ランドマークタワー
- 丸加　伝統横濱スカーフ関内店
- 横浜銀行協会（旧横浜銀行集会所）
- 旧富士銀行横浜支店（旧安田銀行横浜支店）
- 旧英国7番館（戸田平和記念館）
- 岩田健夫邸

さらに見る…

管理者

電気通信大学 情報システム学研究科 山本研究室 藤田駿

E-mail:fujita@si.is.uec.ac.jp

No.	Description
1	Menu bar (A: Go to the homepage B: Submitting function of sightseeing spot information C: Support function of tour planning D: Registering function of activity history E: Recommendation function of sightseeing spot information F: Viewing function of sightseeing spot information)
2	Go to user information change and registration page
3	Display of user information
4	Display of ten latest pieces of submitted sightseeing spot information
5	Display of administrator information
6	Explanation about this system
7	Display of sightseeing spot information on digital map
8	Marker legend (Food and drinks, Shops, Entertainment, Event, Landscape, Art, Recreation)

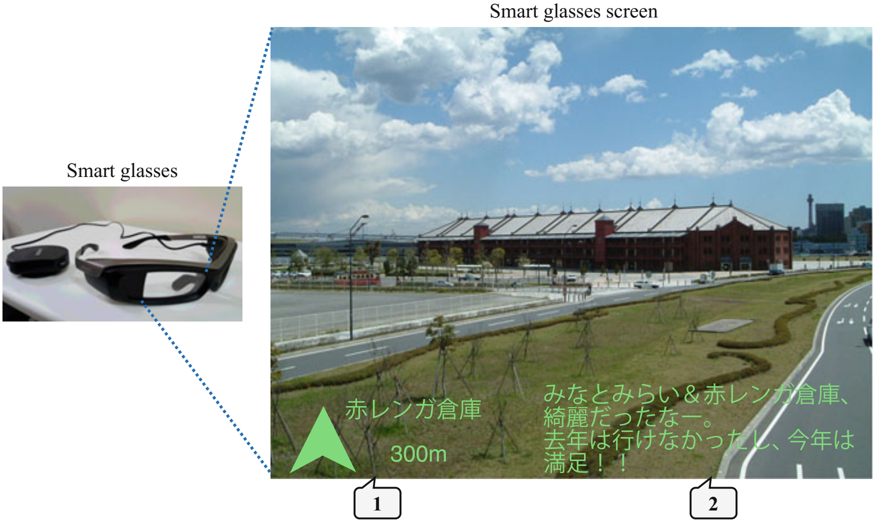
Fig. 3 Interface for PCs (Normal mode assuming normal conditions)

No.	Description
1	Menu bar (Submitting function of sightseeing spot information, Support function of tour planning, Registering function of activity history, Recommendation function of sightseeing spot information, Viewing function of sightseeing spot information)
2	Go to the homepage
3	Display of tourist spot information on digital map
4	Marker legend (Food and drinks, Shops, Entertainment, Event, Landscape, Art, Recreation)

Fig. 4 Interface for mobile information terminals (Normal mode assuming normal conditions)

basically the same as PCs, by changing the layout of items according to the size of the screen, the operability of this system is made easy. Regarding the interface for smart glasses screens (Fig. 5), the distance and direction of the destination from user's present location will be displayed, and comments and Tweets concerning the destination will also be provided when necessary. Additionally, in order to maintain safety while users are walking, information will be displayed only on the bottom half of the screen.

An Administrator can manage information saved in the database, which include users' personal information and submitted information, on the administrator's screen. As mentioned in the previous section, the authors play a role as an administrator. Information is displayed in a list form and is deleted using the GUI (Graphical User Interface) operation on the administrator's screen.



No.	Description
1	Display of the distance and direction of the destination from user's present location
2	Display of comments and Tweets concerning the destination

Fig. 5 Interface for smart glasses (Normal mode assuming normal conditions)

5 Operation

5.1 Operation Directly via the Web Using PCs and Mobile Information Terminals

Firstly, the operation directly via the web using PCs and mobile information terminals was conducted. Whether inside or outside the region of operation, the operation of this system was advertised using the website of the authors' lab, and the tourism department of Kanagawa Prefecture and Yokohama City in addition to the Yokohama Convention and Visitors Bureau (Yokohama City Tourism Association) supported this study by distributing pamphlets and operating manuals.

After seven weeks of operation in normal mode assuming normal conditions, the operation in emergency mode assuming disasters was also conducted in the same region of operation with the same users for one week. Table 1 shows the details of users during the eight-week operation, and the total number of users was 86. After having each user use this system for a month, the evaluation based on the online questionnaire survey was conducted. In order to solve the cold-start problem, the 181 items of sightseeing spot information gathered by Ikeda and Yamamoto (2014) was prepared as initial data. The cold-start problem is that it is difficult to make appropriate recommendations for users new to using this system, and difficult to recommend items which have been newly registered to this system for users. As the

Table 1 Outline of users and online questionnaire survey respondents

	10–19	20–29	30–39	40–49	50–59	60+	Total
Operation directly via the web using PCs and mobile information terminal							
Number of users	4	59	7	10	2	4	86
Number of questionnaire respondents	3	37	2	6	1	2	51
Valid response rate (%)	75.0	62.7	28.6	60.0	50.0	50.0	59.3
Operation via smart glasses							
Number of users	4	10	3	8	7	2	34

total number of submissions during the operation was 170, a total of 351 sightseeing spot information items were accumulated in this system. Additionally, with almost all submitted information, related images were also submitted.

First, the access log analysis of users during the operation while in normal mode assuming normal conditions was conducted. The total number of sessions was 358, and concerning the information terminals used as the method for accessing this system, PCs were 77% and mobile information terminals were 23%. The most accessed was the “viewing function of sightseeing spot information (27%)”, followed by the “support function of tour planning (20%)” and the “register function of activity history (19%)”. From these results, it can be said that PCs are used as the main access method chiefly for those outside the region of operation, and that the gathering of information and tour planning are the main purpose of use.

Next, the access log analysis of users during the operation while in emergency mode assuming disasters was also conducted. The total number of sessions during the one-week operation period was 28, and concerning the information terminals used as a method of access to this system, the ratio of PCs and mobile information terminals were 5:5. From the increase in percentage of mobile information terminals in comparison to normal conditions, it can be said that the tendency for the users to use mobile information terminals became stronger when disasters are assumed. Concerning the number of times each function was accessed, although the “viewing function of support facilities in the event of disasters” was accessed by almost half with 45%, functions using location information including the “navigation function to the closest evacuation location” and the “search function of support facilities near users in the event of disasters” are respectively 33 and 22%. From these results, it can be said that functions requiring location information were also actively used.

5.2 *Operation via Smart Glasses*

Secondly, the operation directly via the web using smart glasses was conducted. Between Yamashita Park and the Yokohama Red Brick Warehouse located within the region of operation, on December 11th and 18th, 2015, the operation via the smart glasses was conducted with tourists as subjects. Users put the smart glasses on and received navigation for 600 m between the above-mentioned two places. The reason why such a route was chosen is because there are no cars which enables users to safely receive . Additionally, in consideration for the safety of users, an escort was assigned to all users. Table 1 also shows the details of users during the two days of the operation period as mentioned above, and the total number of users was 34, with 18 male users and 16 female users. When divided according to age, although those in their 20's were the most numerous occupying 29% of the total number of users, the age of users were scattered, and no one had experience using the smart glasses. Just after the operation, all users were required to answer the online questionnaire survey.

6 Evaluation

6.1 Evaluation Based on the Questionnaire Survey Results Concerning the Operation Directly via the Web Using PCs and Mobile Information Terminals

Figure 6 shows the evaluation results concerning the use of the system directly via the web using PCs and mobile information terminals in normal conditions and in the event of disasters. Regarding the usefulness in urban sightseeing areas in normal conditions, all answered were either "I agree" and "I somewhat agree", and 74% answered "I agree" which is a significantly high number. Concerning the smooth use when switching from normal mode assuming normal conditions to emergency mode assuming disasters, although a high number of 88% answered "I agree" or "I somewhat agree", 12% answered "I somewhat disagree" or "I completely disagree". Because the functions of this system used in the event of disasters completely differ

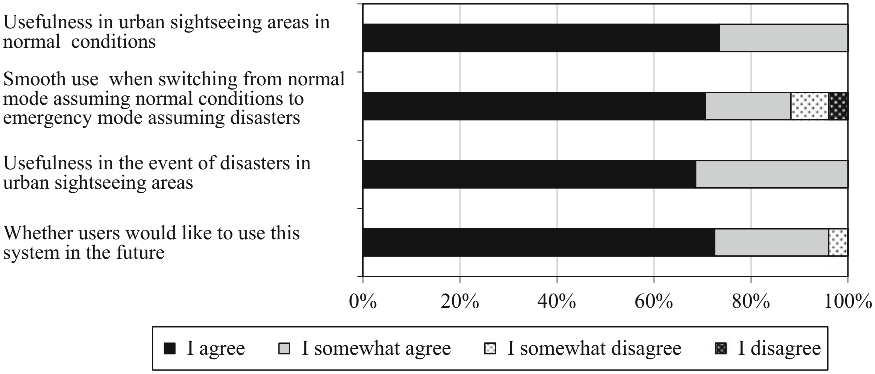


Fig. 6 Evaluation results concerning the use of the system directly via the web using PCs and mobile information terminals

from those used in normal conditions. However, concerning the usefulness in the event of disasters in urban sightseeing areas, with all answers being either "I agree" and "I somewhat agree", a significantly high percentage of 69% answered "I agree". From the above, regarding the support of both sightseeing in normal conditions and the evacuation in the event of disasters, it can be said that this system is effective. Additionally, concerning whether users would like to use this system in the future, as 96% answered "I agree" or "I somewhat agree", the continuous operation of this system in the future can be expected.

6.2 Evaluation Based on the Questionnaire Survey Results of the Operation via Smart Glasses

Figure 7 shows the evaluation results concerning the use of the system via smart glasses. 94% answered "easy" or "relatively easy" regarding the usability of the smart glasses. From the fact that all users had no experience previously using the smart glasses, it can be said that the use of the smart glasses concerning this system is easy even for users who have never used it before. Concerning the suitability of smart glasses in comparison to smartphones while sightseeing, in addition to the suitability of navigation by means of the smart glasses, 91% answered "suitable" or "relatively suitable" for both situations. The former had especially high results as 74% answered "suitable". The reason for this is that, in addition to the usability of the smart glasses as mentioned above, as the smart glasses, unlike mobile information terminals, can display information right in front of users, they can take in information while looking ahead instead of looking down. Therefore, in order to realize efficient and safe navigation which is the aim of the present study, it is beneficial to use the smart glasses for this system instead of only using mobile information terminals.

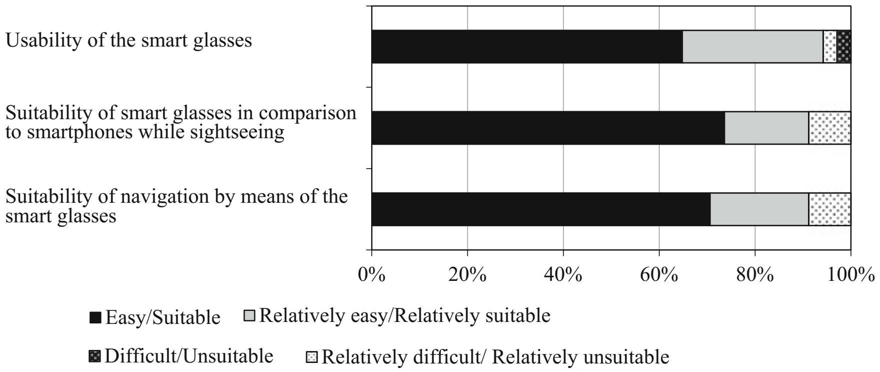


Fig. 7 Evaluation results concerning the use of the system via smart glasses

7 Conclusion

Thus, in order to support sightseeing in normal conditions and evacuation in the event of disasters, by integrating SNS, Twitter, Web-GIS, the recommendation system and the smart glasses, as well as gathering high real-time information concerning urban sightseeing areas, a navigation system that can actively change routes was designed and developed. By means of this, concerning both normal conditions and disasters, it was possible for users to accumulate, share and recommend information in addition to navigate to their destination.

From the evaluation results based on the questionnaire survey to users after the operation, it was clear that this system can appropriately support both sightseeing in normal conditions as well as evacuation in the event of disasters, and the safe and efficient navigation using the smart glasses has been realized. Using smart glasses was safer, because information was displayed in front of users without any special effort on their part, making it easier for them to perceive their surroundings than with mobile information terminals. Consequently, the present study showed the possibility that this system will support both tour planning and disaster management planning in smarter urban futures, by connecting the real world with the virtual world.

From the evaluation results in the previous section, the following two points of improvement for this system can be summarized as shown below.

1. Implementation of the automatic switch function to emergency mode

By obtaining information of the disasters in the region of operation and reflecting it in this system, the automatic switch from normal mode to emergency mode can be made possible. This will not only lighten the load of the administrator, but will enable the switch to emergency mode and support the evacuation of users, regardless of the administrator's situation in the event of disasters.

2. Color classification of displayed routes concerning navigation

When navigating multiple sightseeing spots on the Web-GIS, by color-coding each displayed route between sightseeing spots, the discernment of routes are made easier. This enables the operability of the navigation function to improve, and a more efficient sightseeing support is also made possible.

Acknowledgement In the operation of the dynamic real-time navigation system and the online questionnaire surveys of the present study, enormous cooperation was received from those mainly in the Kanto region such as Kanagawa Prefecture and Tokyo Metropolis. We would like to take this opportunity to gratefully acknowledge them.

References

Chen, M., Li, F., Yu, G., & Yang, D. (2016). Extreme learning machine based point-of-interest recommendation in location-based social networks. *Proceedings of ELM-2015*, 2, 249–261.

Fujitsuka, T., Harada, T., Sato, H., & Takadama, K. (2014). Recommendation system for sightseeing plan using pattern mining to evaluate time series action. *Proceedings of the Annual Conference on Society of Instrument and Control Engineering, 2014*(SS12-10), 802–807.

Ikeda, T., & Yamamoto, K. (2014). Development of social recommendation GIS for tourist spots. *International Journal of Advanced Computer Science and Applications, 5*(12), 8–21.

Kurata, Y. (2012). Introducing a hot-start mechanism to a Web-based tour planner CT-Planner and increasing its coverage areas. *Papers and Proceedings of the Geographic Information Systems Association of Japan*, 21, CD-ROM.

Murakoshi, T., & Yamamoto, K. (2014). Study on a social media GIS to support the utilization of disaster information: For disaster reduction measures from normal times to disaster outbreak times. *Socio-Informatics, 3*(2), 17–31.

Noguera, J. M., Barranco, M. J., Segura, R. J., & Martinez, L. (2012). A mobile 3D-GIS hybrid recommender system for tourism. *Information Sciences, 215,* 37–52.

Okuma, T., & Yamamoto, K. (2013). Study on a social media GIS to accumulate urban disaster information: Accumulation of disaster information during normal times for disaster reduction measures. *Socio-Informatics, 2*(2), 49–65.

Sasaki, J., Uetake, T., Horikawa, M., Sugawara, M. (2013). Development of personal sightseeing support system during long-term stay. *Proceedings of 75th National Convention of IPSJ*, 727–728.

Ueda, T., Ooka, R., Kumano, K., Tarumi, H., Hayashi, T., & Yaegashi, M. (2015). Sightseeing support system to support generation and sharing of sightseeing information. *The Special Interest Group Technical Reports of IPSJ: Information system and Social environment (IS)*, 2015-IS-131(4), 1–7.

Yamada, S., & Yamamoto, K. (2013). Development of social media GIS for information exchange between regions. *International Journal of Advanced Computer Science and Applications, 4*(8), 62–73.

Yamamoto, K., & Fujita, S. (2015). Development of social media GIS to support information utilization from normal times to disaster outbreak times. *International Journal of Advanced Computer Science and Applications, 6*(9), 1–14.

Ye, M., Yin, P., Lee W. C., & Lee, D. L. (2011). Exploiting geographical influence for collaborative point-of-interest recommendation. *Proceedings of the 34th international ACM SIGIR conference on Research and Development in Information Retrieval*, 325–334.

Yuan, Q., Cong, G., Ma, Z., Sun, A., & Thalmann, N. M. (2013). Time-aware point-of-interest recommendation. *Proceedings of the 36th International ACM SIGIR Conference on Research and Development in Information Retrieval*, 363–372.

Chapter 11
An Advanced Web API for Isochrones Calculation Using OpenStreetMap Data

Yiqun Chen, Abbas Rajabifard and Jennifer Day

Abstract This chapter demonstrates a software that finally makes urban reachability analysis free, open-source, and usable for non-technical urban analysts. We aim to provide researchers with a highly-parametric API (Application Programming Interface) for creating isochrones worldwide, meeting various scenario requirements with high accuracy. We start with OpenStreetMap road data that the software cleans by applying a sub-graph algorithm, removing isolated road links. This results in a fully-connected network for isochrones calculation, improving the web API stability. Then, a non-recursive breadth-first-search algorithm runs in parallel to generate isochrone links. The isochrones are then constructed using either link buffers or concave hulls to meet various accuracy requirements. The final outputs, including isochrones polygons, lines, and nodes with traverse distance attributes, can be exported in popular formats. The API supports thousands of isochrone calculations simultaneously, and is fully accessible online. The source code will also be provided for free for anyone to take and modify.

Keywords Isochrones calculation · Service area analysis · Walkability analysis · Web API

Y. Chen (✉) · A. Rajabifard
Department of Infrastructure Engineering, The University of Melbourne,
Parkville, VIC, Australia
e-mail: yiqun.c@unimelb.edu.au

A. Rajabifard
e-mail: abbas.r@unimelb.edu.au

J. Day
Faculty of Architecture, Building, and Planning, The University of Melbourne,
Parkville, VIC, Australia
e-mail: jday@unimelb.edu.au

S. Geertman et al. (eds.), *Planning Support Science for Smarter Urban Futures*, Lecture Notes in Geoinformation and Cartography,
DOI 10.1007/978-3-319-57819-4_11

1 Introduction

Reachability analysis is one of the fundamental tasks in urban planning and business intelligence, measuring the service area that schools, hospitals, fire brigades, train stations, franchise shops or warehouses can cover (Bauer et al. 2008; Efentakis et al. 2013). This kind of analysis helps urban planners to strategically optimise the location of public facilities and analyse how changes to the system will disrupt or enhance access (Marciuska and Gamper 2010).

Given the broad importance of isochrones analysis, there are few viable options that offer flexible and comprehensive parameter configurations to control the isochrones-generation process. Some commercial solutions do exist for analysts wanting to conduct reachability analysis, but they are limited in a number of ways. One tool is the "*Service Area Analysis*" Network Analyst extension (ESRI 2016), which requires a special license to run and requires the analyst to prepare the road network. The other is the "*calculateisoline*" service offered by Here Map Routing API (Here 2016). It provides global isochrones calculation capability but requires that users pay a monthly fee and imposes transaction limits. Other ad hoc online solutions such as ISOGA (Innerebner et al. 2013) and Iso4App (2016) either have similar problems or only support isochrones analysis in limited places.

The result is that planners use these tools less than they might. In this chapter, we demonstrate a free isochrones calculation web service as our own response to the limited options available. The backend system architecture is scalable enough for enabling isochrones generation globally with high accuracy and processing speed. Two travel models (drive and walk) are currently supported with abundant input parameters, giving users fine control of the isochrones construction. Users can also configure outputs formats to meet their own needs.

Our isochrones tool is currently wrapped as an API (Application Programming Interface), rather than as an application. The difference is that applications generally come with a graphical user interface (GUI) to enable parameters setup and outputs visualisation. Just as a GUI makes it easier for people to use programs, APIs make it easier for people (often developers) to build their own applications. In our API, most of input parameters are self-explanatory. We also provide detailed usage instructions and examples. The tool is designed to be legible for users without any programming background.

The following sections articulate the logic of our core isochrones algorithm, the steps for preparing OpenStreetmap (OSM) road network data for isochrones calculation, and some typical usage scenarios with examples. The API performance benchmarks and future improvements are discussed at the end of this chapter.

2 Isochrones Algorithm Overview

2.1 Isochrones Definition

Previous research (Gamper et al. 2011, 2012; Efentakis et al. 2013; Buchhold 2015) define an isochrone as a minimal graph (or diagram, road network) that connects all vertices (or nodes, locations) which can be reached within a certain travel cost constraint from a given source. Buchhold (2015) frames this problem more precisely and our improved expression is described as: Given a graph $G = (V, E)$ and a travel cost function f which assigns a non-negative travel cost to traverse an edge e (u, v). An isochrone subgraph $Gi = (Vi, Ei)$ can be constructed by using a source vertex s and travel cost limit c, if $f(s, u) + f(u, v) \leq c$, then edge $e(u, v) \in Ei$ and is **fully traversable** within Gi; if $f(s, u) < c$ but $f(s, u) + f(u, v) > c$, then edge $e(u, v)$ is **partially traversable** within Gi; if $f(s, u) \geq c$ then edge $e(u, v) \notin Ei$ and is **non-traversable** within Gi.

The travel cost function, f, can be expressed as either travel time or travel distance. However, the time-based function requires some additional attributes, such as speed limits on each edge and waiting time at intersections, to support time calculations. In this software, we adopt the more generic distance-based travel cost function and both **fully traversable** and **partially traversable** edges are considered and computed to build isochrones.

2.2 Calculation Logics

Our core calculation logics for isochrones derive from breadth-first-search (BFS) algorithm developed from graph theory. Compared with BFS for graph traverse, there are two major challenges in the isochrones calculation which make the process more complicated. The first one is that during the traverse, if a vertex can be reached by another edge with smaller traverse distance than its existing value, then these vertices as well as all subsequently-connected vertices, need to be revisited. This operation increases computational complexity but is imperative to ensure all vertices can be reached at the minimal traverse distance, and in turn to guarantee maximum isochrones reachability. Figure 1 illustrates this common situation in isochrones calculation. In Fig. 1a, node N3 and N4 have already been assigned with traverse distance values of 30 and 35 respectively via a previously found path (N0–N1–N3–N4); while later on another path (N0–N2–N3–N4) is found as shown in Fig. 1b. The traverse distance value of N3 is updated to 20, which is smaller than its previous value 30. In this case, node N3 has to be put back to the end of BFS **toVisitNodes** queue again for a revisit in future, so that the traverse distance values of its subsequent nodes (e.g., N4) can be updated accordingly.

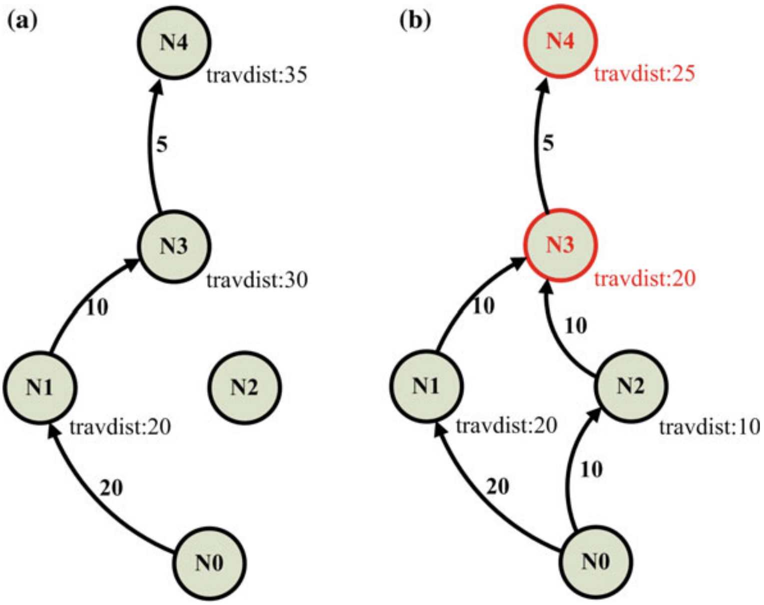


Fig. 1 Node traverse distance update process. The *left* **a** shows that N3 and N4 have been visited with travdist values assigned. The *right* **b** illustrates that after N2 is visited, N3 will have a smaller travdist value, and N3 needs to be queued again so N4 can be updated accordingly

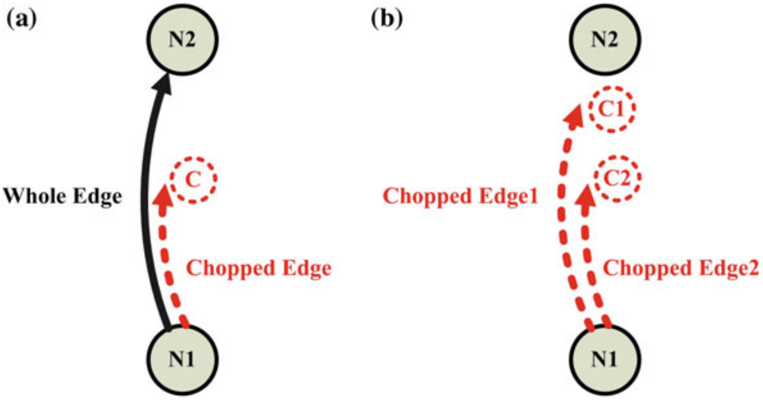


Fig. 2 Spatial relationships of whole-chopped edges (**a**), chopped-chopped edges (**b**)

We categorise two edge types in isochrones: the whole edge and chopped edge, which respectively represent **fully traversable** and **partially traversable** edges denoted in previous section. The second challenge is to manage the spatial relationships of whole-chopped edges and chopped-chopped edges. Figure 2 demonstrates these two scenarios. In Fig. 2a, a whole edge from node N1 to N2 is fully

Table 1 Pseudo-code for a non-recursive BFS isochrones calculation

```
while (!toVisitNodes.isEmpty()) {
  //popup the first node in toVisitNodes
  curNode = toVisitNodes.removeFirst();
  //put it in visitedNodes
  visitedNodes.put(curNode);
  for (edge in curNode.getEdges()) {
    // if a whole edge can be added, no edge chopping required
    if (edge.len + curNode.travdist <= maxtravdist) {
      // calcualte the edge travdist
      edge.travdist = edge.len + curNode.travdist;
      // check if visitedWEs has already contains
      if (!visitedWEs.contains(edge)) {visitedWEs.put(edge); }
      else{
        if (edge.travdist < visitedWEs.get(edge).travdist) {
          visitedWEs.put(edge);
        }
      }
      // create a tiny buffer for all visited whole edge
      // this helps to eliminate chopped edge later on
      if (!visitedWEBufs.contains(edge)) {
        visitedWEBufs.put(edge.geometry.buffer(1));}
        // if its next node is not in visitedNodes yet
        if (!visitedNodes.contains(edge.getNextNode())) {
          // if not a leaf, then put it into toVisitNodeList
          // so it can be visited later
          if (!edge.isLeaf) {toVisitNodes.addLast(edge.getNextNode());}
          else{
            // otherwise put it visitedNodes
            visitedNodes.put(edge.getNextNode());
          }
        }else{
          // if its next node is already in visitedNodes yet,
          // check if current travdist is smaller than the existing value
          if ((edge.len + curNode.travdist) <
              visitedNodes.get(edge.getNextNode()).travdist) {
            // if yes, update the visited node in
            // visitedNodeswith with smaller travdist value
            visitedNodes.put(edge.getNextNode());
            // if this is not a leaf, then put it into
            // toVisitNodeList so it can be revisited later
```

(continued)

(Table 1 continued)

```
            if (!isLeaf) {
              toVisitNodeList.addLast(edge.getNextNode());
            }
          }
        }
     }else{
      // if a whole edge can NOT be added,
      // then edge chopping required chop the edge to a proper length
     newEdge = edge.chop(maxtravdist-(edge.len + curNode.travdist));
      // check if new chopped edge is within the buffer in visitedWEBufs
      if (visitedWEBufs.contains(edge)) {
        if (newEdge.geometry.within(visitedWEBufs.get(edge))) {
          // if yes, this chopped can be ignored
          // since an existing whole edge covering this chopped edge.
          ignoreCE = true;
         }
       }
       // continue check if chopped edge exists in visitedCEs
       if (visitedCEs.contains(newEdge)) {
          // if yes, then check if the length of existing
       // chopped edge is shorter than that of the new one.
       existingCELeng = visitedCEs.get(newEdge).geometry.getLength();
       newCELeng = newEdge.geometry.getLength();
       if (existingCELeng > newCELeng) {
          // if yes,set ignoreCE = false so it can be replaced by the new one
          // this is critical to ensure only longest chopped edge is retained
            ignoreCE = true;
          }
       }
       // if cannot ignore chopped edge, put its next node in visitedNodes
       // and put it in visitedCEs
       if (!ignoreCE) {
          visitedNodes.put(newEdge.getNextNode());
          visitedCEs.put(newEdge);
       }
     }
   }
}
```

traversable; however, due to the travel cost constraints applied in another traverse search, the edge from N1 to N2 is partially traversable (chopped) from N1 to C. In this case, the chopped edge will be excluded from the final output since the existing whole edge can reach further. Figure 2b shows a different scenario, in which there is no whole edge that can be traversed between N1 and N2. Only two chopped edges (from N1 to C1 and from N1 to C2) are constructed. This is common when the path search algorithm sprawls to the fringe of isochrones, where chopped edges are leaf edges and overlap with each other. In this scenario, the longest chopped edge will be retained in the output because it maximises the reach of isochrones. When handling the real road network, it is essential to remove chopped edges to ensure isochrones outputs contain clean geometries.

The pseudo-code in Table 1 shows the algorithm we implement. It is designed with a non-recursive BFS architecture. All nodes to be visited are stored into a queue called **toVisitNodes**, and the algorithm stops once there is no element in this queue. In the main loop, for each time, the first node in the queue is stored in the list, **visitedNodes**, and then its connected edges are used for the isochrones calculations. Both whole edges and chopped edges are considered in the construction of isochrones. The algorithm separately manages visited whole edges in list **visitedWEs** and visited chopped edges in list **visitedCEs**. The first challenge is resolved in line 34–44: a non-leaf node is put back into **toVisitNodes** for a revisit if the current traverse distance is smaller than existing value. To address the second challenge, for each visited whole edge, a line buffer polygon is created and stored in **visitedWEBufs** (line 21), which can be used to eliminate chopped edges when necessary (line 51–57). For those overlapped chopped leaf edges, line 59–69 assures that only the longest chopped leaf edges will be recorded. This maximises the size of the resulting isochrones.

3 OSM Road Network Data Preparation

3.1 Data Acquisition

Road network data is required for isochrones calculation. Theoretically, any polyline-based data with correct topology representing the real world network can be adopted. For this chapter, we extract the road network from OpenStreetMap, both because it is free online and for its global coverage. The raw OSM data is obtained from one of this data's mirror websites (download.geofabrik.de) and the ".bz" format data for individual countries is processed separately. Figure 3 depicts the steps for bringing OSM road network into our system.

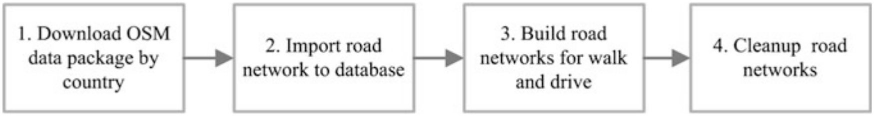


Fig. 3 OSM road network processing steps

Once the raw data is downloaded, we use "osm2pgrouting" tool for the road network data import. This tool uses an XML configuration file to choose different road types and classes to import to a PostgreSQL database. In OSM, the key "highway" is the primary key used for all types of streets or ways (OSM 2016). For example, when we built the Australian road network data (raw data obtained in February 2016), links labelled as one of the following "highway" types in Table 2 were imported.

3.2 Drive Versus Walk

The API is designed to calculate isochrones for both drive and walk modes. These two modes can be differentiated by the road types involved for the computation (OSM 2016). In this work, after analysing the definition of every type of road in OSM, we assume people can walk on all 24 types of road in Table 2 and can drive on 16 types of road, excluding the eight shown in Table 3. For each country, two separate road networks are constructed, and users can choose which network should be used for isochrones generation when sending requests to the API.

3.3 Isolated Road Links Elimination

Another issue is the isolated road links problem. Isolated roads are those that are topologically disconnected from the main road network, whose links are fully connected and traversable. Isolated roads cannot be traversed, though they might be

Table 2 Imported values for key "highway" in OSM road network for Australia, raw data obtained in February 2016

Value	LinksNum	Value	LinksNum
Road	7847	Track	166446
Motorway	10001	Pedestrian	6525
Motorway link	8746	Services	77
Trunk	60524	Bus guideway	75
Trunk link	3875	Path	70423
Primary	94865	Cycleway	65902
Primary link	5538	Footway	154339
Secondary	137673	Bridleway	1064
Tertiary	216619	Steps	5212
Residential	964964	Unclassified	224752
Living street	2226	Secondary link	3790
Service	290424	Tertiary link	5410

Table 3 Excluded key "highway" values for drive mode

Value	Comment	Photo
Pedestrian	For roads used mainly/exclusively for pedestrians in shopping and some residential areas	
Services	For access roads to, or within an industrial estate, camp site, business park, car park etcetera	
Bus guideway	A busway where the vehicle guided by the way (though not a railway) and is not suitable for other traffic	
Path	A non-specific path	
Cycleway	For designated cycleways	
Footway	For designated footpaths; i.e., mainly/exclusively for pedestrians. This includes walking tracks and gravel paths	
Bridleway	For horses	
Steps	For flights of steps (stairs) on footways	

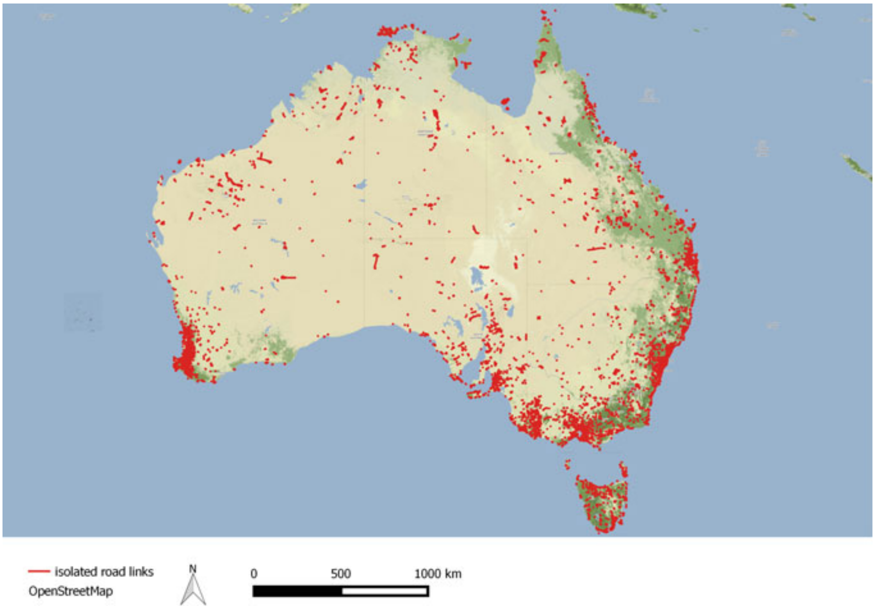


Fig. 4 OSM isolated road links across Australia

geographically close to the main network. When calculating isochrones at a given point, that point will first be attached to its closest road link before the core algorithm can proceed. If the road link is not physically linked to the main network, the isochrones may be constrained to the local road network and might not reflect the accessibility conditions.

In OSM data, though the proportion of isolated links is insignificant, they are ubiquitous and dispersed across the road network. Figure 4 shows the isolated road links in Australia, which comprise about 0.98% of the total number of road links. Figure 5 gives detailed examples of some isolated links in the Melbourne CBD area.

Despite their low incidence, the existence of isolated links decreases the isochrones' API stability; hence, an extra step needs to be taken to eliminate these isolated links. We adopt the "pgr_labelgraph" function (pgRouting Manual 2016) to create an integer column called "subgraph". This function assigns the same integer values to all those links in the network which are connected topologically. For example, for Australia, two main sub-networks are identified after "pgr_labelgraph" analysis is performed. One is for the mainland (2,435,512 links), and the other is for the island of Tasmania (61,965 links). After these adjustments, the road network data is ready for isochrones calculation.

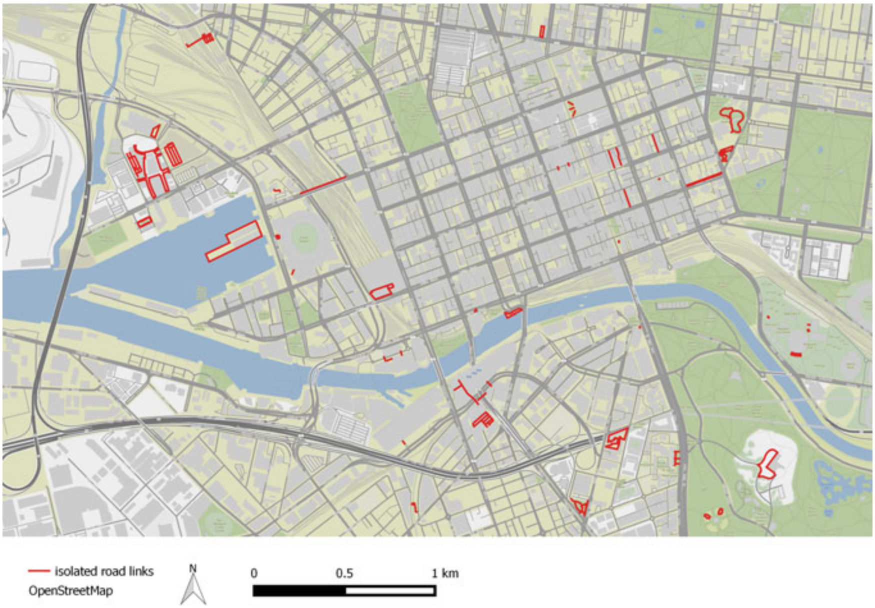


Fig. 5 OSM isolated road links around Melbourne CBD area

4 API Implementation

4.1 Processing Workflow

Instead of performing isochrones calculation at the database layer (Gamper et al. 2011, 2012; Efentakis et al. 2013), we developed the algorithm in Java at the application layer. We take this approach to system architecture to take advantage of parallel computation capability and to retain more control of the outputs. The system is wrapped up as a web service to support diverse isochrones calculation scenarios and to be easily and widely accessible to interested users and researchers.

The following example demonstrates all key steps for completing a simple isochrones calculation. We calculate an isochrone using a distance of 800 m about a point. In this case, only two parameters are passed to the API. One is the seed point location, which is described using the WGS84 (EPSG:4326) coordinate system. The other is the road network traverse distance, which is used as a threshold to terminate the core isochrones algorithm. It is straightforward to frame an isochrones calculation request from user’s viewpoint, while significant computational work is completed underneath, on the server end, to respond users’ requests.

When importing the OSM road network for each country into the system, the road link geometries are stored in WGS84 geographic coordinate system (GCS), which uses an angular unit of measure (i.e., latitude and longitude). This Coordinate Reference Systems (CRS) for spatial data storage has been widely adopted for handling global spatial datasets, implemented in products such as OSM and Google Earth. However, the internal calculation requires a projected CRS to transform spatial measurement units from arc degrees to meters. In our application, we use Universal Transverse Mercator (UTM) coordinate systems for the projection.

Given a seed point with WGS84 coordinates, the API first finds the correct UTM zone. It then obtains the corresponding zone code, which serves as the key parameter for CRS transformation. Next, the seed point coordinates are projected into the UTM zone coordinates, which use meters as the unit of measurement. Then, the API applies a circular buffer around the projected seed point using road network traverse distance. This buffer defines the upper bound of all possible reachable road links from the seed point for a given traverse distance. This means that any link that meets the isochrones calculation criteria must be strictly within the buffer. This rule is paramount and can reduce the computation time significantly by loading a subnetwork rather than the entire road network.

To obtain a subnetwork, the projected buffer needs to be transformed from UTM back to WGS84 so that its bounding box (described in longitude and latitude) can be applied as a query filter over the OSM road network. Then, the returned subnetwork data is re-projected into the same UTM zone and fed into the isochrones core algorithm. Once the calculation is complete, the isochrones polygons, polylines and points are eventually transformed back into WGS84 as the outputs.

4.2 Input Parameters

The API provides users with comprehensive parameters to fully control the isochrones generation process. Table 4 describes all important parameters. Next, the "Usage Scenarios" section describes isochrones calculation requests using parameter combinations representing a diverse set of usage scenarios.

4.3 Output Data Structure

The API output is described in JSON (JavaScript Object Notation), a prevailing data exchange format of web services. Currently, the output contains two hierarchies of information and the most important part is wrapped in the "data" attribute, as Table 5 illustrates.

Table 4 API input parameters

Parameters	Description	Default
Key	API key to access this service	N/A
Coordarr	An array of seed point coordinates	N/A
Radiusarr	An array of road network traverse distance (in meter) that the algorithm can reach	[500]
Traveltype	Use "drive" or "walk" road network for isochrones calculation	Walk
Bufsize	The width (in meters) of buffer around road links	50
Removeholes	When **polygondetaillevel** is set to 'high', isochrones polygon is constructed by merging all buffer polygons around reachable road links. Holes might exist in the merged polygon. Setting this parameter to "true" removes these holes	True
Returnline	Indicates road links are included as a part of the output	False
Returnpoint	Indicates road nodes are included as a part of the output	False
Combotype	Use "simple" or "composite" to control isochrones generation behaviour. If set to "simple", the algorithm will enforce the length of **radiusarr** as equal to the lengths of **coordarr** so that each seed point will be assigned with one radius value; if set to "composite", the algorithm will apply all radius values defined in **radiusarr** to each seed point	Simple
Format	Use "geojson" or "shp" to control the output format. If set to "shp", a shpfile download url will be provided in the outputs	Geojson
Polygondetaillevel	Use "high", "mid" or "low" to control how isochrones polygons can be created. If set to "high", it will use the buffered lines as the isochrones polygons, which offers the most precise outputs for isochrones calculation; if set to "mid", it will build a concave hull by using all leaf nodes of the road links to represent the isochrones polygon, and the **concavehullthreshold** value used for the concave hull generation will be dynamically determined; if set to "low", it will use a concave hull to represent the service area, and the user-defined **concavehullthreshold** value will be used for the concave hull generation	High
Concavehullthreshold	This only takes effect when **polygondetaillevel** is set to "low". The concave hull is created according to this threshold	200

5 Usage Scenarios

This section demonstrates the capabilities of our isochrones API by addressing four typical usage scenarios with examples. We will discuss how to combine parameters to build comprehensive requests for the API, how to control the isochrones calculation process and how to interpret and visualise the outputs. In the following examples, the default "walk" road network is used for isochrones calculation and

Table 5 API output data structure

Attributes	Description	
Version	Version number of API	
Lastupdate	Last update time of API	
Status	Whether algorithm completes successfully, 0: success 1: failure	
Errdesc	Error description	
Data	processingtime	Algorithm processing time (in second)
	crs	The coordinate reference system of the output spatial components, e.g., EPSG:4326
	geojson_polygon	Isochrones polygons described in geojson format
	geojson_line	Isochrones road links (with travel distance attribute) described in geojson format
	geojson_point	Isochrones road nodes (with travel distance attribute) described in geojson format
	shpurl_polygon	A download url for isochrones polygon shpfiles (a zipped package)
	shpurl_line	A download url for Isochrones road links shpfiles (a zipped package)
	shpurl_point	A download url for Isochrones road nodes shpfiles (a zipped package)
	…	Rest attributes are identical to input parameters

the base part of API url is described here http://nearbit.com/api-isochrones/. The main focus is on how to use combinations of rest parameters.

5.1 N Points with 1 Distance

This is the most common isochrones calculation request—using a single fixed road network traverse distance to calculate isochrones polygons for each element in a point array. For example, Fig. 6 shows the isochrones polygons for three points with 800 m road network distance using following parameters:

> *&coordarr=[{"lat":-37.8043,"lng":144.9617},{"lat":-37.8021, "lng":144.9891},{"lat":-37.7829,"lng":144.9802}]&radiusarr=[800]*

5.2 N Points with N Distances

This calculation request applies a different road network traverse distance to calculate isochrones polygons for each element in a point array. For example, Fig. 7

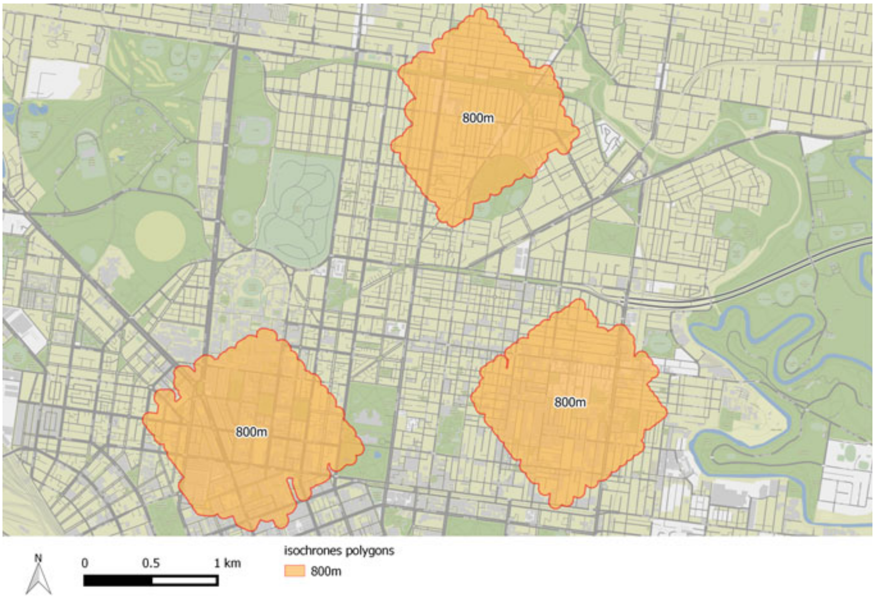


Fig. 6 Calculate isochrones for N points with one distance (by walk)

shows different sizes of isochrones polygons (400, 600, 800 m) for each point using following parameters:

&coordarr=[{"lat":-37.8043,"lng":144.9617},{"lat":-37.8021, "lng":144.9891},{"lat":-37.7829,"lng":144.9802}] &radiusarr=[400,600,800]

5.3 N Point with M Distances

With parameter **combotype** set to "*composite*", this calculation request applies a series of road network traverse distances to calculate isochrones polygons for each element in a point array. For example, Fig. 8 shows three different sizes of isochrones polygons (400, 600, 800 m) for each point using the following parameters (nine isochrones polygons are generated in total):

&coordarr=[{"lat":-37.8043,"lng":144.9617},{"lat":-37.8021, "lng":144.9891},{"lat":-37.7829,"lng":144.9802}] &radiusarr=[400,600,800]& combotype=composite

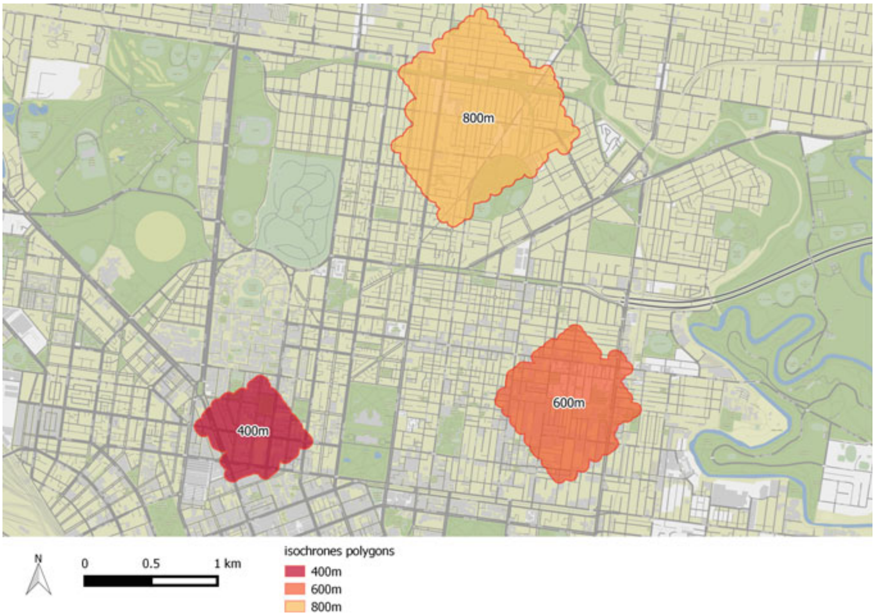


Fig. 7 Calculate isochrones for N points with various distances (by walk)

5.4 Isochrones with Links and Nodes

In some cases, road links and nodes with travel distance values of each link are equally important for analysis. With parameters **returnline** and **returnpoint** set to "true", a road link layer and node layer will be returned as a part of the outputs. For example, Fig. 9 shows 1000 m isochrones polygons, links, and nodes, which are rendered in colors based on their traverse distance from the seed point. It is generated using following parameters:

*&coordarr=[{"lat":-37.804390,"lng":144.961753}]&radiusarr=[1000]
&returnline=true&returnpoint=true*

6 Performance and Known Issues

Assuming that the isochrones algorithm is flawless and always yields correct outputs, calculation time is our main performance concern. We test the API performance by measuring the processing time for resolving walk isochrones using three network traverse distances (500, 1000 and 1500 m). We choose the region of Urban Centres and Localities (UCLs) of Melbourne, Australia, as a case area. UCLs are

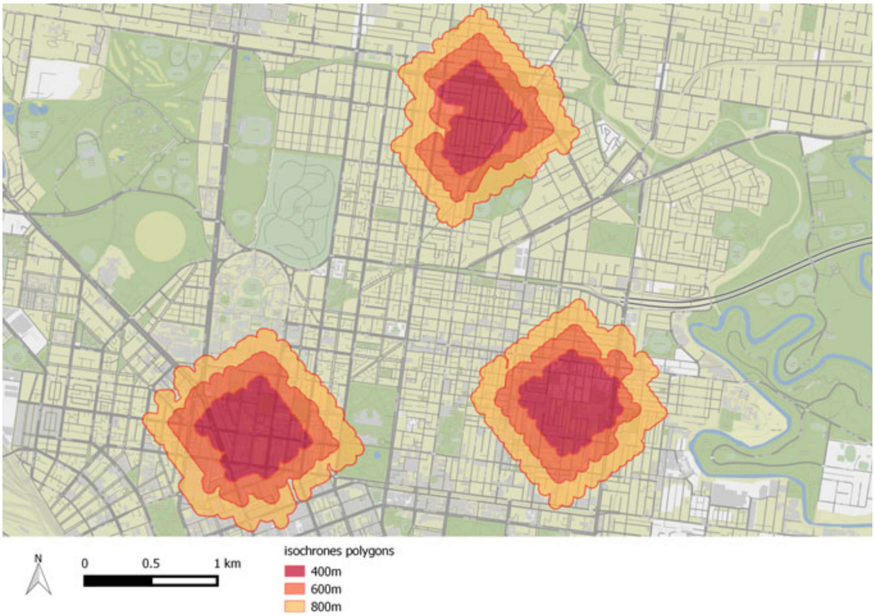


Fig. 8 Calculate isochrones for N points with various distances with **combotype** set to "*composite*" (by walk)

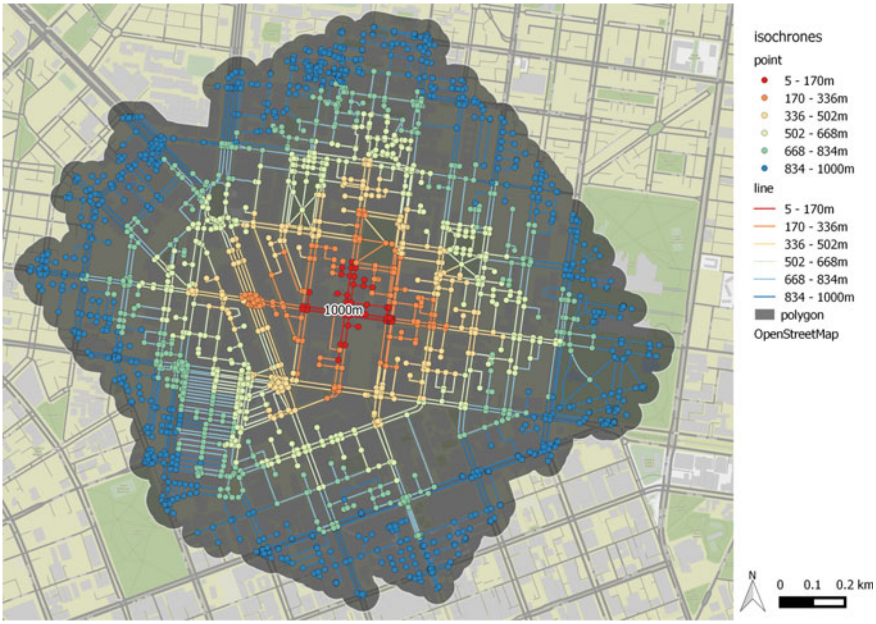


Fig. 9 Isochrones outputs with *polygons*, *line*, and *points* (by walk)

geographical units that describe Australian population centres with populations exceeding two hundred persons. The test area's road network density is higher than the rest of Melbourne.

To start testing, we first randomly created 2000 points within Melbourne's UCLs. Then from this pool, we randomly selected 500 seed points and requested the API to calculate isochrones for each point with the three distances. The average processing time of 500 points was used as the performance benchmark for isochrones with different traverse distance thresholds.

The API application runs on a virtual machine (Ubuntu 14.04 installed) provided by NeCTAR Research Cloud. The server has 64 GB RAM with 16 cores of 2.3 GHz AMD Opteron 63xx class CPU. The database (PostgreSQL 9.4 installed) runs on another dedicated virtual machine located in the same NeCTAR Data Centre with the same hardware configurations.

The following three charts show the API performance when computing 500, 1000 and 1500 m isochrones in Melbourne. The number of raw links indicates the scale of the subnetwork fetched from database. Clearly, the larger the traverse distance threshold, the more raw links will be included. Since the seed points were randomly picked, their adjacent road network configurations vary significantly. For example in Fig. 10, the raw link number ranges from 120 to 1590, which is reflective of the real existing road network. The y-axis on left shows the number of road links, and the y-axis on right shows the API processing time. Each 'column' on the x-axis refers to a random seed point. When the algorithm reaches the end, a set of road links, including both whole and chopped edges, are exported as isochrones links. Both the total processing time and the number of isochrones are positively correlated with the scale of the sub road network in use (Figs. 11 and 12).

Table 6 summaries the key API performance indicators. The numbers are average values. The "bfs_time" is also listed. This indicates the running time of the core isochrones BFS algorithm. It is worth mentioning that this step only takes up a small proportion of the total "proc_time", which involves many other processing steps such as data fetching and graph generation.

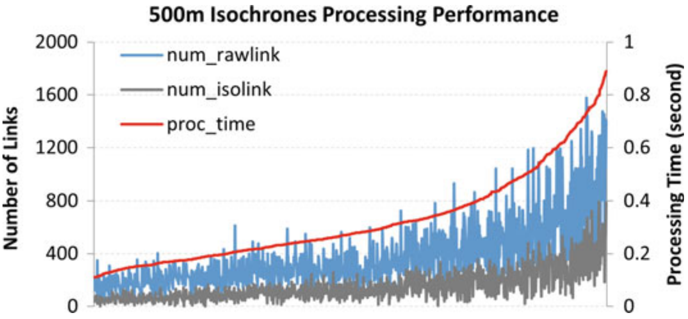


Fig. 10 API performance measure for 500 m isochrones calculation

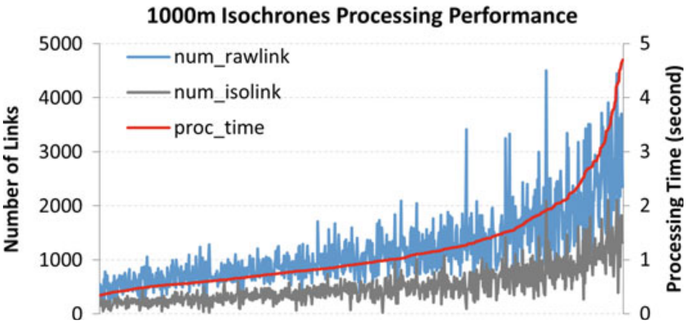


Fig. 11 API performance measure for 1000 m isochrones calculation

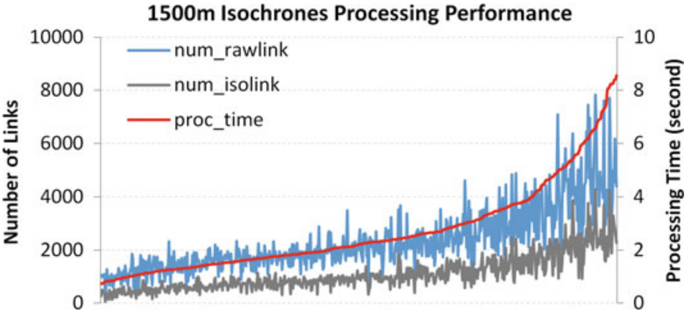


Fig. 12 API performance measure for 1500 m isochrones calculation

Table 6 The measure of key API performance

	proc_time	bfs_time	num_rawlink	num_isolink
500 m	0.32	0.04	373	151
1000 m	1.18	0.31	1177	511
1500 m	2.69	0.93	2329	1083

Usually the isochrones calculation time and complexity expands quadratically as the scale of problem increases. The current API uses detailed road data and will take considerable time to complete the calculation if the isochrones search distance is over 20 km. To enable long-distance isochrones calculation, we can reduce the number of raw road links. For example, we can specially build a road network from OSM using only the "highway" values of "trunk", "primary" and "secondary". Using this simplified road network will speed up long-distance isochrones calculations.

7 Conclusions

This chapter describes the architecture and logic of a free, open source isochrones calculation web service. A non-recursive BFS algorithm was proposed and implemented to compute isochrones for both walk and drive travel modes. The raw road network data came from OSM, and our algorithm correct corrected the OSM's isolated road links problem. Our isochrones API offers users abundant parameters to tune the calculation to meet diverse usage scenarios. The isochrones outputs include not only polygons but also lines and nodes with cleaned geometry and traverse distance attributes. We also demonstrate the performance of the API by launching a large number of calculation requests with three isochrones search distances across the Melbourne region.

The API still has huge room for improvement. It could be modified, for instance, to support large-scale, multimodal transport and travel-time based isochrones calculation. A graphical user interface (GUI) could also be attached, which would assist users in setting up parameters and visualising outputs. Our project website features a future developments roadmap, and we will continue improving the API. We hope urban researchers and analysts will find this free, isochrones generation web service useful to their own work—either as a starting point on which to build, or as a finished product that generates the isochrones they need.

References

Bauer, V., Gamper, J., Loperfido, R., Profanter, S., Putzer, S., & Timko, I. (2008). Computing isochrones in multi-modal, schedule-based transport networks. In *Proceedings of the 16th ACM SIGSPATIAL International Conference on Advances in Geographic Information Systems* (p. 78). ACM.

Buchhold, V. (2015). Fast Computation of Isochrones in Road Networks. *Master Thesis*. https://i11www.iti.uni-karlsruhe.de/_media/teaching/theses/ma-buchhold-15.pdf. Accessed August 18, 2016.

Efentakis, A., Grivas, N., Lamprianidis, G., Magenschab, G., & Pfoser, D. (2013). Isochrones, traffic and DEMOgraphics. In *Proceedings of the 21st ACM SIGSPATIAL International Conference on Advances in Geographic Information Systems* (pp. 548–551). ACM.

ESRI. (2016). Service Area Analysis of ArcGIS Network Analyst extension. https://desktop.arcgis.com/en/arcmap/latest/extensions/network-analyst/service-area.htm. Accessed September 20, 2016.

Gamper, J., Böhlen, M., Cometti, W., & Innerebner, M. (2011). Defining isochrones in multimodal spatial networks. In *Proceedings of the 20th ACM International Conference on Information and Knowledge Management* (pp. 2381–2384). ACM.

Gamper, J., Böhlen, M., Cometti, W., & Innerebner, M. (2012). Scalable computation of isochrones with network expiration. In *Proceedings of the 24th International Conference on Scientific and Statistical Database Management (*pp 526–543). Springer.

HERE. (2016). Calculate Isoline, Routing API. https://developer.here.com/rest-apis/documentation/routing/topics/examples-calculate-isoline.html. Accessed September 20, 2016.

Innerebner, M., Böhlen, M., & Gamper, J. (2013, April). ISOGA: A system for geographical reachability analysis. In *International Symposium on Web and Wireless Geographical Information Systems* (pp. 180–189). Heidelberg: Springer.

Iso4App. (2016). Iso4App JavaScript API. http://www.iso4app.net/#engine. Accessed September 15, 2016.

Marciuska, S., & Gamper, J. (2010). Determining objects within isochrones in spatial network databases. In *East European Conference on Advances in Databases and Information Systems* (pp. 392–405). Heidelberg: Springer.

OSM. (2016). Definitions for OpenStreetMap highway keys. http://wiki.openstreetmap.org/wiki/Key:highway. Accessed November 8, 2016.

pgRouting Manual. (2016). Description of pgr_labelgraph() function. http://docs.pgrouting.org/2.2/en/src/label_graph/doc/pgr_labelGraph.html. Accessed November 8, 2016.

Chapter 12
Household Micro-simulation Model Considering Observed Family Histories in a Suburban New Town

Nao Sugiki, Kazuaki Miyamoto, Akinari Kashimura and Noriko Otani

Abstract During the past several decades, many new towns have emerged in suburbs along new railway lines in Japan. Numerous problems in those towns are emerging as their population age. This study aimed to build a micro-simulation model of households to estimate residents' assessments of quality of life in a suburban new town of a metropolis. Approximately 1500 households were sampled to collect survey data. Using census data and the survey data, base-year household microdata were estimated using the agent-based synthesis method. The survey data provided information on household histories after taking up residence in the present house. A microsimulation model was built using the household history data and simulations were performed to predict household transitions in the study area in five-year increments between 2015 and 2045.

Keywords Micro-simulation · Household micro-data · Family history · Ageing and population decreasing society · Quality of life · Suburban new town

---

N. Sugiki (✉)
Department of Architecture and Civil Engineering, Toyohashi University of Technology,
1-1, Hibarigaoka, Tempaku-cho, Toyohashi, Aichi 441-8580, Japan
e-mail: sugiki@ace.tut.ac.jp

K. Miyamoto
Faculty of Urban Life Studies, Tokyo City University, 8-9-18 Todoroki, Setagaya-ku,
Tokyo 158-8586, Japan
e-mail: miyamoto@tcu.ac.jp

A. Kashimura
Graduate School of Environmental and Information Studies, Tokyo City University,
8-9-18 Todoroki, Setagaya-ku, Tokyo 158-8586, Japan
e-mail: g1583503@tcu.ac.jp

N. Otani
Faculty of Informatics, Tokyo City University, 3-3-1 Ushikubo-nishi, Tsuzuki-ku,
Yokohama 224-8551, Japan
e-mail: otani@tcu.ac.jp

S. Geertman et al. (eds.), *Planning Support Science for Smarter Urban Futures*, Lecture Notes in Geoinformation and Cartography,
DOI 10.1007/978-3-319-57819-4_12

1 Introduction

Japan's aging society with low birthrates is lowering the population in urban as well as rural areas, and the demographic changes are generating numerous new urban problems. Some other developed countries also have these problems, which will eventually spread to developing countries and outlying areas.

One emerging problems is the aging of new towns. During the past several decades, many new towns have developed in Japan's suburbs along railway lines, and, along with changes related to the ages of the people who live there, a variety of problems are emerging. The first step to improve the situation with a public or private sustainable approach might be to learn the extent to which the residents are satisfied and how they assess their quality of life, currently and for the future. Individuals' quality of life depends on the conditions in which they live and the attributes of their households.

This study aimed to develop a microsimulation model of households to estimate quality of life in a suburban new town of a metropolis. Thus, the study employed the household level of analysis and built a microsimulation model of households by directly accounting for observed changes to their attributes and household histories. The case study was conducted in a suburban new town near the Tokyu Den'entoshi railway line running southwest from the center of Tokyo. A questionnaire survey was conducted to learn about household attributes and the changes they experienced after taking up residence in the present house. In addition, census data were used to obtain a base-year microdata set of all households in the study area in 2010 using an adaptation of the agent-based household synthesis method.

To develop the microsimulation model to predict the future, household histories after leaving the study area were used to stochastically simulate changes to all of the households in the study area. Simulations estimated household changes in the study area for 2015–2045 in five-year increments found reasonable performance. The results provide data for public and private entities, including railway enterprises, to formulate measures for the future of the case study area.

2 Conceptual Background and Data

2.1 Household Histories and Quality of Life

Households' attributes change over time. For example, household size changes as the number of family members change because marriages, births, educational relocation, and death. Life events also tend to change households, such as graduation from school, employment, and retirement, along with the aging of household members. Simultaneously, the characteristics of household's areas independently change over time. A household's assessment of quality of life in its area at any given time depends on its attributes present at that time. Moreover, a household's

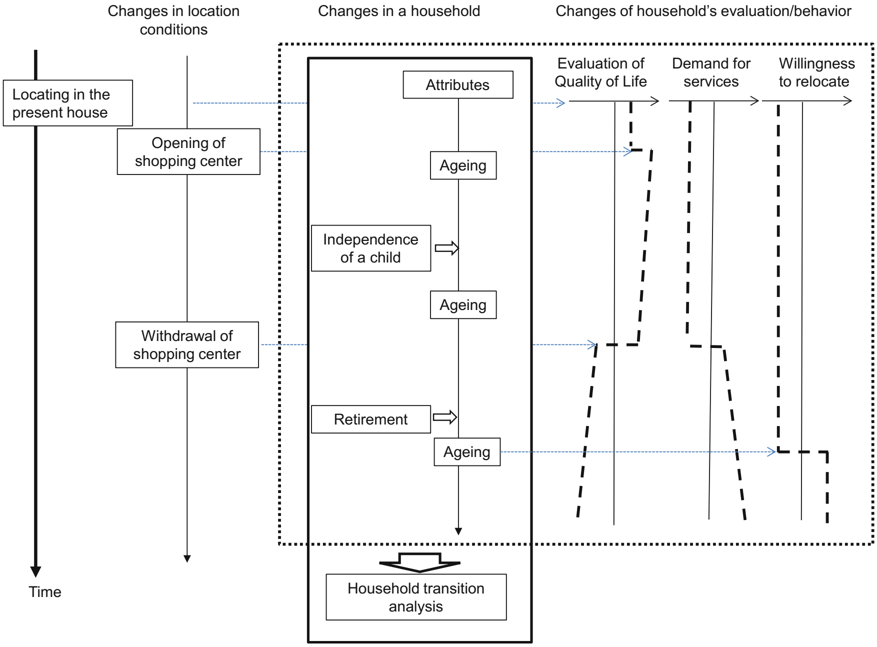


Fig. 1 Scope of the study

demands for public and private services and household members' willingness to relocate depend on the area's conditions and attributes.

The scope of this study is presented in Fig. 1. Although there are many studies which deal micro-simulation of households, few of them directly handle household transitions based on the observed data. This study aimed to develop a microsimulation model that would directly apply to the problem.

2.2 *Questionnaire Survey*

A questionnaire survey was conducted to obtain household data in the study area. The study area is a part of a large new town developed along the Tokyu Den'entoshi Railway line that runs southwest 31.6 km from the center of Tokyo. The study area is near Aobadai Station, which is about 20 km from the center of Tokyo (Fig. 2).

A description of the survey is as follows.

- Dates: December 2014 through January 2015
- Sampling: 28% random sampling stratified by detached house and condominium from 51,601 households

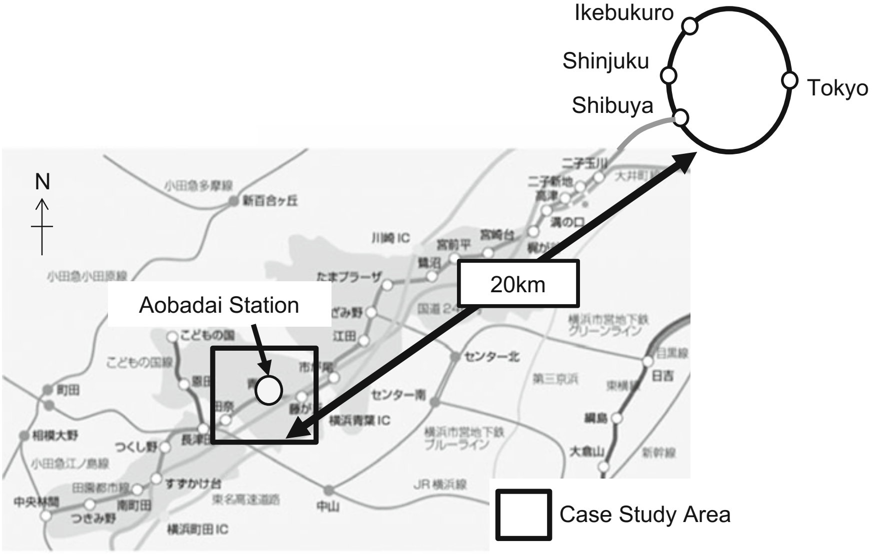


Fig. 2 Study area

- Number of households to which questionnaire was delivered: 14,500
- Number of households that returned the questionnaire: 1691 (11.7%)
- Delivery and collection: Questionnaires were directly posted to every household and returned by mail.

The relevant questionnaire items are as follows.

- Attributes of current household members: gender, age, employment status, and relationship to household head
- Current dwelling attributes: type of house, size of house, location of house
- History of household members: residential histories of all household members after locating to the current house
- Daily behaviors: transportation and consumer behaviors
- Assessment of quality of life: location characteristics, services currently received.

The household histories were the most important part of the questionnaire. To build a microsimulation model, it was necessary to observe real changes to each household. Therefore, the data were used to determine the basic transition patterns to stochastically predict each household's changes, which were estimated for the base year using the agent-based synthesis method. The history data made it possible to build a microsimulation model of household changes using this original approach.

2.3 Previous Research and the Characteristics of the Present Study

There were many studies in the field of on household microdata estimation and future prediction. Micro-data estimation may proceed in one of two ways: cell-based or agent-based approaches. The popular cell-based population synthesis was built mostly by applying the iterative proportional fitting (IPF) method (Pritchard and Miller 2009; Müller and Axhausen 2011; Lee and Fu 2011), while the agent-based approach is emerging (Moeckel et al. 2003; Miyamoto and Sugiki 2009; Miyamoto et al. 2010a, b; Sugiki et al. 2012, 2015). When comparing these two approaches, it has been clarified that the agent-based method clearly showed significantly better agent-based estimation performance in estimating multi-attribute micro data as used in micro simulation model (Miyamoto et al. 2013). Also many urban microsimulation models in which the future predictions for household and their members were conducted have been developed, such as Urbansim (Waddell 2002), ILUTE (Salvini and Miller 2005), ILUMASS (Strauch et al. 2005), PECAS (Abraham et al. 2005; Hunt and Abraham 2009), PUMA (Ettema et al. 2007), SelfSim (Chengxiang et al. 2016). However, few studies could be found that fully applied a microsimulation approach to predict future household changes. Hansen and Stephensen (2013) and Rogers et al. (2014) used Monte Carlo simulation based on average transition probabilities to predict changes to households and individuals. Most previous models employed average rates of change obtained by aggregating households to measure demographic changes in individual households.

The methodology of this study was similar to that of previous studies. However, in contrast to the previous studies' use of Monte Carlo simulation, this study used actual household histories obtained from survey data to predict households' futures. In other words, this study assumed that a household in simulation follows a similar path of change that an actual similar household would follow. The survey design makes this analysis possible because its data provide the necessary details. Moreover, this study analyzed pairs of household and house and developed the method to generate the pairs. This study was to develop a simple future prediction method in micro-simulation based on family historical data that was possible when limited to a suburban new town along a railway line.

3 Micro-data Estimation Methods for Households' Futures

3.1 Estimation Concept

The proposed model had two stages (Fig. 3): estimation of the household and housing stock microdata in the base year, and household transition microsimulations for the future. In the first stage, the base-year household microdata was

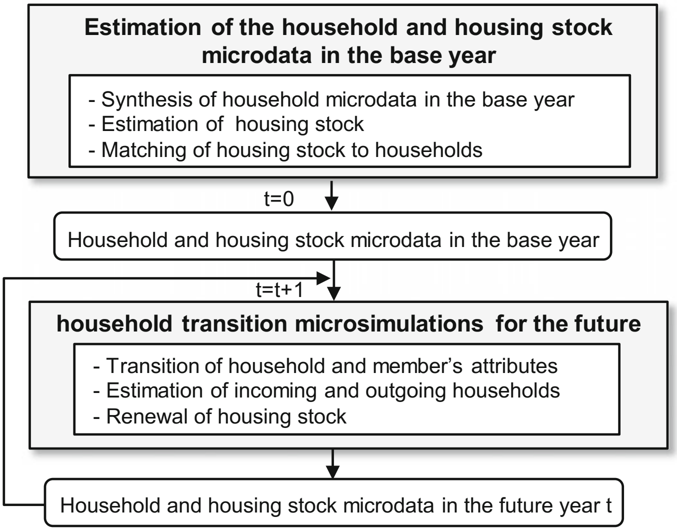


Fig. 3 Estimation concept

synthesized, housing stock was estimated, and then matched to households. As the result, household and housing stock microdata whose attributes were related to each other were estimated. In the second stage, future household and housing stock microdata were estimated for each five-year period by iterating microsimulations of household and members' attributes, estimations of incoming and outgoing households, and renewal of housing stock using the microdata of the previous period. These methods are described in detail in the following sections. The survey data included history of household members makes it possible to estimate in both of these two stages, and it is reasonable in that the model was developed conforming to statistical probabilities in the total number setting and household preferences in the change in household and their members.

3.2 Propositions

This study's model was based on the following propositions.

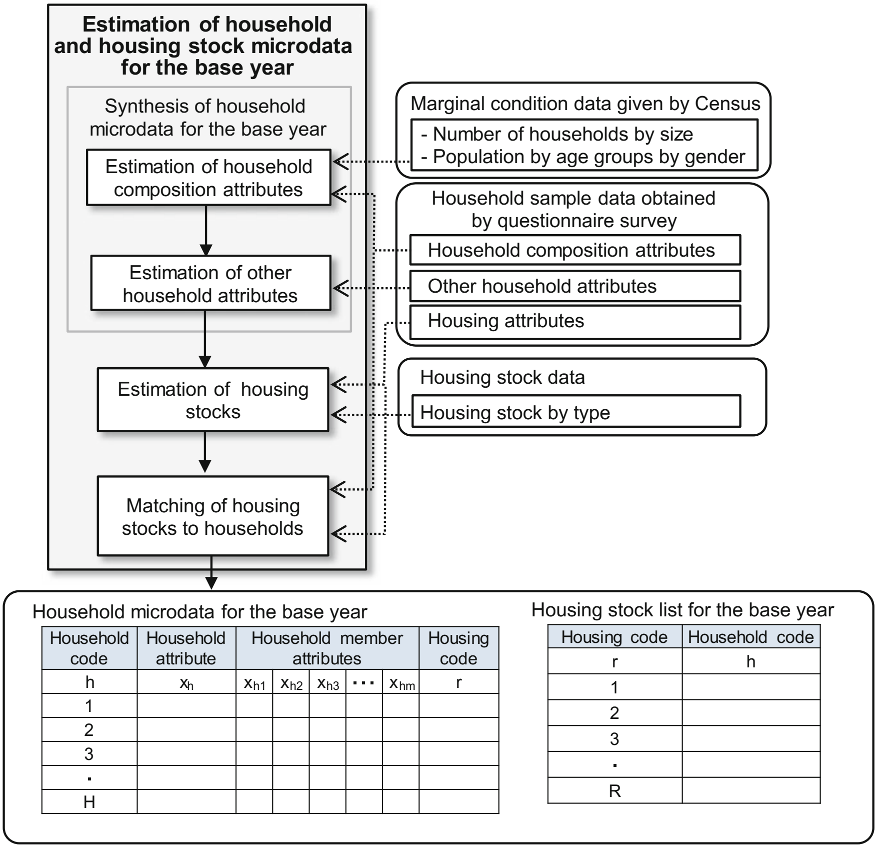
- Households and their members living in a suburban new town are the target units of analysis.
- Households are characterized by their members, and members are characterized by gender, age, and relationship to the household head.

- Households and their members are specified by other attributes, such as type of house, age of house, length of residence, employment or educational status, commuting zone, and so on.
- The study area is divided into zones, for which data on the numbers of households by household size and the numbers of individuals in five-year age groups are available from census data, and the spatial distances between pairs of zones can be identified.
- The number of houses is larger than the number of household agents, and each household is in one house. Unoccupied houses are considered vacant houses.
- All members of one household dwell in the same house unless they moved out or disappear (all of members are die) in which case relocation within the study area is not considered.
- The number of incoming households and their type are given exogenously because the target area is a suburban new town along the railroad and then the move in the target are can be ignored. In addition, we confirmed from the questionnaire survey results that the distribution of the attributes in incoming households has been stable in recent years.
- The numbers of houses in the zone are available from residential data, such as detailed housing maps.
- A certain number of microdata sample is available from a questionnaire survey.
- The microdata includes the current attributes of households, their members, and the changes that occurred to them after moving to the present house.
- Future estimation is performed for five-year increments.

4 Methods Used to Estimate the Household and Housing Stock Microdata for the Base Year

4.1 Outline

The estimation method used on the household and housing stock microdata for the base year comprised of four steps (Fig. 4). In the first step, household member age, gender, and relationship to the household head were estimated to synthesize the household microdata with the information on household composition. In the second step, attributes, such as length of residence, employment or educational status, and commuting zone were synthesized using the attributes of the most similar household in the sample. In the third step, a list of housing stock was made using housing stock data and the questionnaire data. In the last step, housing stock data were matched to households based on similarities in the household data, and the household microdata and the housing stock list for the base year were generated.



Household code	Household attribute	Household member attributes					Housing code
h	x_h	x_{h1}	x_{h2}	x_{h3}	···	x_{hm}	r
1							
2							
3							
·							
H							

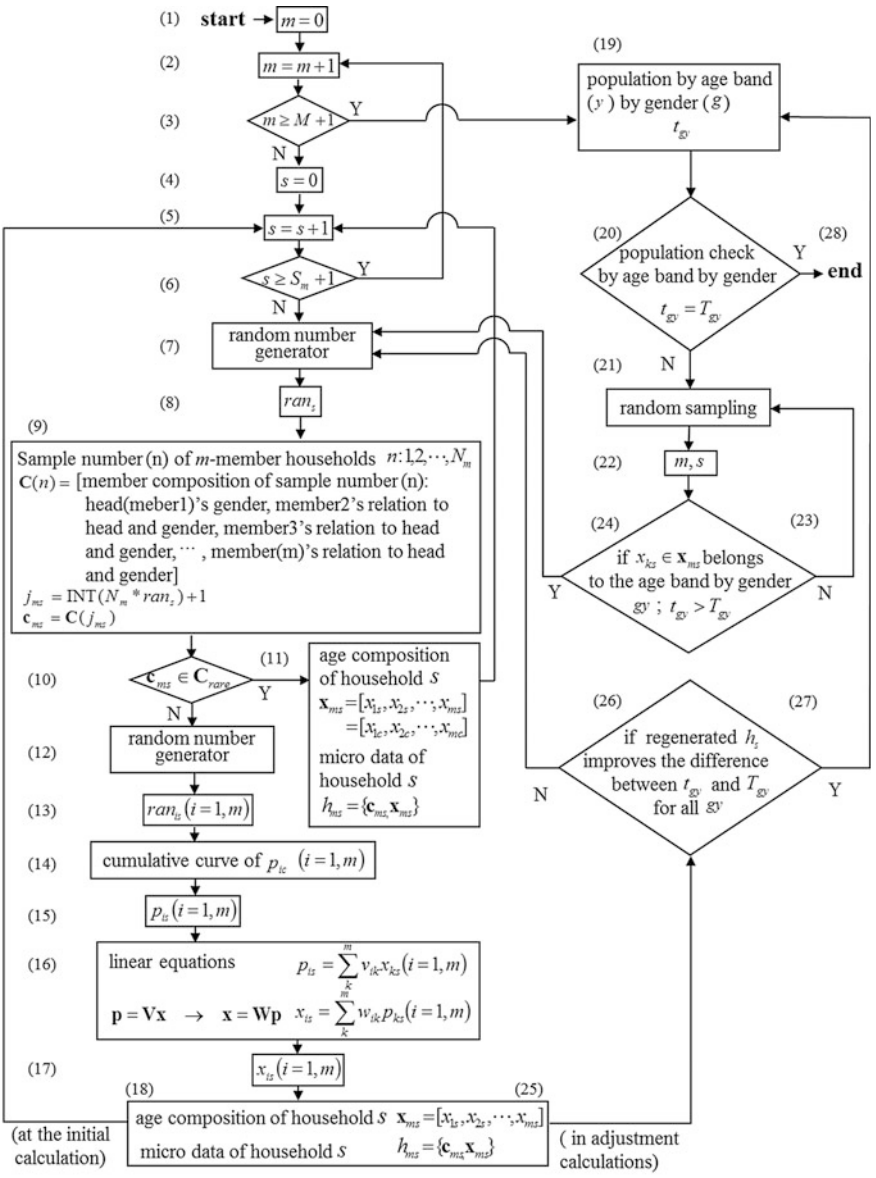
Housing code	Household code
r	h
1	
2	
3	
·	
R	

Fig. 4 Process used to estimate the household and housing stock microdata

4.2 *Estimation of Household Composition Attributes*

Figure 5 illustrates the estimation procedure used on the household composition attributes. The approach followed Miyamoto and Sugiki (2009) and Sugiki et al. (2012). The steps were as follows.

- (1)–(3): Estimation was performed as the number of household members increased from 1 to M, identified in the survey data as the maximum number of household members.
- (4)–(6): Because the number of households with m members, S_m, is usually available from census data, it was exogenously used as the control total of the study area. Estimation was conducted on 1 to S_m households.
- (7)–(8): Random number ran_s $(0 \leq ran_s \leq 1)$ was generated for household s. The household composition $\mathbf{c}_{ms}$ of s was determined as that of case number j_{ms} $(j_{ms} = INT(N_m \cdot ran_s) + 1)$.



$m = [1, \cdots, M]$: number of household members

$s = [1, \cdots, S_m]$: household which has m members

S_m : number of households which has m members (Exogenous as the control total of the study area)

ran : random number $0 \leq ran \leq 1$

C_{rare} : rare household composition

$y = [1, \cdots, Y]$: age band

T_{gy} : total number of observed individuals belonging to g y (Exogenous as the control total of the study area)

$\sum_m (m * S_m) = \sum_{gy} T_{gy}$

t_{gy} : total number of estimated individuals belonging to g y

Fig. 5 Estimation procedures for household composition attributes

- (9)–(10): When the household composition $\mathbf{c}_{ms}$ was rare in the survey data, the age $\mathbf{x}_{ms}$ was the same as case number j_{ms}.
- (9) and (11)–(14): When the household composition $\mathbf{c}_{ms}$ was common, the age $\mathbf{x}_{ms}$ was determined following the principal component approach of Miyamoto and Sugiki (2009).
- (15)–(16): The initial set of synthetic households did not satisfy the marginal conditions for the number of persons by five-year age groups.
- (17)–(18): A Monte Carlo approach was used to randomly select a household (m, s). When every age in $\mathbf{x}_{ms}$ belonged to a gender (g) and age group (y) pair that satisfied the control total, the current household number (m, s) was replaced by a new random sampling.
- (19), (7)–(13), and (20)–(22): When any of the ages in $\mathbf{x}_{ms}$ belonged to a gender (g) and age group (y) pair where the current household number was larger than the observed number, re-estimation was performed. $\mathbf{x}_{ms}$ was replaced by the new household composition $\mathbf{c}_{ms}$ and the genders (g) and ages (y) of the members, which reduced the differences between the estimated and observed totals.

4.3 Estimation of Other Household Attributes

Other household attributes, such as type of house and length of residence, were synthesized using the attributes of the most similar household in the sample. The method was used to identify the goodness-to-fit between the observed and estimated microdata sets (Otani et al. 2010, 2011). This approach was developed to estimate the agent-based household microdata of the base year for a real city (Sugiki et al. 2015).

The measure was defined as the minimum value of the distance summation and applied to the distance between households. In addition to using the household composition attributes, the distance was defined using spatial proximity to determine the attributes of the target microdata, including the surrounding zones.

The estimation method is shown below. The attributes were first estimated for household members and then for households, and they refer to the attributes of a household in the sample with the same number of household members. Target household b and its reference household in the sample s were represented using the following equations in vector format.

$$\mathbf{b} = (a_1^b, \ldots, a_k^b, \ldots, a_K^b, z^b) \tag{1}$$

$$\mathbf{s} = (a_1^s, \ldots, a_k^s, \ldots, a_K^s, z^s) \tag{2}$$

Here, K is the number of combinations of a household member's relationship to the household head and gender, a_k is the age of member k, and z is the zone of the target or referenced household.

The age c_k^m of household member m considered the household member's relationship to the household head and gender, defined as follows.

$$c_k^m = \begin{cases} a_k : k = k^m \\ 999 : k \neq k^m \end{cases} \tag{3}$$

The attributes of member m of target household b were included by searching for individual m' of all households in s using the minimum separation distance. The member-based separation distance $p\_dis(\mathbf{b}_m, \mathbf{s}_{m'})$ was defined by the consistency of a household member's attributes and the zonal spatial proximity, represented as follows.

$$p\_dis(\mathbf{b}_m, \mathbf{s}_{m'}) = \sqrt{\sum_{k=1}^{K} (c_k^{b_m} - c_k^{s_{m'}})^2 + \alpha \cdot (d^{bs})^2} \tag{4}$$

Here, d^{bs} is the spatial distance between the zones of target household b and the reference household in s. In addition, α is a weighting coefficient of the household member's attributes and the spatial distance. When $p\_dis(\mathbf{b}_m, \mathbf{s}_{m'})$ was minimized, the similarity to the reference household member was considered the greatest.

The attributes of target household b were included by searching the household sample using the minimum separation distance. The household-based separation distance $h\_dis(\mathbf{b}, \mathbf{s})$ was identified using the similarity of the household composition and the zonal spatial proximity, represented as follows.

$$h\_dis(\mathbf{b}, \mathbf{s}) = \sqrt{\sum_{k=1}^{K} (a_k^b - a_k^s)^2 + \alpha \cdot (d^{bs})^2} \tag{5}$$

When $h\_dis(\mathbf{b}, \mathbf{s})$ was minimized, the similarity to the reference household was considered the greatest. When two or more cases of minimum separation distance existed, one was selected probabilistically using the Monte Carlo approach.

4.4 Estimation of Housing Stock

Housing stock lists for each zone were made in this step. The attributes of the housing stock microdata were type of house and age of house. First, the numbers of houses by zone and type were obtained from the housing stock data. Next, the house age composition rate by zone by type of house was calculated using type of house provided by the survey data. The number of the house by zone by type of house by house age was obtained by multiplying the composition rate plus the number of houses by zone by type of house. All of housing stock microdata were listed and used as housing stock data.

4.5 Matching the Housing Stock Data to the Household Microdata

The procedure used to match the housing stock data to the household microdata is shown in Fig. 6. The estimation was performed by searching that household in s that had a minimum separation distance from target household b. The separation distance $hr\_dis(\mathbf{b}, \mathbf{s})$ was based on the consistency of a household member's attributes, the zonal spatial proximity, and the length of residence, which is represented as follows.

$$hr\_dis(\mathbf{b}, \mathbf{s}) = \sqrt{\sum_{k=1}^{K} (a_k^b - a_k^s)^2 + \alpha \cdot (z^{bs})^2 + \beta \cdot (ry^b - ry^s)^2} \qquad (6)$$

Here, ry is the length of residence, and β is a weighting coefficient of the household member's attributes and length of residence.

When only the housing attributes of the most similar household was considered, it may not exist the corresponding housing stock along with matching process.

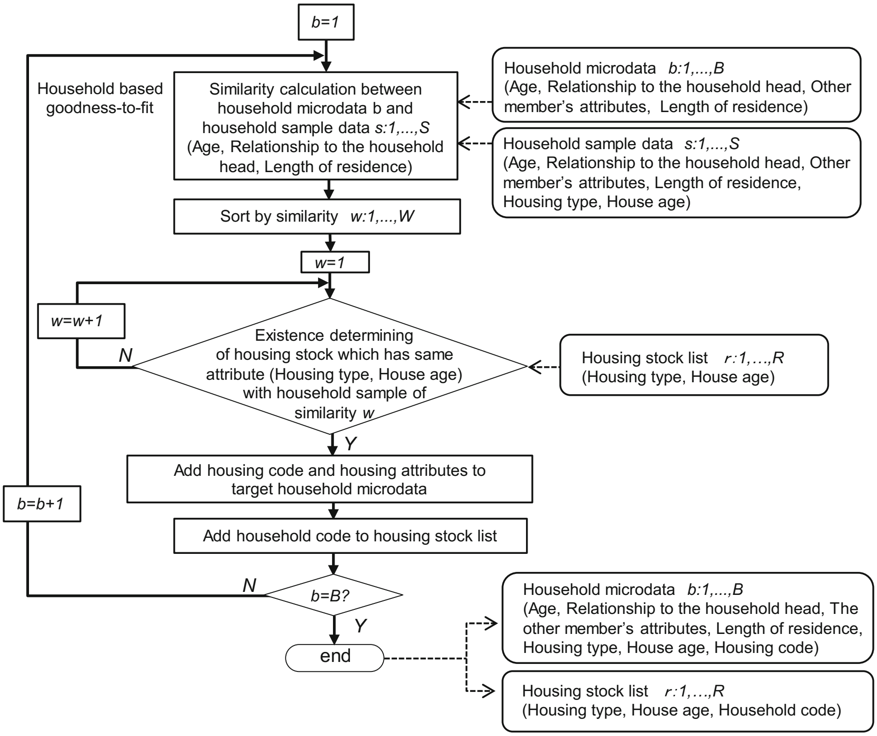


Fig. 6 Procedure used to match the housing stock data to the household microdata

Therefore, the households in the survey data were sorted by separation distance, and, when corresponding housing stock data did not exist, the household with the second-highest similarity was identified. The housing attributes of housing code, type of house, and age of house were included in the household microdata based on the results. Moreover, the household code of the target household was added to the housing stock list. Houses that were not added household codes indicated vacant houses. Based on this estimation process, the household microdata and the housing stock list were produced and used as base-year data in the microsimulation of future household transitions.

5 Microsimulation of Future Household Transitions

5.1 Outline

Figure 7 illustrates the microsimulation of future household transitions. First, households that existed at time *t* were assessed as having remained, moved out,

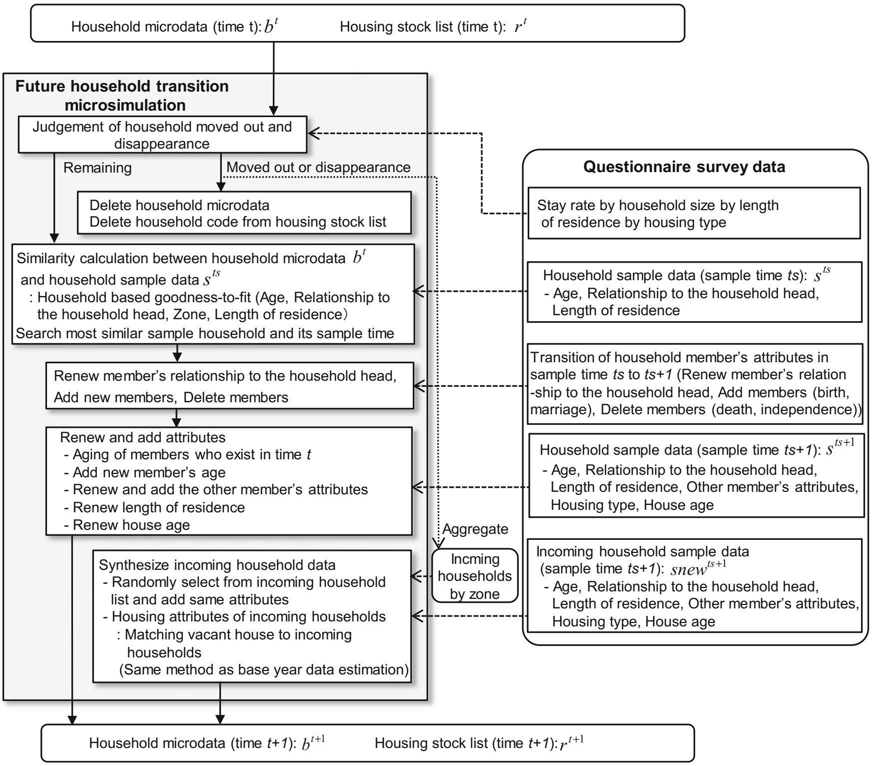


Fig. 7 Microsimulation process of future household transitions

or were disappearing. The transitions to a household and its members' attributes at the next time $t + 1$ was simulated for households that remained by referring to the most similar household in the survey data. It was assumed that the number of households taking up residence in the study area was equal to the number of moved out plus disappear households. Synthesis of the household microdata and matching to housing stock were performed for them. The estimations were iterated for each future period to simulate the household transitions over time.

5.2 Moved Out or Disappear Households

Households that existed at time t were identified as having remained, moved out, or were missing at time $t + 1$. Identification was probabilistically determined based on the stay rate (percentage of households at time $t + 1$ present at time t) by household size by length of residence by type of house using the Monte Carlo approach. The stay rate was calculated using the survey data. When it was determined that a household had moved out or disappear, that household was removed from the household microdata and the corresponding household code in the housing stock list was changed to indicate a vacant house.

5.3 Remaining Households

A household identified as present was remaining and its member attributes at time $t + 1$ referred to the transitions of the household with minimum separation distance from that household.

The separation distance $hf\_dis(\mathbf{b}^t, \mathbf{s}^{ts})$ was defined as follows.

$$hf\_dis(\mathbf{b}^t, \mathbf{s}^{ts}) = \sqrt{\sum_{k=1}^{K} (a_k^{b^t} - a_k^{s^{ts}})^2 + \alpha \cdot (z^{b^t s^{ts}})^2 + \beta \cdot (ry^{b^t} - ry^{s^{ts}})^2} \tag{7}$$

The structure of Eq. (7) is identical to that of Eq. (6) except that the period *ts* is of the household sample. Therefore, the length of residence used to measure attribute renewal was divided into five-year periods, and households and their members' characteristics were digitized at each five-year period *ts*. These data were available from the survey data to investigate household member attributes at the time the member moved into the present house and the years when new members joined the household after locating besides the present situation. The transitions to member attributes were converted into data by identifying the presence of a change between time *ts* and time *ts* + 1. The transitions to household members' attributes were changes to the relationship to the household head, addition of members due to births or marriages, loss of members due to deaths or independence, and changes to other members' attributes, such as employment or schooling status, and commuting zone.

Households and their members' attributes that remained were renewed in the data using the transitions of the most similar household in the sample, as follows.

- Renew member's relationship to the household head at time t, and addition and deletions of members referring to the composition of household in the sample at time $ts + 1$, s_m^{ts+1}.
- Aging of members in five-year increments who were present at time t, and add new members' ages with the same age of member of household in the sample at time $ts + 1$, s_m^{ts+1}.
- Renew and add other members' attributes at time $t + 1$ referring to the attributes of member of household in the sample at time $ts + 1$, s_m^{ts+1}.
- Renew the length of residence by adding five years.
- Renew the house age by adding five years.

5.4 Households Taking up Residence in the Study Area

The number of households taking up residence in the study area was assumed to equal to the number of households that moved out plus disappear households because the number of households was assumed to remain constant over time. The numbers of households removed from the dataset were counted by zone when the Monte Carlo simulation for households that moved out or disappear was performed and used as the numbers of households taking up residence. The list of households taking up residence in the study area was obtained using the household in the sample that had moved into the study area in recent years. Incoming household data were synthesized by randomly selecting cases from the incoming household list and adding the same attributes. These data were added to the household microdata at time $t + 1$. Housing attributes of the incoming households were determined by the same method as used in the base-year data estimation, in which vacant houses and incoming households were matched using the incoming household list. Then, housing attributes were added to the incoming households and the housing stock list was renewed.

6 Model Application

6.1 Outline

This section describes the model application for the study area shown in Fig. 2 above. Two zones, Fujigaoka 1 cho-me (Fujigaoka) and Mitakedai, were targeted (Fig. 8). The zones' characteristics were as follows.

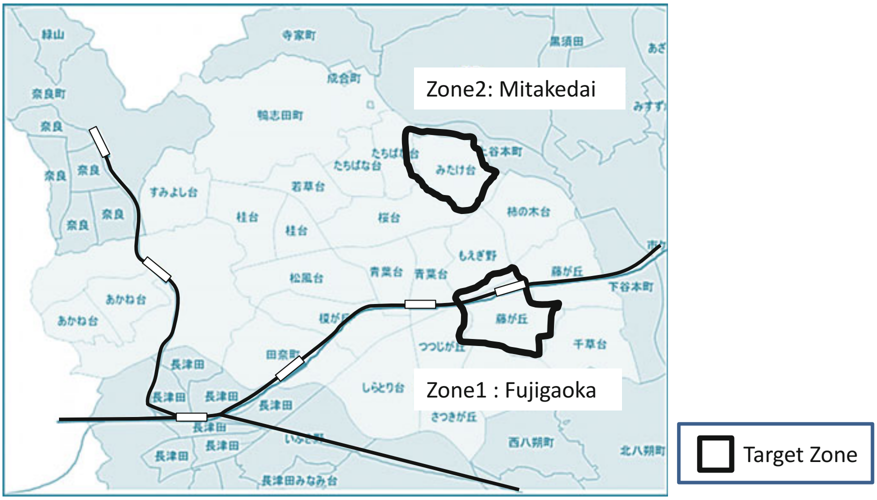


Fig. 8 Targeted zones

[Zone 1] Fujigaoka

- Proximate to Fujigaoka station of the Tokyu Den'entoshi Railway line
- Relatively more apartment houses than in other zones
- About 50 years have passed since initial development and rebuilding is in progress.

[Zone 2] Mitakedai

- About a 15- to 25-min walk from Fujigaoka station
- Many detached houses
- Development began 10 years after Fujigaoka was developed.

Household and housing stock microdata for the base year were estimated in 2010, and simulations were performed for 2015 through 2045 in five-year increments. In the future simulations, the rate of incoming households to outgoing households was set at 1.0 for Zone 1 and 0.95 for Zone 2, which assumed population declines in inconvenient zones.

6.2 Data

The microdata sample was drawn from the survey data described in Sect. 2.2. Questionnaires with serious missing data were discarded, so that there was complete information to estimate the base year using 1619 households and 4206 individuals. Regarding the five-year periods, data on transitions to household member attributes were available for microsimulation of future household transitions on 3484 households and 10,815 individuals.

Data on population by age group by gender and number of households by household size were obtained from the 2010 national census to use as the control totals for each zone. In the national census, the total population derived from the population by age group by gender generally does not equal the total population derived from the number of households by household size because household categories with more than seven members are merged and the numbers of household members who live in certain facilities are unknown. Thus, the population by age group by gender was adjusted to the total population derived from the number of households in our application. The marginal condition data consisted of 3249 households and 7076 individuals in Zone 1 and 1870 households and 5076 individuals in Zone 2.

6.3 *Estimation Results on Base-Year Microdata*

The household microdata and housing stock list were estimated for the two zones. Figure 9 shows the aggregated numbers of households by household type for the base year. More single and couple households were found in Zone 1 than in Zone 2, but there were not many differences regarding the other household type.

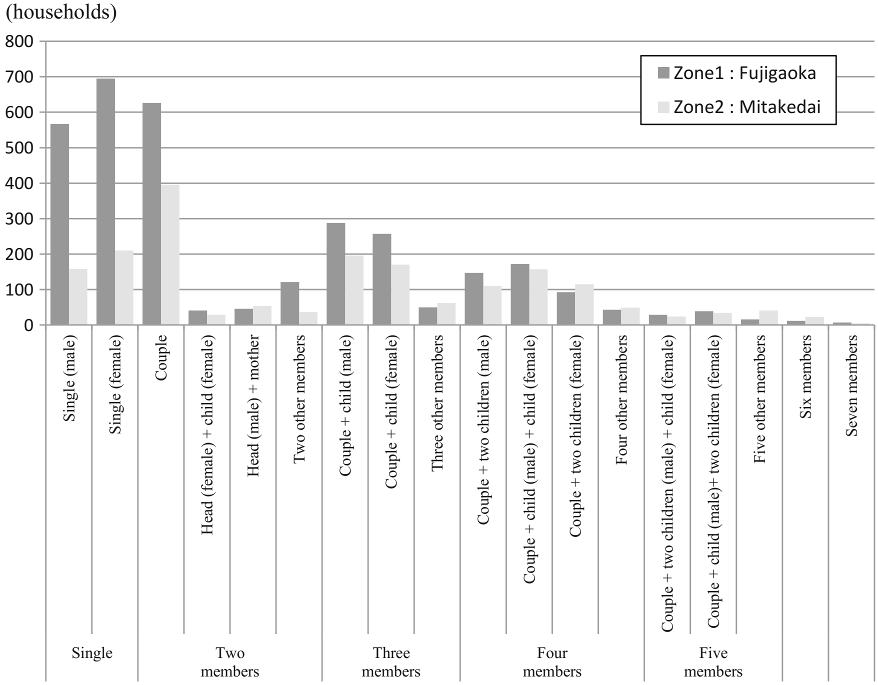


Fig. 9 Base-year estimation results of numbers of households by household type

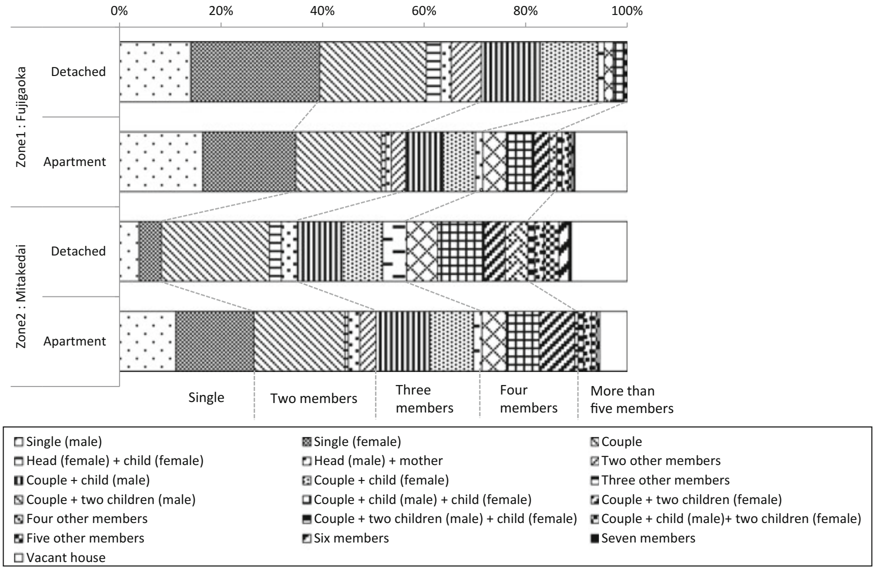


Fig. 10 Base-year estimation results of proportional distribution of household type and vacant house by type of house

Figure 10 shows the proportional distribution of household type and vacant house by type of house for the two zones. Comparing the composition ratio of households with less than two members by type of house, although it is almost the same as Zone 1, the proportion of apartment households is somewhat large in Zone 2. This is because there are many elderly single and couple households in which household size is decreased by death or independence in Zone 1. The model estimated the household microdata in which detailed household attributes were related to the characteristics of each zone.

6.4 Microsimulation Results

Microsimulations of future household transitions were performed using the proposed model on synthesized household and housing stock microdata on the base year. Figure 11 shows the predicted changes to the numbers of households by household type in the two zones. In Zone 1, the number of single-person households decreases and the number of households with more than three members increases across time. In Zone 2, although the total number of households decreases because the ratio of incoming households to outgoing households was set to 0.95, the proportional distribution of household type was little changed. This difference in the two zones indicates that the proposed model well represents the trend of the household type of incoming households and transitions to the remaining households.

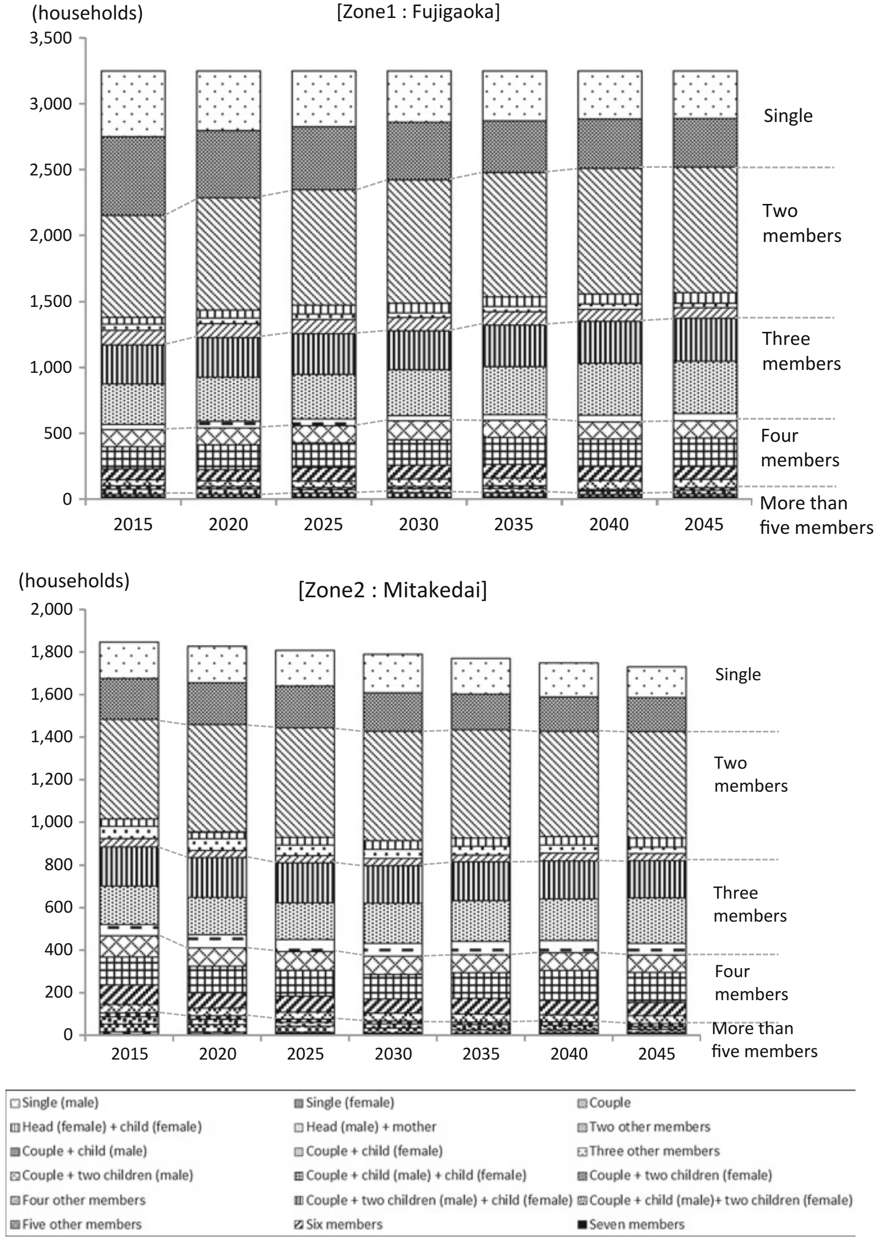


Fig. 11 Simulation results of the numbers of households by household type, 2015–2045

Figure 12 shows the changes in the proportional distribution of household type by type of house for the two zones. In both zones, households with few household members tend to live in apartments. The decrease in single-person households in

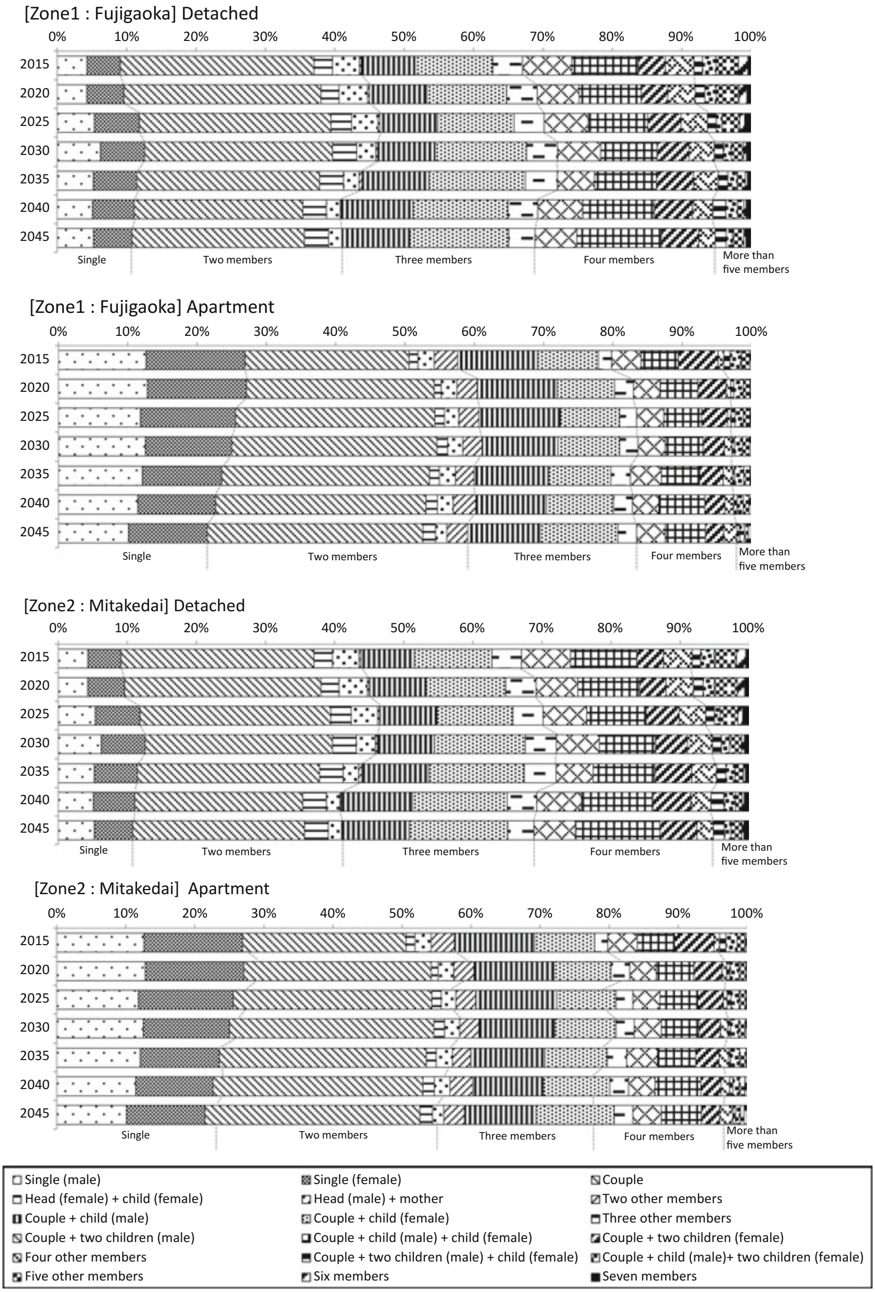


Fig. 12 Simulation results of the proportional distribution of household type, 2015–2045

Zone 1 is remarkable for detached houses. Moreover, the proportion of households with more than three members increases in detached houses, and the proportion of couple households in apartments increases. In Zone 2, the proportion of household type was little changed across time.

Figure 13 shows the change in the vacancy rate by zone by type of house. Vacancy rates increase for detached houses in both zones, but decrease for apartments. This tendency is more evident in Zone 2, where the total number of households decreases. There are no vacant apartments in Zone 2. This is due to bias in housing type preference in the result of questionnaire survey. It is necessary to examine methods such as verifying reproducibility from microdata at two period of time and adjusting housing type preferences. Also, because it can be thought that updating the housing stock is not taken into consideration, it is necessary to improve the model by explicitly incorporating housing stock transitions. It was confirmed that the proposed model performs well in predicting future changes to residential characteristics by household type in both zones and provides useful information for formulating measures for the future the target area although some improvements to the model were necessary. The proposed model statistically expresses transitions in detailed household attributes by describing transitions in households based on distances to the most similar households, and when the proportional distribution of the household type within the study area changes their trends are also reflected. However, it cannot express transitions in long-term preference. It is the same in the existing micro simulation that we cannot express transitions in the future preference.

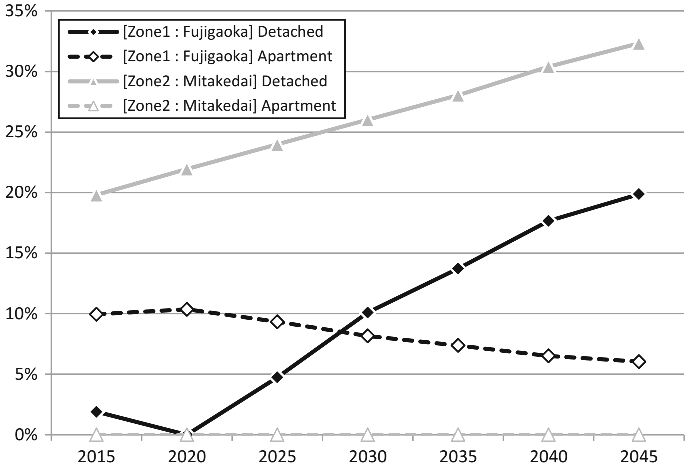


Fig. 13 Simulation results of vacancy rates by type of house, 2015–2045

7 Concluding Remarks

This study developed a microsimulation model to predict transition in households and housing stock in suburban new towns. A unique survey obtained data on individual household changes (histories) after it moved into the present house. This provided a model with household transition patterns and their probabilities. Although the case study is limited in scope and improvement of the model is necessary, such as adjustment of housing preference probability and explicit modeling of transition in housing stock, the results found acceptable change performances in households and housing stock in the district. Using the predictions and future location conditions, the quality of life perceived by households could be analyzed as explained by Fig. 1, and the public and private sectors could formulate measures to improve the situation following Otani et al. (2015).

Acknowledgements The survey fielded in this study was financially supported by Tokyu Research Institute, Inc. The authors deeply appreciate Ms. Ryoko Okumura, TRI, for her kind help with conducting the survey.

References

Abraham, J. E., Garry, G. R., & Hunt, J. D. (2005). The sacramento Pecas model. In *Transportation Research Board Annual Meeting*.

Chengxiang, Z., Chunfu, S., Jian, G., Chunjiao, D., & Hui, Z. (2016). Agent-based joint model of residential location choice and real estate price for land use and transport model. *Computers, Environment and Urban Systems, 57,* 93–105.

Ettema, D., de Jong, K., Timmermans, H., & Bakema, A. (2007). PUMA: Multi-agent modelling of urban systems. In *Modelling land-use change* (pp. 237–258) Springer.

Hansen, J. Z., & Stephensen, P. (2013). Modeling household formation and housing demand in Denmark using the dynamic microsimulation model SMILE. In *DREAM Conference Paper, 4th General Conference of the International Microsimulation Association*.

Hunt, J. D., & Abraham, J. E. (2009). Pecas—for spatial economic modelling: Theoretical formulation, system documentation technical memorandum 1 working draft.

Lee, D. H., & Fu, Y. F. (2011). Cross-entropy optimization model for population synthesis used in activity-based microsimulation models. In *TRB 90th Annual Meeting Compendium of Papers*.

Miyamoto, K., & Sugiki, N. (2009). An estimation method of household micro-data for the base year in land-use micro simulation. In *Proceedings of CUPUM'09*.

Miyamoto, K., Sugiki, N., Otani, N., & Vichiensan, V. (2010a). An agent based estimation method of household micro-data for the base year in land-use microsimulation. In *TRB 89th Annual Meeting Compendium of Papers*.

Miyamoto, K., Sugiki, N., Otani, N., & Vichiensan, V. (2010b). An agent based estimation method of household micro-data including housing information for the base year in land-use microsimulation. In *Selected Proceedings of 12th WCTR*.

Miyamoto, K., Sugiki, N., Otani, N., & Vichiensan, V. (2013). Qualitative and quantitative comparisons of agent-based and cell-based synthesis estimation methods of base-year data for land-use microsimulations. In S. Geertman et al. (Eds.), *Planning Support Systems for Sustainable Urban Development, Lecture Notes in Geoinformation and Cartography* (pp. 91–106).

Moeckel, R., Spiekermann, K., & Wegener, M. (2003). Creating a synthetic population. In: *Proceedings of 8th International Conference on Computers in Urban Planning and Urban Management*.

Müller, K., & Axhausen, K. W. (2011). Population synthesis for microsimulation: State of the art. In *TRB 90th Annual Meeting Compendium of Papers*.

Otani, N., Fukuoka, Y., Sugiki, N., & Miyamoto, K. (2015). Tailor-made selection of policy measures for households based on the detailed attributes by segmentation approach with decision tree analysis. In: *Proceedings of CUPUM'15*.

Otani, N., Sugiki, N., & Miyamoto, K. (2010). Goodness-of-fit evaluation method between two sets of household micro-data for land-use microsimulation model. In: *Selected Proceedings of 12th WCTR*.

Otani, N., Sugiki, N., & Miyamoto, K. (2011). Goodness-of-fit evaluation method for agent-based household micro-data sets composed of generalized attributes. *Transportation Research Record, 2254,* 97–103.

Pritchard, D. R., & Miller, E. J. (2009). Advances in agent population synthesis and application in an integrated land use/transportation model. In *TRB 88th Annual Meeting Compendium of Papers*.

Rogers, S. M., et al. (2014). A geospatial dynamic microsimulation model for household population projections. *International Journal of Microsimulation, 7*(2), 119–146.

Salvini, P., & Miller, E. J. (2005). ILUTE: An operational prototype of a comprehensive microsimulation model of urban systems. *Networks and Spatial Economics, 5*(2), 217–234.

Strauch, D., Moeckel, R., Wegener, M., Gräfe, J., Mühlhans, H., Rindsfüser, G., et al. (2005). Linking transport and land use planning: The microscopic dynamic simulation model ILUMASS. In *Geodynamics* (pp. 295–311).

Sugiki, N., Muranaka, T., Otani, N., & Miyamoto, K. (2015). Agent-based estimation of household micro-data with detailed attributes for a real city. In *Proceedings of CUPUM'15*.

Sugiki, N., Vichiensan, V., Otani, N., & Miyamoto, K. (2012). Agent-based household micro-datasets: An estimation method composed of generalized attributes with probabilistic distributions from sample data and available control totals by attribute. *Asian Transport Studies, 2*(1), 3–18.

Waddell, P. (2002). UrbanSim: Modeling urban development for land use, transportation, and environmental planning. *Journal of the American Planning Association, 68*(3), 297–314.

Chapter 13
Social Sensing: The Necessary Component of Planning Support System for Smart City in the Era of Big Data

Wencheng Yu, Qizhi Mao, Song Yang, Songmao Zhang and Yilong Rong

Abstract Social sensing belongs to an interdisciplinary research field formed in the background of Information and Communication Technology (ICT) and big data development. This can be attributed to the continuous improvements in data acquisition, processing and analysis capacity for urban and social economy studies. It has been recognized that social sensing holds potential benefits across a number of industry sectors. This chapter analyzes the influences of social sensing on Planning Support System (PSS) and decision making with specific applications in supporting data, technology, function and application aspects. A case study is provided which focuses on the renovation planning in Changxindian old town, Beijing. The case study proves that social sensing has positive effects in addressing some of the disadvantages of PSSs and enabling such systems to play a greater role in planning practice. Based on analysis, this chapter puts forward the proposition that social sensing should be adopted as a critical component of PSS for urban planning in a smart city.

Keywords Planning Support System · Social sensing · Smart city · Urban planning · Big data

---

W. Yu (✉) · S. Yang · Y. Rong
Planning Information Center, Beijing Municipal Institute of Urban Planning and Design,
No. 60, Nalishi Road, Beijing, China
e-mail: yuwencheng@bmicpd.com.cn

S. Yang
e-mail: yangsong@bmicpd.com.cn

Y. Rong
e-mail: rongyilong@bmicpd.com.cn

Q. Mao
School of Architecture, Tsinghua University, No. 30, Shuangqing Road, Beijing, China
e-mail: qizhi@mail.tsinghua.edu.cn

S. Zhang
Key Laboratory of Management, Decision and Information System,
Chinese Academy of Sciences, No. 55, Zhongguancun East Road, Beijing, China
e-mail: smzhang@math.ac.cn

S. Geertman et al. (eds.), *Planning Support Science for Smarter Urban Futures*, Lecture Notes in Geoinformation and Cartography,
DOI 10.1007/978-3-319-57819-4_13

1 Introduction

The urban planning sector has long been engaged in integrating Information and Communication Technology (ICT) into its routine work to enhance work efficiency and analysis ability of planners. In a variety of practices, the research and development of Planning Support System (PSS) has a long history and attracts significant attention. Since the late (Harris 1989), various PSSs have been developed along with different information technologies by virtue of using models, Geographical Information System (GIS), Public Participation Geographical Information System (PPGIS), Three Dimension Geographical Information System (3DGIS), decision support technology, etcetera. (Harris and Batty 1993; Klosterman 2001; Geertman 2001; Geertman and Stillwell 2003). PSS has wide practical applicability for numerous aspects of urban planning, including problem analysis, data collection, participation enhancement, space and trend analysis, data modelling, visualization and presentation, scenario design, decision making, and collaborative planning (Geertman and Stillwell 2004). Thus PSS has a crucial role to play in planning practice. Even though most planners affirmed the beneficial effects of PSSs on urban planning, it is undeniable that their usage still lags far behind expectations from planners (Vonk 2006; Brömmelstroet 2012; Russo et al. 2015). Therefore, with the deepening of applications, PSS adoption should also be expected to improve.

During the last twenty years, information about all kinds of activities of people has been recorded and perceived, thus forming numerous human ‘digital footprints’ (Zhang et al. 2010), which constitute important contents of big data. Social sensing is a new method to collect and analyze these ‘digital footprints’ (Allbach et al. 2014). It has greatly enriched the data foundation by carrying out city-related researches in human activities and movements, social relations, as well as emotions and feelings (Liu et al. 2015). For PSSs, social sensing is a novel technical ability that can assist in addressing the problem of insufficient data (lacking qualitative and quantitative) required to undertake urban research utilizing PSS applications. Social sensing may also have potential benefits in assisting planners in perceiving the current status of city and society and thus improve observation and comprehension of the influences exerted by urban planning. Similarly, under a ‘smart city’ development strategy, urban planning needs to possess the ability of obtaining an overall big picture understanding of the city that is established on the basis of comprehensive perception of the city (Eräranta and Staffans 2015), and ultimately provides the city with more accurate, dynamic and effective services.

The purpose of this chapter is to analyze possible influences of social sensing on PSS and suggest the response in practice to further promote the relationship between PSS and urban society. The chapter proposes that social sensing should become a component of PSS to promote the rationality and practicability of planning results; to give the research and practice of urban planning and PSS the characteristics of modern society; and to advance the concept of smarter cities.

2 Theoretical Framework

2.1 PSS Objectives and Bottlenecks

The overarching goal of PSSs is to provide support for urban planning. It is an integrated system combining a series of computer-oriented methods and models (Harris 1989; Geertman and Stillwell 2003) and an information framework consisting of information technology useful for planning (Klosterman 1997). Different types of knowledge interactions can be established in PSS during the planning process (Klosterman 2001). PSSs also help to improve the strategic capacity and the ability of planning actors to go through a shared 'enlightenment' process and create 'negotiated knowledge' (Amara et al. 2004; Gudmundsson 2011). Even though the targets envisioned in PSS can meet the demands of urban planning, its application in practice is far different from the people's expectations. This is specifically reflected in its complexity, rigidity, slowness, difficulty in understanding, insufficient transparency of mathematics and its inability to match the unpredictable and dynamic characteristics of a strategy formulation process (Brömmelstroet 2016). In addition, it is technology-oriented (instead of problem-oriented), not flexible, not friendly to users, and only restricted to focus on technical rationality (Brömmelstroet 2013). Although some scholars have carried out in-depth researches on performance and usability to measure and assess PSSs in recent years (Brömmelstroet 2013; Pelzer et al. 2015; Russo et al. 2015), these has been little reported on the benefits of social sensing techniques.

Generally, whether in PSS's general definition and objective or self-assessment and improvement, research ideas have reflected the perspective of technical rationality. For the manifestation of PSS disadvantages, some factors are related to technical methods and system implementation such as complexity, inflexibility and issues in system usability. However, it is undeniable that PSSs have not been closely connected with citizen engagement and society. This has somewhat been manifested in the deficiency of data acquisition, analysis and mining of society status, the separation of PSS developers and PSS users, and the lack of humanistic color. Although numerous trials have been made in PSSs to enhance participation of the public by using ICT to integrate more stakeholders into planning processes, as the public participation is a process that is difficult to organize (Exner 2015), the effects of PSSs in this aspect are unsatisfactory.

2.2 Social Sensing

As a concept, social sensing was defined as the act of collecting observations about the physical environment from humans or devices acting on their behalf (Wang et al. 2015). Thanks to contributions from social networks and sensors, everyone can participate and jointly constitute the unique status of an observer who records current events. The majority of information uploaded to the Internet and social media reports uploaders' observations from their surrounding physical environment and their thoughts and comments. From the perspective of big data era at present, it is thought that the purpose of using various types of data source marked with time and space labels to observe people's behaviors and the purpose of using relevant analysis methods is to observe characteristics of social economy in geographic space. The concept of social sensing is used to name data of vast geographic space and relevant analysis methods (Liu et al. 2015). The data of social sensing is about individuals in three aspects, namely (i) activity and movement, (ii) social bonding, and (iii) emotions and feelings. These three aspects are mutually related and are influenced by the social-economic environment.

In the practice of social sensing, 'digital footprints' of humankind are used to carry out applications of public health (Widener and Li 2014), natural disaster (Sakaki et al. 2010), public behaviors (Wang and Tu 2014), interpersonal interactions (Sarfraz et al. 2012), transportation (Calabrese et al. 2013), urban management and service (Ruiz-Correa et al. 2014), etcetera. These preliminarily studies reflect that social sensing can bring deep insights into the status and changes of urban space and social development. Moreover, social sensing is a useful technique for gathering personal and group wisdom to improve urban management and public governance.

2.3 Smart City

A smart city is the product of urbanization and informatization development to a certain stage, and is the development direction of many future cities. Early understanding and practices of the smart city focused more on technical aspects, and paid more attention to building new urban infrastructures by using Internet of Things, cloud computing, mobile internet, big data and other emerging information technologies to implement the interconnections and interflows of these new technologies in urban management. In the evolution process, people have come to realize that a smart city is not only the construction of intelligent city infrastructure, but also that its essence is to apply advanced information technologies to urban planning and urban management to enhance citizens' community intelligence assembly, to solve various problems in the current urbanization process, to promote city intelligence and sustainable development, to create a fair, just and inclusive society, and to create better city lives (Batty et al. 2012; Connected Smart Cities Network 2013; Staffans and Horelli 2014; Batty 2014). In other words, in the process of constructing and managing a city, 'smart' thoughts and methods should be key drivers. In this sense, there is a natural integration of smart city strategy, urban planning and the use of PSS tools. A smart city should use the ubiquitous feedback information sensed by intelligent sensors to achieve a full range of perceptions of the urban running state and society development. PSS can improve the efficiency of planning process, which can also help to improve the efficiency of the whole city system (Exner 2015). The smart city needs smart planning and the support of PSS, and it is also an important application field for which PSS researches and developers should embrace.

3 Methodology

On the whole, present social sensing research and applications related to urban planning mainly focus on macro urban space structure, population flow, public transport analysis, citizens' activities and less on semantic cognition and social relations. In this technical aspect, statistical analysis, spatial analysis and data visualization are mainly used. Methods that blend the technologies of semantic analysis and text mining are less common. The future development prospect of social sensing and semantic analysis has been noted (Sheth 2010; Barnaghi et al. 2013; Liu et al. 2015) due to the values and benefits of those content generated by using digital media, social network, and We-media on the Internet.

Based on this understanding, this chapter uses the old town renovation planning of Changxindian, Beijing as a social sensing application case. Social media content that can reflect social hotspots, expert ideas, public opinions related to Changxindian area are scraped, mined and integrated. By using technical methods of data cleaning and de-noising, Chinese word segmentation, clustering, sentiment analysis, topic analysis, the goal of gathering citizens' opinions, thoughts, intelligence and providing service for PSS and decision-making can be realized. Social sensing can potentially also assist in improving the sensitivity and insights of the planners to the present situation and problems in Changxindian area.

4 Case Study

4.1 Project Survey

The renovation of Changxindian is a planning research project, which is part of the Changxindian Old Town Revitalization Action Plan. It was sponsored by the Beijing Municipal Institute of Urban Planning and Design in 2015. Changxindian is an old town on the side of Lugou Bridge in Southwest Beijing, only 19 km away from Tiananmen Square which is the center of city. It has been the only artery to Beijing from southwest for over one thousand years. In ancient China, it was a noisy and lively transportation hub full of chariots and horses and was alive with residents and visitors. There are many historic sites and cultural resources in this town. However, because of its long history, common problems of old towns have become very prominent in recent years, such as environment issues, aging buildings, old facilities, employment difficulties, traffic inconveniences, and historical and cultural resources gradually fading and disappearing in the process of urbanization. It is a public welfare project that is devoted to retain the cultural characteristics and historical memory of Changxindian and improve its citizens' livelihood and landscape. It is also hoped to collectively gather various social ideas and intelligence and to promote the renewal of the old town.

4.2 Dataset

Social media content is mainly from Sina microblog, forum and part of digital news. Sina microblog is a social network site launched by Sina.com (www.sina.com.cn) to provide a micro-blogging service. Users can write what they see, hear or think in brief words or send a picture to share and discuss them with friends through computer or mobile phone at anytime and anywhere. Sina microblog not only provides convenience for citizens to communicate and interact about the topics that they see, think and are interested in but also becomes the main platform for users to participate in public matters. Because Internet forums also possess a diversification of contents and some local forums or channels are popular among regional Internet users, the research uses the posts related to Changxindian area from the Tianya Forum (http://bbs.tianya.cn/), the Strong Community (http://bbs1.people.com.cn/), the Kaidi Club (http://club.kdnet.net/index.asp), and the Baidu Post Bar (http://tieba.baidu.com) to analysis content. In addition, considering that digital news on the Internet breaks through the traditional news dissemination concept, the research uses related net news from the Ifeng City Channel (city.ifeng.com) and the Sina News (http://news.sina.com.cn/). Overall, during the research process, 8221 microblog posts, 3220 forum posts and 600 Internet news articles are used as corpus resources for semantic analysis, with a total of more than 3.2 million Chinese characters.

At the same time, the research adopts traditional GIS data, including spatial data of places, education facilities, medical facilities, commercial facilities, offices, industries, etc. On the one hand, they are used as the target sites of social sensing and for spatial analysis; on the other hand, they are used for achieving visualization of the semantic analysis.

4.3 Sensing Results

For semantic analysis technology, the research mainly adopts topic analysis based on keyword extraction and sentiment analysis technology to understand the social public's understanding, opinions and voices regarding the Changxindian area.

To help planners establish an overall impression of the research scope and to understand public's attention to hotspots in the area and the existing primary problems, the research adopts topic analysis by extracting keywords from corpuses

Fig. 1 The word cloud of overall impression in the Changxindian study area

(Fig. 1). The keywords are generated based on their weights in the corpus, which are calculated by taking the factors of word frequency, AV (Accessor Variety) (Feng et al. 2004), locality estimation (Huang et al. 2009) and the location of the word in the sentence into account, and those common words are excluded. As a result, the generated keywords can be better used by the planners to summarize public topics closely related to urban planning. Through analyzing and summing up these keywords, it can be found that citizens' focus mainly relates to the topic of urban house removal and resettlement, infrastructure, transportation development, history and renovation, ecology and environment, etc., reflecting the current situation of the millenary old town and its influence on residents.

At the beginning of the project, planners thought that the renovation of the old town should be an organic updating led by cultural industries because of its rich historical and cultural resources. Similarly, by adopting topic analysis based on keywords extracted from corpuses related to the cultural theme (Fig. 2), the planners have further found that the understanding and opinions from the social public, experts and scholars are focused on cultural brands, historical events, historical heritage sites, and cultural creativity industries in this area, which can be used as a reference to help planners orient the developing direction and analyze development tactics.

In addition, the project conducts sentiment analysis for 17 communities and over 70 places in the Changxindian study area. The sentiment distribution map is generated by means of summarizing the sentiment polarity of the corpus related to a specific community or place (Fig. 3). A dictionary-based method is employed to classify sentiment polarities. The primary dictionary resource is the emotion thesaurus developed by Dalian University of Technology (Xu et al. 2008) which contains 27,466 emotion words and includes the sentiment category, strength, polarity, etc. The sentiment polarity helps to perceive citizens' favourable or derogatory attitudes and positive or negative subjective assessment towards a specific community or place. Furthermore, through the topic analysis by extracting

Fig. 2 The word cloud of cultural theme analysis in the Changxindian study area

Fig. 3 The sentiment analysis of communities and locations in the research region

keywords from those corpus related to a specific community or place, planners could obtain the main content of public's feelings. This information can be used together with GIS data and PSS analysis methods, which help to improve the ability of finding and solving problems. In this project, with the hints provided by sentiment analysis and by using GIS data, such as infrastructure, industry, roads, and historic buildings, and spatial analysis techniques, planners can identify those places in critical need of protection or renovation and further study the causes of the problems. For instance, citizens' feelings toward Nanguan West Community are generally negative, and the problems mainly focus on the issues of environment and

Location: 486,880.211 294,206.652 Meters

Field	Value
FID	7
Shape	Point ZM
EnName	Nanguan West Community
Keywords	Environmental impact assessment, Resettlement housing, Environmental impact foreasting, Relocated housing, Xifeng Temple, Resettlement population, The villagers' congress,
Evaluation	Negative

Fig. 4 The sentiment analysis result for Nanguan West Community

relocated housing (Fig. 4). Based on these clues, by using GIS data and applying overlay analysis and buffer analysis, it can be discovered that Beijing Binfeng Machinery Manufacture Company would likely have a significant impact on the environment of the community and should receive due consideration during the planning.

5 Discussion

5.1 *Effect of Social Sensing on PSS*

Through the old town renovation planning of Changxindian, it is found that social sensing affects PSS comprehensively in terms of data, technology, function and application.

Traditionally, PSSs generally obtain spatial data support from the urban planning and government management department. In recent years, the researches and practices on PPGIS have been increasing. They have tried to use the online systems and Web mapping software to get more spatial data and involve more stakeholders into the decision-making process. But there are a range of the problems in representing people's opinions, beliefs, perceptions and value judgements in a PSS and then incorporating and using them in GIS together with more policy data (Geertman and Stillwell 2009). What is more, PPGIS applications often rely technically on expert systems and only a few methods are designed for lay persons. (Kahila and Kytta 2009). Compared to PPGIS, the citizens' interaction with professional tools is not the prerequisite in the process of social sensing. Social sensing can assist planners to initially acquire objective quantitative and qualitative data from massive amounts of 'digital footprints' that are generated by citizens in their daily life. Those data provide a way for planners to understand and analyze urban status, pluralistic society and people's opinion. As in the case study, social sensing is used as a comparatively low cost means of acquiring information quickly that can assist planners acquire perceptions about a region from the citizens which in turn can provide indicators of community issues and problems which exist within the urban context.

In past PSS practices, the planning models, GIS spatial statistics and analysis, spatial data visualization and WebGIS were highlighted as key components. As a comprehensive method for acquiring and analyzing data in the era of big data, social sensing offers exciting potential for incorporation into PSSs with some technologies regarding social computing, visualization, classification, text mining and semantic analysis and social network analysis, which are also useful and sustainable for analyzing urban complex problems, and it could assist PSSs in overcoming past technical deficiencies in mining non-spatial data, analyzing urban problems deeply, and enhancing public participation. Like the use of text mining and semantic analysis technologies in the case study, social sensing can bring to bear the power of non-spatial data to PSS tools and establish a relationship between spatial data and non-spatial data via techniques such as sentiment analysis.

In recent years, a variety of PSS applications have shown that they can provide better support in spatial analysis modeling, land utilization analysis, policy influence analysis, data management and visualization (Geertman and Stillwell 2004, 2009). In addition to the above functions driven by technical rationalities, social sensing can enrich the social and cultural color of PSS and help to establish richer content between PSS developers and users. As in the case study, planners have learned public views and feelings for the study region and regarded them as background information to communicate with different stakeholders. This process made project participants feel a sense of esteem, helped to find the relevant conflict points and enhanced the conversation and negotiation abilities of PSS in urban planning.

The applications of PSSs in urban planning focus on simulation, analysis and decision-making with regard to city spatial layout, land utilization, environmental protection and public service delivery. Generally, the scale is usually rather meso or macroscopic. Due to human perceptive and analytical ability, their perception not only describes personal feelings towards the immediate environment but is also a thoughtful expression with more profound meaning, enhancing human comprehension of the impact of the urban built environment on a specific place. Taking the case study as an example, with the help of social sensing, the project can perform a planning analysis about a specific location with different themes from sentiment data and produce more convincing results.

5.2 Response Strategy of PSS

PSS must integrate elements of the planning process with planning context (Geertman and Stillwell 2004). The integration framework of PSS and social sensing is illustrated in Fig. 5. It can be regarded as an extended framework of PSS for the smart city in the era of big data. Under this framework, at different stages of planning formulation, approval, implementation and evaluation, through the analysis of big data, open data, statistical investigation result and operational data from government departments, planners and decision makers can initiatively perceive the social sentiment and judge, dig and integrate the contents reflecting public behavior patterns, social media hotspots, expert thoughts and popular will. These capabilities would provide better decision-making support and application services for smart planning and a smart city.

Specifically, the Changxindian renovation project has demonstrated that in addition to those conventional methods, planners can enrich the investigational contents, expand the formulation thinking with the help of social sensing during the planning formulation period, especially improve the ability to identify the public concerns. During the period of planning approval, planners will be capable of gathering social public opinions towards planning layout and applying them in prioritizing and choosing the most popular design. During the period of planning implementation, planners will be able to learn about the problems in the planning implementation and the current urban construction status through the analysis of public behaviors and sentiments, which will help to guide and adjust the time order of the planning implementation. During the period of planning evaluation, planners can evaluate the implementation effect of significant planning programs and lay a

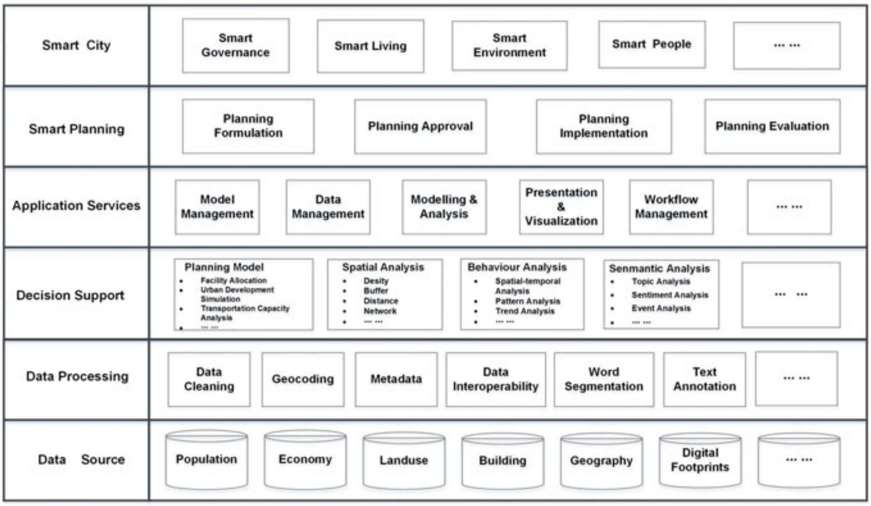


Fig. 5 The integration framework of PSS and social sensing in the urban planning process

solid foundation for a new planning formulation or revision in the future through an analysis of the changes of public emotions and behaviors, their interactions in spatial terms, etc.

6 Conclusion

The city is not a machine, but a thoughtful and behavioral organism (Geddes 1915). Every city may have similarities in spatial forms or landscape, where city infrastructure, management facilities and sensor equipment are implemented in similar patterns and the subtle differences lie only in spatial arrangement and quantity. However, the city has become unique and distinctive in terms of thoughts, vitality and characteristics driven through the behavior and interactions of its citizens. Accordingly, a PSS should improve its sensing ability for non-material contents of the city, especially those contents of human space-time behaviours, thoughts and emotions, and grasp the pulse of this organism and develop the social value of the PSS in smart city planning, design and construction.

Social sensing, which is an indispensable element of PSS, can provide a positive influence on a PSS from four aspects, namely: (i) data, (ii) technology, (iii) function and (iv) application. In the process of moving toward the smart city, which focuses on the principal task of transforming data and information into knowledge and wisdom, social sensing and PSS can be integrated to assist in decision making. In this way, the breadth, speed and depth of acquiring knowledge can be expanded, and improvements in sensing ability, perceiving ability and decision-making ability could be realized, thus providing more complete, objective, time-efficient, intelligent knowledge products and services for urban planning and urban management.

References

Allbach, B., Henninger, S., & Deitche, E. (2014). An urban sensing system as backbone of smart cities. In *Proceedings REAL CORP 2014 Tagungs-band, 21–23 May 2014*. Austria: Vienna.

Amara, N., Ouimet, M., & Landry, R. (2004). New evidence on instrumental, conceptual, and symbolic utilization of university research in government agencies. *Scientific Communication, 26*(1), 75–106.

Batty, M. (2014). Can it happen again? Planning support, Lee's Requiem and the rise of the smart cities movement. *Environment and Planning B: Planning and Design, 41*(3), 388–391. doi:10.1068/b4103c2

Batty, M., Axhausen, K. W., Giannotti, F., Pozdnoukhov, A., Bazzani, A., et al. (2012). Smart cities of the future. *The European Physical Journal Special Topics, 214*(1), 481–518.

Barnaghi, P., Sheth, A., & Henson, C. (2013). From data to actionable knowledge: Big data challenges in the web of things. *Intelligent Systems IEEE, 28*(6), 6–11.

Brömmelstroet, M. T. (2012). Transparency, flexibility, simplicity: From buzzwords towards strategies for real PSS improvement. *Computers, Environment and Urban Systems, 36*(1), 96–104.

Brömmelstroet, M. T. (2013). Performance of planning support systems what is it, and how do we report on it? *Computers, Environment and Urban Systems, 41*(41), 299–308.

Brömmelstroet, M. T. (2016). PSS are more user-friendly, but are they also increasingly useful? PSS are more user-friendly, but are they also increasingly useful? *Transportation Research Part A, 91,* 166–177.

Calabrese, F., Diao, M., Lorenzo, G. D., & Joseph, F. (2013). Patterns from urban sensing data: A mobile phone trace example. *Transportation Research Part C, 26,* 301–313.

Connected Smart Cities Network. (2013). Why smart cities? Connected smart cities. http://connectedsmartcities.eu/why-smart-cities

Eräranta, S., & Staffan, A. (2015). From situation awareness to smart city planning and decision making. In *International Conference on Computers in Urban Planning and Urban Management*, 2015, Boston, USA.

Exner, J. P. (2015). Smart cities—Field of application for Planning Support Systems in the 21st Century? In *International Conference on Computers in Urban Planning and Urban Management*, 2015, Boston, USA.

Feng, H. D., Chen, K., Deng, X. T., & Zheng, W. M. (2004). Accessor variety criteria for Chinese word extraction. *Computational Linguistics, 30*(1), 75–93.

Geddes, P. (1915). *Cities in evolution*. London: Williams & Norrgate.

Geertman, S. (2001). Participatory planning and GIS: A PSS to bridge the gap. *Environment and Planning B: Planning and Design, 29*(1), 21–35.

Geertman, S., & Stillwell, J. (2003). *Planning support systems in practice*. Heidelberg: Springer.

Geertman, S., & Stillwell, J. (2004). Planning support systems: An inventory of current practice. *Computers, Environment and Urban Systems, 28*(4), 291–310.

Geertman, S., & Stillwell, J. (2009). *Planning support systems—best practice and new methods*. Heidelberg: Springer.

Gudmundsson, H. (2011). Analysing models as a knowledge technology in transport planning. *Transport Reviews, 31*(2), 145–159.

Harris, B., & Batty, M. (1993). Location models, geographic information and planning support systems. *Journal of Planning Education and Research, 12,* 184–198.

Huang, Y. L., Gong, C. C., Xu, H. B., & Cheng, X. Q. (2009). A meaningful string extraction algorithm based on locality. In *Proceeding of the 6th China conference on information retrieval,* Mudanjiang, China.

Kahilia, M., & Kytta, M. (2009). SoftGIS as a bridge-builder in collaborative urban planning. In S. Geertman & J. Stillwell (Eds.), *Planning support systems best practice and new methods* (pp. 389–412). Netherlands: Springer.

Klosterman, R. E. (1997). Planning support systems: A new perspective on computer-aided planning. *Journal of Planning Education and Research, 17*(1), 45–54.

Klosterman, R. E. (2001). *Planning support systems: Integrating geographic information systems, models, and visualization tools*. ESRI Press.

Liu, Y., Liu, X., Gao, S., Gong, L., Kang, C. G., Zhi, Y., et al. (2015). Social sensing: A new approach to understanding our socio-economic environments. *Annals of the Association of American Geographers, 105*(3), 512–530. doi:10.1080/00045608.2015.1018773

Pelzer, P., Arciniegas, G., Geertman, S., & Lenferink, S. (2015). Planning support systems and task-technology fit: A comparative case study. *Applied Spatial Analysis and Policy, 8*(2), 1–21.

Ruiz-Correa, S., Santani, D., & Gatica-Perez, D. (2014). The young and the city: Crowdsourcing urban awareness in a developing country. In *International Conference on Iot in Urban Space*, Rome, Italy.

Russo, P., Costabile, F. M., Lanzilotti, R., & Pettit, C. J. (2015). Usability of planning support systems: An evaluation framework. In S. Geertman, J. Stillwell, J. Ferreira, & J. Goodspeed (Eds.), *Smart cities and planning support systems* (pp. 337–353). Switzerland: Springer International Publishing.

Sakaki, T., Okazaki, M., & Matsuo, Y. (2010). Earthquake shakes Twitter users: Real-time event detection by social sensors. In *Proceeding of 19th International Conference on World Wide Web* (pp. 851–860). Raleigh, USA.

Sarfraz, N., Christos, E., Cecilia, M., & Kenichi, S. (2012). *Social sensing in the field: Challenges in detecting social interactions in construction sites*. MCSS'12, June 25, 2012, Low Wood Bay, Lake District, UK.

Sheth, A. (2010). Computing for human experience: Semantics-empowered sensors, services, and social computing on the ubiquitous web. *IEEE Internet Computing, 14*(1), 88–97.

Staffans, A., & Horelli, L. (2014). Expanded urban planning as a vehicle for understanding and shaping smart, liveable cities. *The Journal of Community Informatics,* 10(3).

Vonk, G. A. (2006). Improving planning support: The use of planning support systems for spatial planning. Utrecht: Nederlandse Geografische Studies (340).

Wang, D., Abdelzaher, T., & Kaplan, L. (2015). *Social sensing: Building reliable system on unreliable data*. Burlington.MA: Elsevier Science.

Wang, Z. H., Tu, L., Guo, Z., Yang, L. T., & Huang, B. X. (2014). Analysis of user behaviors by mining large network data sets. *Future Generation Computer Systems, 37*(7), 429–437.

Widener, M., & Li, W. (2014). Using geolocated twitter data to monitor the prevalence of health and unhealthy food references across us. *Applied Geography, 54,* 189–197.

Xu, L. H., Lin, H. F., Pan, Y., et al. (2008). Constructing an ontology for sentiment vocabularies (in Chinese). *Chinese Journal of Information, 27*(2), 180–185.

Zhang, D., Guo, B., Li, B., & Yu, Z. W. (2010). Extracting social and commuting intelligence from digital footprints: An emerging research area. *Ubiquitous Intelligence and Computing*. Heidelberg: Springer.

Part II
Smarter Urban Futures

Chapter 14
Opening the Search Space for the Design of a Future Transport System Using ‘Big Data’

Vinutha Magal Shreenath and Sebastiaan Meijer

Abstract The advent of ‘big data’ already enables a wide range of conveniences to citizens. However, the dominant utilization of this data for systematic improvement is geared towards operations such as informing on real-time events in cities. The impact of big data on the long-term planning and design purposes in cities is still unclear. This chapter presents an application of big data where locations, suitable for deploying charging infrastructure for vehicles, are mined. We conducted an experiment to observe the impact of this information on designs of Electrical Road Systems (ERS). Results prove that insights mined from big data outside the design process do influence the designing process and the resulting designs. Therefore it seems promising to further explore this influence on the quality of designing.

Keywords Big data · Design process · Transport system

1 Introduction

The necessity of participatory methodologies for effective inclusion of diverse needs and opinions in urban planning is paramount. An abundance of experiments and new approaches can be found in the literature and in real-world experimentation, with both positive and negative results. The design of future transport systems as part of urban planning can be formulated as a joint activity of multiple stakeholders (Raghothama and Meijer 2015), responsible for different parts of the system.

V.M. Shreenath (✉) · S. Meijer
School of Technology and Health, KTH Royal Institute of Technology,
Hälsovägen 11, 141 52 Huddinge, Sweden
e-mail: vinutha@kth.se

S. Meijer
e-mail: smeijer@kth.se

S. Geertman et al. (eds.), *Planning Support Science for Smarter Urban Futures*, Lecture Notes in Geoinformation and Cartography,
DOI 10.1007/978-3-319-57819-4_14

Envisioning a desirable future and being able to reach that vision via a viable path are not necessarily related, especially if the first is done without acknowledging the current needs of the city. Initial design choices are critical to ensure future implementation. The role of big data at this stage is still somewhat ambiguous, because the nature of big data methods does not naturally match the open nature of the urban design problem. So the question becomes whether what might be termed the ‘search space’ of these designers, can be enlarged by providing them with insights from big data analytics. And if this is so, what consequence do the data insights have on the designing process?

The state of the art in big data provides for rapid and massive monitoring of state of artifacts and activities of people in the city, and is predominantly used either for operational understanding or as an improved data source for existing design methods. It is challenging to use the data for long term planning, as the translation between what the real-time data means and its transformation in the long run are much different. By providing data analytics from the outside of the design process, it potentially supports a revision of assumptions and offers scope to discuss various issues related to the system, thus providing impetus to change their designs.

In this chapter, we present a case study where big data of the movements of vehicles in the city of Stockholm in Sweden is used to enlarge the search space for designing Electrical Road Systems (ERS), thus opening up the search space for consideration of more options in designs. The criteria for potential locations for electrical road installations were gathered from experts working with ERS. Based on the criteria, a mining process retrieved both potential locations for placing static charging installations and relevant road segments to place dynamic charging installations. Groups of experts were asked to design a future transportation system for Stockholm, incorporating ERS. During the design process, the locations obtained from data mining were presented, and the resulting changes to the designs tracked.

The experiment provides evidence for the potential of using big data to inform intricate detail-intensive processes such as transport system design, demonstrating the impact of big data on designing large-scale systems.

2 ‘Big Data’ in Planning Support Systems

The design of a transportation system for a city is a problem that can be viewed from various levels of abstractions. Transportation can be viewed as an interacting system of systems (Taylor 2007), of vehicles and infrastructure, public transport and personal vehicles, networks of cycle lanes, pedestrian ways, and more. Planning, particularly in urban contexts, faces continuous transitions from a rational predictive approach to a holistic view and from a relatively simple institutional context to a complex one with multiple participating stakeholders with conflicting values and goals. These transitions posit new ways of generating and employing knowledge to support planning (Healey 2006).

Real-time data on movements of people and goods can have various sources such as travel cards, phone traces identifying locations on a regular basis throughout the day, activities on social media, et cetera. Personalized services such as ride sharing, route finding, recommendations of relevant locations and people are enabled by big data (Thakuriah et al. 2015; Zheng et al. 2014). At an individual level, they cater to a user's needs around a city. At a collective level, this data that is generated from individuals is being utilized for detecting traffic anomalies, monitoring energy consumption, air quality, noise pollution, detecting functional regions in the city, preparedness for events, rapid response to situations unfolding in the city and so on (Zheng et al. 2014). A wide variety of applications and services enabling better governance, transparency and progress is now possible because of big data. (Batty et al. 2012).

The non-scientific (Ward and Barker 2013) definition of big data being volume-variety-velocity-veracity-value speaks to the magnitude of data that cannot be dealt with conventional computational methods (Ward and Barker 2013). While technological progress has enabled public and private institutions to provide services, the impact of using technology and data on privacy, rights, and governance is yet to be ascertained (Kitchin 2014). Consistent and significant effort is required to make sense of this data for governance, considering it is typically generated for other purposes (Leszczynski 2016). While big data has enabled more vibrant lives for citizens, even the most detailed data on behaviors and forecasts cannot practically solve urban planning for cities as it is computationally intractable (Bettencourt 2014).

Hidden and complex processes generate this big data. The data, despite its vastness, does not directly represent the system it is emanating from. While data can contain insights that were unknown before, it is important to include the knowledge of the actors in the system to interpret and use this data for the design of future systems.

3 Electrical Road Systems

Electrical Road System (ERS) can be defined as transport infrastructure that can deliver the electrical power to charge EVs efficiently while stationary or even in motion, using specific conductive or contactless charging systems (Chen et al. 2015). ERS consists of 2 distinct modes to charge vehicles:

- Static charging: Vehicles charge when they are parked and charging begins on automatic confirmation or when manually charging the vehicle.
- Dynamic charging: Vehicles can charge via conductive charging i.e., by contact with overhead wires while the vehicle is moving or through the road; or via inductive charging through magnetic coupling of coils embedded in the roads.

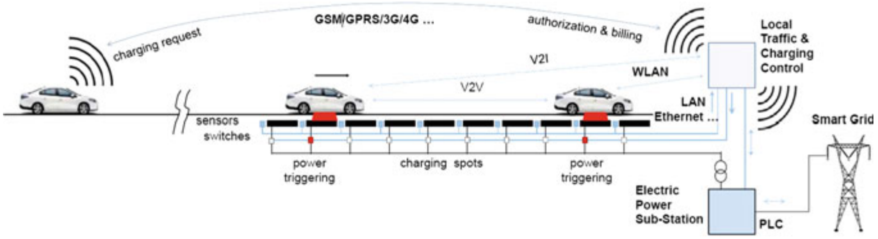


Fig. 1 Technical infrastructure required for an ERS (FABRIC 2014)

ERS is a collective effort from many stakeholders such as vehicle manufacturers, city authorities, logistical companies, electric grid operators and road manufacturers to increase the use of Electrical Vehicles (EV) at a societal scale to achieve a significant reduction in carbon emissions. The design of ERS at such scales is a complex and open problem where the uptake of ERS is dependent on many factors and many institutions (Bakker et al. 2014). Deployment of ERS is a significant part that involves co-ordination among many institutions in matters such as policy, pricing, Information and Communications Technology (ICT), adaptation of the road network and the electrical grid. The design of such a system intertwines infrastructures, vehicles and operations (Fig. 1).

Different stakeholders have their own optimized technology solutions, depending on their goals. However, there is no guarantee that the summation of all these technologies will lead to the most suitable system (Chen et al. 2015).

A critical component of this multi-dimensional design problem is the choice of the location of installations- both static and dynamic—in a city, which will determine the uptake, usage and efficiency of an ERS (Hauge et al. 2015). This is of interest of all stakeholders as it affects their individual solutions.

In the next section we describe an application to retrieve potential locations for ERS by data mining of movements of vehicles and then discuss how this information influences the design of an ERS in a city.

4 Application

Scania CV AB, a major heavy-duty vehicle manufacturer in Sweden, holds a dataset collected over 2 years of approximately a billion instances of location information from several thousands of trucks. An application with the goal of retrieving locations ideal for different types of charging infrastructure for different cities was conceptualized. For the pilot phase of the project, data from the city of Stockholm was considered. This dataset consisted of approximately 4 million instances from around 4 thousand trucks. Each instance of the data consists of a unique identifier of the vehicle, timestamp, and its latitude and longitude. Each vehicle emits data every 10 minutes.

4.1 Methodology

The methodology emerges from the discussion presented in Sects. 2 and 3. In order to interpret the data and focus on pertinent questions, opinions and criteria were gathered from experts. The criteria were then technically formulated. These were used to mine big data and the results of this application were presented to experts again to observe the value of big data in design processes. In order to assess the appropriateness of the data mining method itself, relevant data mined results for the design exercise will be used. This methodology is depicted in Fig. 2.

4.2 Questions and Criteria

The application being described is guided by the goal of mining potential locations for ERS in a city. The guiding question is: *Which locations are suitable for electrical road installations, either static electrical installation* (*a location*) i.e., *plug-in points; or dynamic electrical road installation* (*a stretch of road*)?

The criteria for the locations to be mined were formulated as:

The locations suitable for static electrical installation, should have the "most" vehicles being stationary at the said location. The stretch of road suitable for dynamic electrical installation should be the "most common road" taken by most vehicles. The stretch of road suitable for dynamic electrical road installation can also be a trajectory "most consistently" used throughout the day, though it need not be used by "most" vehicles.

Experts agreed on 1000s as a threshold to create a trajectory or be considered as a stay point. This duration indicates a vehicle was actually stationary and not just a happenstance feature of the data, which is emitted every 600s.

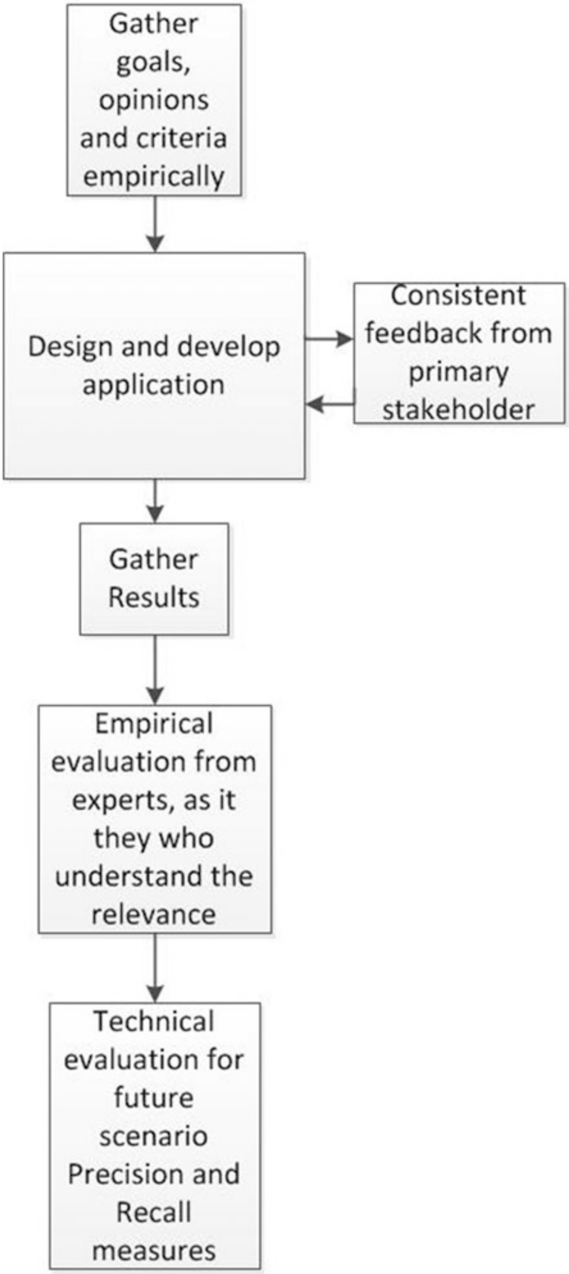
The application should also allow exploratory analysis on data for question such as:

- Which are the routes that are repeated by some vehicles?
- Does the change in parameters such as time spent at a location, affect the results?
- How do these locations change if a dataset is sliced over different time periods?

4.3 Technical Framework

Based on the dataset, and the criteria, the concepts that relate to static road charging was stay point detection and the concepts that related to most relevant roads was trajectory formulation and clustering (Giannotti et al. 2007; Zheng 2015). The technical framework has been described in Shreenath and Meijer (2016). Figure 3 describes the workflow of the application. By following the workflow, similar analysis has been generated for other cities.

Fig. 2 Methodology



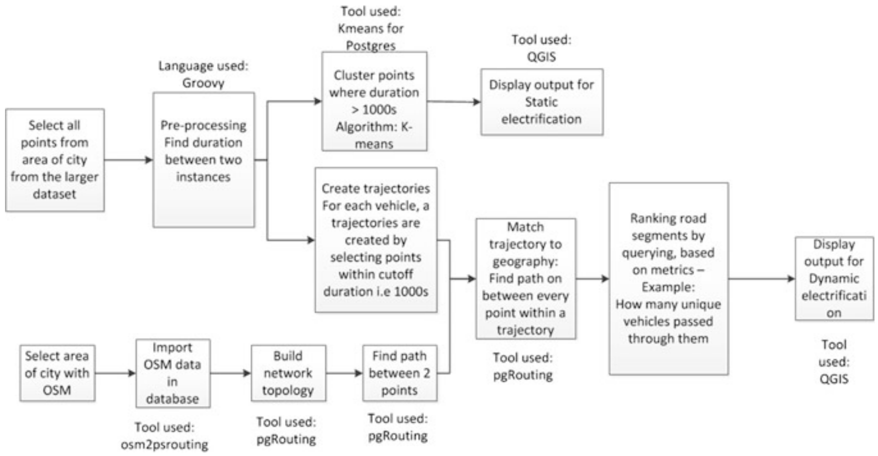


Fig. 3 Workflow of the application

4.4 *Results of the Application*

From the application, 50 clusters of stay points of vehicles were generated. Approximately 700,000 trajectories of various lengths were constructed. Trajectories were projected on to a map of Stockholm obtained from OpenStreetMap as described in Shreenath and Meijer (2016). Part 1 in Fig. 4 depicts the clusters of movements where vehicles have stopped for more than 1000s. Part 2 depicts the trajectory of an individual vehicle from a stay point to a consecutive stay point. Part 3 depicts the conversion of the trajectory from a geometric object to an actual route on OpenStreetMap. Part 4 depicts the clustering of trajectories and roads commonly traveled on by vehicles, hence ideal for dynamic charging. A preliminary evaluation of the results was conducted through a discussion with the same experts who formulated the criteria. The results were deemed “correct” in terms of expectations of where the locations should be. Some unexpected locations were retrieved which on investigation were revealed to be construction sites. The impact of the information retrieved by this data mining application, on design has been described in the following sections.

5 Experiment

An experiment was conducted with the goal of observing the influence of data mined information on designs created by different stakeholders for ERS. The experiment was conducted in a workshop during the FABRIC consortium meeting. The participants had different backgrounds, different levels of experience and knowledge in different domains in ERS. Considering their background, it was

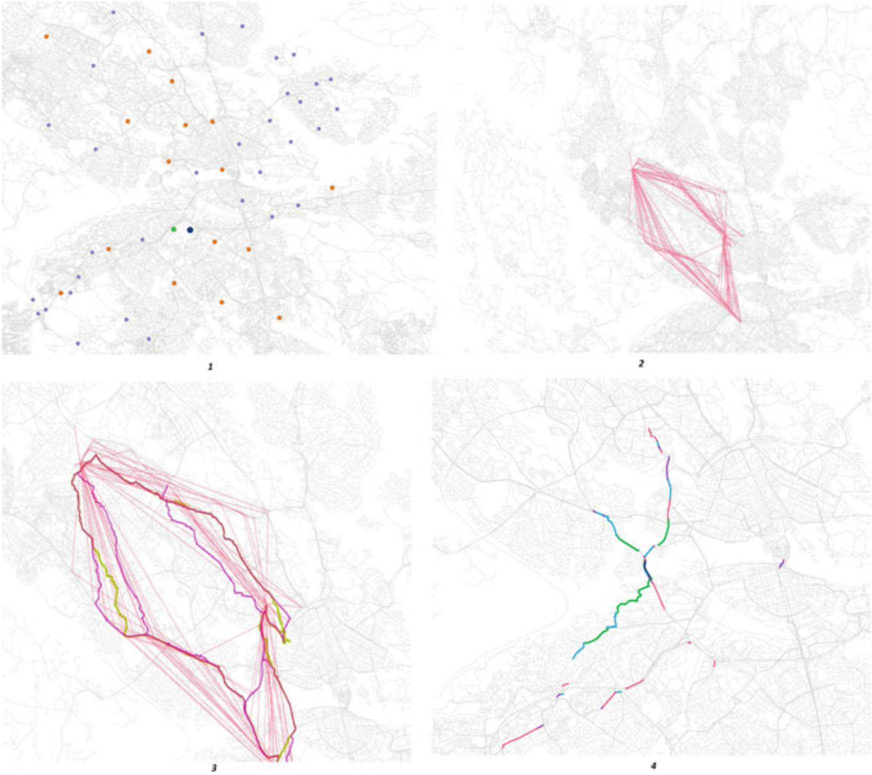


Fig. 4 Results of the application: Part 1 depicts locations suitable for static charging. Part 2 and 3 depict trajectory of a single vehicle. Part 4 depicts roads suitable for dynamic charging

assumed that all participants had knowledge of EV as well as technology and limitations in capacities and distances. 20 participants were divided in groups of 2.

The experiment was divided into two sessions. During the first session the groups were given the task of designing an ERS for Stockholm city, in different phases such that the number of electrical vehicles in the city would eventually be 100%. The participants were asked to place electrical road infrastructure strategically such that most "important" routes with many vehicles are serviced by the infrastructure and were given an hour to do so.

The participants were asked to create a design of electrical road system in Stockholm along 3 main dimensions: by choosing the locations for deployment, technological solutions (static, stationary, inductive or conductive charging), along with choice of vehicles (cars, buses, trucks, light duty vehicles), in progressive phases.

Since most of the participants were not native to Stockholm city, a booklet consisting of basic facts about Stockholm's population, transport infrastructure, logistical flows around the city and weather patterns were handed out. A3 sized maps of Stockholm with data on annual average daily traffic sourced from the transport authority in Sweden (Trafikverket) were also provided as an indicator of traffic in Stockholm.

Participants were given A3 maps of Stockholm city and a worksheet to describe the phases of electrification of road infrastructure.

After the completion of the first session and a break, the results of the application (as described in the previous section), were introduced as new information in the second session. This information was presented in three A3 maps of Stockholm. The first map depicted locations ideal for static charging, with the metric of number of visits to these locations. The second map highlighted roads ideal for dynamic charging, along with the metric of a unique number of vehicles driving along them and the third map depicted repeated trips taken by certain vehicles.

The participants were asked to redesign their ERS for Stockholm, with any changes and to any extent considering the new information and using copies of the maps and worksheets used in the first session. At the end of second session, all participants were requested to individually complete an exit questionnaire.

6 Results

The groups created designs based on their knowledge of ERS, complemented by information related to Stockholm. The maps, handouts and questionnaires were analyzed for changes in design.

The following results have been derived from questionnaires answered by individual participants and worksheets reported by groups. The designs the components within them, reasoning for initial designs and changes in designs are presented.

6.1 Designs for a Future Transport System

Designs for a future transport system that consists of an ERS were created according to 3 criteria:

- Vehicles: To increase number of electrical vehicles—be it buses, cars or trucks.
- Charging technology: Either static charging—such that vehicles can charge when they are stationary; or dynamic charging such that vehicles can charge as they are driving on the road. The charging infrastructure is designed for the type of vehicles it can support.
- Location: Installations around the city such that vehicles get access to appropriate charging equipment, considering range, charging capacity, demand and so on.

Table 1 depicts the changes in vehicles and charging technology from the first session to the second per group. For example, Group 1 created a design that consists of inductive charging installations along most of the major corridors in the western area of Stockholm and static charging installations for cars as shown in the first cell of Fig. 5. On introduction of the data mined information, this group significantly reduced the extent of dynamic charging in the corridor and added inductive charging for all vehicles around the city. Hence the group changed their design only in the location dimension. Samples of designs from some groups are depicted in Fig. 5.

6.2 Reasoning Initial Designs

Following the transcription of the participants' comments in the worksheets and questionnaires, the data was analyzed for major themes that emerged. The authors tagged all comments with keywords from the ERS and transport vocabulary, and then grouped them in themes that link to the designs of ERS as presented in Table 1. The themes presented in Table 2 represent the reasons for the design that emerged during both sessions, with groups that considered them.

The 3 groups took into account geographical considerations such as major corridors and industrial locations.

Traffic density throughout the city was considered. While one group mentioned that high traffic densities would be a good case for inductive charging, another group held the view that congested roads should be avoided for such installations.

Public transport, mainly buses were recommended as an essential use for ERS. The groups differed in addressing the strategy to electrify buses. Whilst 2 groups mentioned that buses could be charged along their route, one group recommended that static charging take place at the end of the line. Public transport was also relied upon to reduce the number of cars, to generally be a mediator between other modes and to be a critical component to intermodal transport in the city. Freight transportation was reported to be an essential use for ERS. Minimal disturbance to the city center was the main reason for selecting static charging in the city center as opposed to dynamic charging. Battery size minimization was considered important.

6.3 Changes in Designs

None of the groups discarded the themes considered for initial designs. However, new themes emerged after the introduction of new information. For example, Groups 1 and 2 came up with new themes. They significantly reduced the extent of the installations while adding technology that was not initially considered. 8 groups changed their designs. The extent of the changes is depicted in Table 1 and the change in reasoning is depicted in Table 2. 2 groups did not change their designs. Group 6 did not change their design as they perceived that new information was

Table 1 Change in designs

	Session 1		Session 2		Changes	
	Vehicle	Technology	Vehicle	Technology	Dimensions	Description of changes
Group 1	Cars and trucks	Inductive charging	Cars and trucks	Inductive charging	1	Number charging installations reduced on major corridors. New inductive charging link added around city center for all vehicles. This is a change in locations shown in column 1 of Fig. 5
	All vehicles	Static charging	All vehicles	Static charging		
Group 2	Fully electric or hybrid trucks	Inductive charging	Trucks	Inductive charging	3	Number of charging installations reduced and buses are not part of new design
	Electric cars, buses	Static charging	Electric cars	Static charging		
Group 3	Cars, Buses	Static charging	Trucks (Plugin/hybrid)	Static charging	3	Addition of charging solution for trucks. More static charging installations for logistical areas
			Trucks and others	Inductive charging		
Group 4	Cars, light duty vehicles	Static charging	Cars, light duty vehicles, trucks	Static charging	2	Addition of inductive charging installation for trucks
	All vehicles	Inductive charging	Trucks	Inductive charging		
Group 5	For Freight transport: Light railways and light electric trucks	Static and inductive charging	Same as initial design	Same as initial design	1	Addition of light rail near the city center
	For people: Tram and cars	Inductive solution	Same as initial design	Same as initial design		
			Light rail	Inductive charging		

(continued)

Table 1 (continued)

	Session 1		Session 2		Changes	
	Vehicle	Technology	Vehicle	Technology	Dimensions	Description of changes
Group 6	Cars	Static charging	Same as initial design	Same as initial design	0	No changes
	All vehicles	Inductive charging	Same as initial design	Same as initial design		
Group 7	Cars	Static charging	All vehicles	Addition of inductive charging	2	Addition of inductive charging for trucks
	Trucks, cars, buses	Inductive charging				
Group 8	Buses, Cars	Static charging	Buses, Cars	Static charging	1	Addition of static charging at logistic centers for trucks and more charging for commuters' cars
			Trucks	Static charging		
Group 9	Buses	Static or stationary charging	Buses	Same as initial design	2	Addition of inductive charging installation for trucks and cars
	Cars, trucks	Inductive charging	Cars	Static and Inductive charging		
			Trucks	Inductive charging		
Group 10	Buses	Static charging	Same as initial design	Same as initial design	0	No changes
	Freight trucks	Inductive charging	Same as initial design	Same as initial design		

irrelevant, as it was based on trucks. Group 10 did not change their design as they considered new information to be out of scope for their design. Their design addressed the freight routes to the harbor and electric buses for city center.

7 Discussion

Table 1 depicts the shift in designs in dimensions of technology choice, vehicle choice or location choice for 8 groups and no changes in any of the dimensions for 2 groups. Among 8 groups that changed designs, there were 2 groups that changed designs in 3 dimensions. The reasoning for initial designs was that these were based

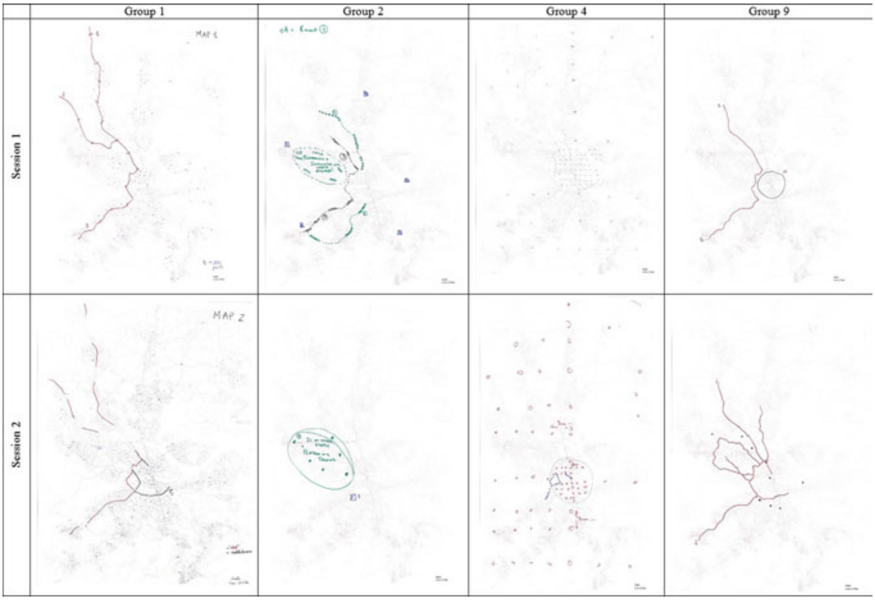


Fig. 5 Sample of change in locations in design of ERS

Table 2 Common themes considered during both sessions of the experiment

	Themes	G1	G2	G3	G4	G5	G6	G7	G8	G9	G10
Session 1	Geographical considerations, location of industry and major arteries	✓		✓				✓			
	Traffic density		✓					✓		✓	
	Public transport reliance		✓	✓				✓	✓	✓	✓
	Freight transport	✓				✓					✓
	Less disturbance to city center				✓		✓				✓
	Battery size minimization				✓						
Session 2	Air quality	✓									
	Vehicle range	✓									
	Platooning		✓								
	Addition of technology	✓			✓	✓		✓			
	Addition of vehicle type		✓		✓			✓			
	Combining technologies			✓						✓	
	Reconfiguring				✓				✓		

on charging infrastructure that could be needed to serve a city. Some groups considered more themes than others. The detail of design also varied across groups. Groups that had particular themes in common addressed them differently, especially in regard to public transport.

After new information was introduced there were more discussions on being more accurate and concise in determining the locations. There was more effort to deploy infrastructure that catered to more than one type vehicle. The introduction of new information made location choices more precise, evidenced by reductions in the number and length of charging installations. Instead of filling in an entire transport corridor, dynamic charging became more intermittent, matching the new information. In the second session, groups had a better idea of needs. While there was an equivalent priority given to technology and vehicle type during the first session, groups thought of technology that caters to more vehicle types as requiring importance.

Although all participants were aware of conductive charging technology, none of the designs chose that for deployment. Either cars or buses were considered more suitable for phase 1 of the deployment of ERS and trucks were considered less. After the introduction of new information, trucks were considered more feasible than before and inductive charging was accepted as a choice for all vehicles. This could be because the new information was based on data from movements of trucks exclusively.

The groups that had the most detailed designs were least likely to reconsider them. The participants who were most determined on their knowledge of the entire system were least likely to consider new information.

8 Conclusion

From the experiment it follows that results from data mining on big data introduced new perspectives and changed most designs. Most of the designers were open to the new information from data mining and changed their designs accordingly. The uptake of information did not directly translate into the design but triggered other thoughts and wider range of topics. The new information acts as a trigger thus opening the search space for design, based on previously unavailable information. As some of the designers reported, the new information made them re-elaborate their ideas.

The big data that is the foundation for this experiment is collected for real-time services and therefore required an expert based translation to lead to insights that could support designing.

This translation process however is a promising investment as big data could be used to generate and explore many viable designs for urban planning in the future. While generating a complete urban design is computationally intractable, it is possible to generate many design options from big data and use the knowledge of the experts to translate these options into designs.

References

Bakker, S., Maat, K., & van Wee, B. (2014). Stakeholders interests, expectations, and strategies regarding the development and implementation of electric vehicles: The case of the Netherlands. *Transportation Research Part A: Policy and Practice, 66,* 52–64.

Batty, M., Axhausen, K. W., Giannotti, F., Pozdnoukhov, A., Bazzani, A., Wachowicz, M., et al. (2012). Smart cities of the future. *The European Physical Journal Special Topics, 214*(1), 481–518.

Bettencourt, L. M. A. (2014). The uses of big data in cities. *Big Data, 2*(1), 12–22.

Chen, F., Taylor, N., & Kringos, N. (2015). Electrification of roads: Opportunities and challenges. *Applied Energy, 150,* 109–119.

FABRIC, E. (2014). Feasibility analysis and development of on-road charging solutions for future electric vehicles (FABRIC). http://www.fabric-project.eu/. Accessed 12 Dec 2015.

Giannotti, F., Nanni, M., Pinelli, F., & Pedreschi, D. (2007). Trajectory pattern mining. In *Proceedings of the 13th ACM SIGKDD International Conference on Knowledge Discovery and Data Mining* (pp. 330–339). ACM.

Hauge, J., Shreenath, V., Meijer, S., de Bias, J., Spessa, E., & Wang, Q., et al. (2015). Feasibility study on societal perspectives towards on road charging and set of current data regarding societal dimension (Public). EU.

Healey, P. (2006). Urban complexity and spatial strategies: Towards a relational planning for our times. Routledge.

Kitchin, R. (2014). The real-time city? Big data and smart urbanism. *GeoJournal, 79*(1), 1–14.

Leszczynski, A. (2016). Speculative futures: Cities, data, and governance beyond smart urbanism. *Environment and Planning A, 48*(9), 1691–1708.

Raghothama, J., & Meijer, S. (2015). Gaming, urban planning and transportation design process. In *Planning Support Systems and Smart Cities* (pp. 297–312). Springer International Publishing.

Shreenath, V. M., & Meijer, S. (2016). Spatial big data for designing large scale infrastructure: A case-study of electrical road systems. In *Proceedings of the 3rd IEEE/ACM International Conference on Big Data Computing, Applications and Technologies* (pp. 143–148). ACM.

Taylor, C. (2007). Integrated transportation system design optimization. Massachusetts Institute of Technology. Retrieved from http://ssl.mit.edu/publications/theses/PhD-2007-TaylorChristine.pdf

Thakuriah, P. V., Tilahun, N., Zellner, M., Thakuriah, P., Tilahun, N., & Zellner, M. (2015). Big data and urban informatics: Innovations and challenges to urban planning and knowledge discovery. In *Proceedings of the NSF Workshop on Big Data and Urban Informatics* (pp. 4–32).

Ward, J. S., & Barker, A. (2013). Undefined by data: A survey of big data definitions. arXiv preprint arXiv:1309.5821. Accessed 21 Dec 2016.

Zheng, Y. (2015). Trajectory data mining: An overview. *ACM Trans-actions on Intelligent Systems and Technology, 6*(3), 1–41.

Zheng, Y., Capra, L., Wolfson, O., & Yang, H. (2014). Urban computing: Concepts, methodologies, and applications. *ACM Transactions on Intelligent Systems and Technology, 5*(3), 1–55.

Chapter 15
Investigating Theoretical Development for Integrated Transport and Land Use Modelling Systems

Li Meng, Andrew Allan and Sekhar Somenahalli

Abstract A lack of integration in transport and land use modelling systems has been a major handicap for strategic planning operations in many cities; hence there is a need for a more interactive, flexible and accurate system that can meet various sustainable planning objectives. This chapter discusses the theoretical development of the relationship between transport and land use models. Previous practices show that a combination of bid-rent theory and random utility theory would provide mutual benefits for transport and land use models. Bid-rent models provide the location of activities with households and firms, which helps the estimation of random utility mode choice models in transport models. In turn, the output of transport models can be used to measure accessibility in land use models. This chapter also highlights the importance of using data base manager to include Revealed Preference data, Stated Preference data and Bluetooth data. Two current practices in Adelaide and Perth are analyzed. The application of a combined bid-rent theory and utility function theory are proposed for future empirical studies.

Keywords Integrated transport land use model · Random utility · Bid-Rent · Willingness to pay · Stated preference data

---

L. Meng (✉) · A. Allan · S. Somenahalli
School of Natural and Built Environments, University of South Australia,
Adelaide, SA, Australia
e-mail: li.meng@unisa.edu.au

S. Somenahalli
e-mail: Sekhar.Somenahalli@unisa.edu.au

A. Allan
School of Art, Architecture and Design, University of South Australia,
Adelaide, SA, Australia
e-mail: Andrew.Allan@unisa.edu.au

S. Geertman et al. (eds.), *Planning Support Science for Smarter Urban Futures*, Lecture Notes in Geoinformation and Cartography,
DOI 10.1007/978-3-319-57819-4_15

1 Introduction

Urban development is becoming ever larger and increasingly complex. Various concerns have been raised since the middle of last century and remain unsolved, including the consideration of integrating economic analysis into the planning process at an early stage (Thompson 1965), efficiency planning with community equity (Hanley and Spash 1993), the ignorance of professional networks, political insiders, and cultural elites (Woolcock 1998), the disconnect of welfare, political forces, physical, social and economic structures (Kleinhans 2004) and the conflicts between adaptation and mitigation of climate change (Hamin and Gurran 2009). In an unavoidable democratic system, urban transport planning involves many stakeholders with conflicting values and priorities. It is neither feasible nor appropriate to deal with land use and transportation policies and investments as isolated choices or within a single organisation (Waddell and Ulfarsson 2004). These complexities put traditionally applied tools encountering challenges to consider all factors in one integrated package.

Transport policy decisions have a profound effect on urban development (McFadden 1974a). Earlier transport and land use models were designed to support urban development began in the 1950s, followed by decades of developments as a form of large scale computation tool. Waddell and Ulfarsson (2004) provided a useful summary of the history of transport and land use model development. They stated that transport and land use modelling was focused on determining transportation road capacity needs from the 1960s through to the 1980s; over the 1970s and 1980s, there was pressure from environmental protections and proponents of transit which led to a substantial change in policy objectives. By 1990, the development faced environmental consequences from emissions and a loss of open space as stimulation largely focused on low-density development or urban fringe. Waddell and Ulfarsson were critical of computerized transportation and land use planning processes did not adequately account for these complex feedbacks between transportation improvements, land use, and air quality.

Accounting the importance of transport and land use modelling, researchers frequently reviewed these models and tried to highlight the lessons learnt in the past. Lee (1973) carried out an important work to critically question these models and pointed out that the models were too complex and required excessive data. Twenty years later, Wegener (1994) reviewed 20 modelling applications and selected 12 of them in terms of techniques, dynamics, data requirements, calibration and validation, operation, and actual and potential applications. He stated that the models are mainly used to solve a very narrow set of planning problems, and, in particular, lack sensitivity to issues of equity and environmental sustainability. Southworth (1995) reviewed a list of models and found that analytic complexity and significant data requirements are highlighting various shortcoming. He further expressed special concerns over the sustainability, environmental and social aspects in acceptable travel reduction strategies. By reviewing six modelling frameworks (ITLUP, MEPLAN, TRANUS, MUSSA, HYMTC-LUM and UrbanSim), Hunt et al. (2005) noted that none of the models matches the ideal for all envisaged items of physical systems, decision-makers and processes. They recommended improvement through the strengthening of the behavioural basis and relaxation of some of the more restrictive assumptions. Chang (2006) suggested that the current direction of model development focused on too many details of the issues rather than the refinement of the foundational relationship between transport and land use. Iacono et al. (2008, p. 335) noted that preferences for individuals of a different race, income, or any other form of social stratification were shown to lead to highly segregated outcomes under a variety of initial conditions and preference structures.

This chapter seeks a solution to refining and improving these models' fundamental methodology, which would lead to reducing large data requirements, reflecting an interactive relationship between transport and land use, and with a capacity for assessing complex urban development issues.

2 Literature Review

Applied transport and land use models are categorised into three main types of models: spatial interaction gravity-based models, including Lowry's model, ITLUP (DRAM, EMPAL) (Putman 1983); econometric models, including MEPLAN (Hunt 1997), TRANUS, MUSSA (Martínez 1996) and microsimulation models, such as UrbanSim (Waddell 2002). The microsimulation model includes activity-based models, cell-based models and multi-agent models (Iacono et al. 2008). For the theoretical development of the models, Southworth (1995, p. vii) stressed the importance of combining spatial interaction theory with economically rational notions of utility maximization and consumer choice, as well as the importance of seeking equilibration between transportation demand and supply and linking it to a residential market sales process. He commented that the methodology of the practised models utilize both non-linear mathematical programming methods and inter-regional input-output methods. The economic models apply microsimulation to model jointly the demands by using the bid-rent function to determine residents' willingness to pay for a house location.

Understanding the relationship between transportation network growth and changes in land use and the location of economic activity help improve accessibility, which has been a common task for transport modellers (Iacono et al. 2008). The core difficulty in modelling spatial and dynamic urban systems is a lack of theory regarding the spatial decision behaviour of land users such as businesses, households or individuals (Wegener 1982). Analysing accessibility with spatial interaction theory and the economically rational notions was dominated in the utility maximization (Southworth 1995). Utility maximization (entropy-maximization) was introduced by Wilson (1967) and largely applied in transport modelling as a replacement gravity model. The introduction of random utility models or discrete choice models helps predict choices between alternatives as a function of assessing attributes of the alternatives, subject to stochastic discrete constraints in the transport modelling work (Domencich and McFadden 1975; McFadden 1974b). Anas (1983) clarified that the random utility model could be derived and identically estimated by the information minimizing and utility maximizing method and the behavior valid 'gravity models' can be estimated from disaggregated data on individual choices. Random utility models have been well utilized in formulating the problems of travel mode and location decisions in microeconomic consumer choice among discrete alternatives (Anas 1983). The method has been applied in transport and housing studies, for example, modelling travel behaviour and forecasting travel demands (McFadden 1974a) and testing individual's responsiveness to the level of service affecting travel mode choice (Bhat 1998). It was also highly applied in studying the housing choice and related work issues, for example, providing forecasts used to model household location decisions in relation to other choices of housing, automobile ownership and mode to work (Lerman 1976), examining the nature of residence location choice, housing tenure and workplace location in a dispersed job location area (Waddell 1993). Recently, some studies used it to examine the relationship between housing and travel mode choices, for example, modelling household location in relation to vehicle availability choice (Sermons and Seredich 2001), and assessing residents' housing location choice in terms of the distance to public transport and services (Meng et al. 2016).

The econometric modelling theory of urban land markets or bid-rent theory was originally carried out by Alonso (1964), which described both the demand side of how much people want to buy to live at each location, and on the supply side the house is assumed to be rented to the highest bidder, under the considerations of apparent character, neighbourhood and the quality of the schools in the vicinity. However, Alonso's model assumed unit location was a homogeneous product with the same price. Rosen (1974) advocated that the products are described by a vector of objectively measured characteristics which define a set of 'hedonic' prices and the market performs as a natural equilibrium between buyers' and sellers' choices. Ellickson (1981) developed a new approach in which bid price links logit equations and hedonic theory. Inverse to random utility model predicting a consumer chooses a type of location, Ellickson's model observed individual location, where the random variable is the bid from the decision maker. Lerman and Kern (1983) extended Ellickson's model into estimating willingness to pay for house attributes by utilizing the observable information on the price paid by the winning bidder. This enabled a test of conditional probability that a dwelling unit will be occupied by a household of a particular type given the characteristics of the housing structure. Based on Ellickson and Lerman and Kern's framework, Gross (1988) estimated willingness to pay for housing characteristics. He compared forecast bid-rents to actual rents, examined the demand prices and previous hedonic type housing demand research and found that the bid-rent model works as well as or better than the hedonic approach in forecasting demand for housing attributes.

The bid-rent theory and discrete choice random utility theory both support microeconomic transport and land use modelling. Martinez (1992) compared these two theories and suggested the bid and choice approaches are equivalent, consistent and inseparable. He further combined these two theories into a bid-choice theory and developed an empirical application of an integrated transport and land use called 5-LUT which consists of a bid-rent model called MUSSA and a transport model called ESTRAUS which is a four-stage static simulaneous equilibrium model of urban transport developed in 1986 by the Chilean government (Martínez 1996). The MUSSA model estimates land rents considering land availability and developer's behaviour. Its outputs of locations of activities (households and firms) can feed ESTRAUS, ESTRAUS can then calculate trip frequencies by daily periods and trip purposes. ESTRAUS' outputs of trip patterns and costs, impact on transport systems, and in turn, provide measures of accessibility for MUSSA. Recently, MUSSA was built into a Cube software system called Cube Land enabling direct interaction between MUSSA and Cube Voyager and providing the possibility of an integrated transport and land use modelling (Citilabs 2015).

Another similar application was developed by Miyamoto and Udomsri (1996), who integrated land-use, transport and the environment to design an improved model of Random Utility/Rent-Bidding Analysis (RUBRAN). The study assumed the land market consists of locators and sites; the locator chooses a site with the highest utility compared with alternative sites and must bid the highest rent among alternative locators. This explanation was similarly applied into the level of aggregated locator groups and zones. The probability of a locator group choosing a zone is this locator group who bid the highest rent in the zone and obtained by logit models. There are four levels of choice hierarchy being land use levels of location choice and destination choice, and transport levels of mode choice and route choice. The bid-rent theory is similar to MUSSA (Martínez 1996). Chang and Mackett (2006) also developed a multiclass bid-rent network model for an integrated land use and transport application. The model investigated the processes of households' location decision making and tried to achieve an equilibrium which was supported by the optimal location for each household and therefore gain an efficient urban structure.

New or upgraded transport infrastructures add value to land, making the forecasting of land value changes important for both transport and land development plans. Value capture is introduced as a financing scheme to generate revenues for urban development and is generally facilitated via the sale price of properties. In urban development, value capture includes transit ridership and real estate market demand. Successful examples can be found in Rail + Property (R + P) projects developed in Hong Kong SAR, China and Tokyo (Suzuki et al. 2013). These R + P projects demonstrated how a value capture scheme could help generate income to invest in transit development, create market demand, and to gain higher ridership and real estate returns. Studies state that value capture is determined by the perceived relationship between buyers and sellers (Bowman and Ambrosini 2000) while the urban area, transport mode, lifecycle of the transport system, and the property market are the key elements of a land value capture program (Medda 2012). The application of random utility and bid rent theories can serve as a suitable feeding system to value capture incorporating land, transport, and the property market as well as behaviour choices regarding land values. These methods also provide more reliable information and measures for the value capture process.

3 Modelling Theory

This section describes the details of random utility theory and bid rent theory.

3.1 Random Utility Model (Discrete Choice Model)

Random utility models or discrete choice models analyse individual behaviour under hypothetical choices with variable attributes. The mathematical introduction for discrete choice models always commences with the fundamental specification of the Multinomial Logit (MNL) model.

The MNL model is defined as:

$$P_{jn,s} = \frac{\exp(U_{jn,s})}{\sum_j \exp(U_{jn,s})}, j = 1, \ldots, J_{ns}, s = 1, \ldots S_n \tag{1}$$

where $p_{jn,s}$ represents the probability that individual n will select alternative j from each alternative scenarios s, where the value of each alternative to n is given by its utility function $U_{jn,s}$.

$$U_{jn} = V_{jn} + \varepsilon_{jn},\ j = 1, \ldots J, n = 1, \ldots n \tag{2}$$

where V_{jn} represents a function of the observed attributes, and ε_{jn} represents unobserved attributes. A full derivation of the MNL model and description of the utility function can be found in many papers such as Domencich and McFadden (1975), Train (2003), and Ortúzar and Willumsen (2002).

3.2 Bid-Rent Model

The bid-rent model is fully specified by stochastic Willingness to Pay (WP) functions of market agents (Martínez 1996; Martinez 1992), which are represented by

$$WP_{hvi} = WP_h(d_v, z_i; \beta_h : y_h, U_h) \tag{3}$$

which indicates individual h*'s* willingness to pay for a property with a dwelling type v located in zone I; y_h represents household income; β_h represents the set of personal preference parameters and U_h represents the maximum utility level achievable by consumer h with such income at a location described by (d, z).

The zonal spatial distribution of activities provides equilibrium when the consumer maximizes their surplus at exogenous prices in a dwelling-zone option and the consumer finally located in a given lot must be the maximum bidder in order to maximize the owner's profit. These two should be satisfied simultaneously to allow equilibrium (which is reached by accommodating households and firms in the available options then the prices enable a maximum consumers' surplus).

The consumers:

- Maximum Consumer Surplus (*CS*) at exogenous prices (*p*)

$$max_{(v,i)\in S}\, CS = max_{(v,i)\in S}\, WP_{hvi} - p_{vi} \quad \forall h \tag{4}$$

Owners:

- Maximum owner's profit

$$p_{v,i} = max_{g\in H}\, WP_{hvi} \quad \forall (v,i) \in S \tag{5}$$

Equilibrium:

- Equilibrium of the urban dwelling and land market

$$max_{(v,i)\in S}\, CS = max_{(v,i)\in S}\, WP_{hvi} - max_{g\in H}\, WP_{hvi} \quad \forall h \tag{6}$$

In the equilibrium model, change in life quality is introduced as an adjustment variable because supply and income are dependent on outside factors. Indeed, if consumer h is the best bidder at (v,i), then the price is given by h's WP value; hence, $\mathrm{CS}_{\mathrm{hvi}}$ is equal to zero; otherwise, $\mathrm{CS}_{\mathrm{hvi}}$ is less than zero.

4 Data Requirement

Data currency and quality are major problems for large-scale models. Anas (1983) stressed the use of data, its aggregation value and judgments used in specifying the explanatory attributes make many theoretically similar models function differently. In a modelling review summary, Hunt et al. (2005) pointed out that a lack of good data limits modelling capacity. The existing modelling applications have various ways of inputting and outputting data; they cannot be used as standard parts which constitute a large simulation system (Miyamoto and Udomsri 1996). In a metropolitan transport modelling review report, Taylor and Scrafton (2003, p. ii) suggested travel demand models require a combination of data resources including:

- a multi-modal network inventory database, including details of the main road network and of the public transport networks, including routes and services operating on those routes
- demographic, employment and land use data for the region, including projections of future scenarios
- personal travel demand data, including revealed preference and stated preference data
- freight movement data, and
- data for model calibration, estimation and validation, including origin-destination movements, screenline flows, and network performance variables such a travel times and delays, traffic signal settings, passenger boardings and alightings, and transit vehicle headways and service frequencies.

Revealed Preference (RP) data and Stated Preference (SP) data are important for travel demand modelling, which are mainly used indiscrete choice models. RP data are derived from real markets but selected by the decision maker's perceptions of the real market. RP data questionnaires are designed as straight forward questions to collect socio-demographic information, including age, gender, income, car ownership and travel patterns. For example, travel pattern data can be collected at a transit station by asking individuals about their current travel origin, destination, transit time or travel purpose (Louviere et al. 2000). SP data are collected by asking respondents to make choices from hypothetical choice scenarios sets which are composed by the experiment design. These scenarios need to be designed by the analyst to be as close to a realistic situation as possible. A computer program may assist in combining and allocating attributes and their levels for experiment design. Each designed choice has a different combination of attribute levels and obtains information that is available on the selected alternative as well as on the rejected ones. The stated preference approach can be used to investigate people's perception of new facilities or future scenarios that may not yet exist. The choice data for this study was selected by respondents in a household survey and is analysed in a discrete choice model.

To use the information collected on non–chosen alternatives and reflect the true choice observed over the population, it is important to combine RP and SP data sets (Earnhart 2002; Hensher et al. 2005). RP data provide the basis for comparison while SP data can supplement the RP data and thus overcome the limitations associated with RP data for choice modelling (Louviere et al. 2000). The combination of the two types of data also overcomes the limitations of each single set and helps identify estimated parameters for an optimal design (Hensher et al. 2005; Louviere et al. 2000). In estimating a model, SP data can help identify parameters that RP data could not, thereby improving the efficiency of the modelling process (Hensher et al. 2005). Great care is necessary for designing a SP survey to include the behaviour and conditions pre-existing at the study site which can be better understood through undertaking observations, such as transit station observations and focus groups. However, RP data have been known to produce biases in selecting appropriate variables and generating a choice set.

For an integrated transport and land use model, Martínez (1996) utilized a central database with a graphic interface (geographic information system) under Windows for software communication. He applied Data Base Manager using Paradox data bases with object PAL language. Its database includes households' origin-destination survey data, firms, dwellings, zones and access measures. For future development in transport and land use modelling, data base manager can be extended to SP data and other newer technologies, such as applying blue tooth data which has been utilized in collecting transport data (Bhaskar and Chung 2013). Other types of data can include, for example, to capture non-traditional travel reduction options, such as telecommuting and teleshopping, Southworth (1995) suggested applicable multi-criteria decision-making methods to capture non-traditional trips via qualitative data (Roy 1991). According to Chaaraoui et al. (2012), visual techniques are now in great demand to analyse human behavior. They suggested a pose, gaze and motion estimation to behaviour recognition, following an initially defined classification which enables a vision and multimodal-based approach for analysis.

5 Two Potential Case Study Applications

Australia shares similar modelling issues as international applications, with separated transport and land use planning systems, dated data and mostly just fit in for limited policy purpose. This section discusses the application of random utility and bid-rent theories to current Australian transport and land use models. The analyses focus on systems being used in Adelaide and Perth, making further recommendations to implement bid-rent theories into existing modelling systems. The exemplars of a recommended modelling approach are capable of overcoming current modelling shortcomings and providing multiple scenarios for strategic planning.

5.1 Adelaide's MASTEM

In South Australia, the Metropolitan Adelaide Strategic Transport Evaluation Model (MASTEM) is based in the Cube Voyager transport planning software environment (Holyoak et al. 2005). It is a policy tool for medium to long range strategic planning of metropolitan Adelaide's transport system and the estimation and assessment of travel patterns and behaviour across the network. Cube Voyager is an integrated collection of software modules that provides a travel forecasting system with capabilities in the planning of transportation systems (Citilabs 2015). It is comprised of base elements incorporating a hierarchy of models on the same platform. Based on the widely used traditional four-stage modelling process. MASTEM derives the individual trips produced and attracted throughout the study region, distributes the trip productions to the attractions, assigns the trips to a mode of travel and to a network route to identify travel from origin to destination. In addition, traffic from external loading points and freight demands are included. MASTEM allows for an assessment of environmental, economic and safety impacts as well as the development of demands for microsimulation assessment. The outputs of MASTEM are limited due to a lack of current and quality data as well as insufficient land use and transport interaction (Taylor and Scrafton 2003). Recently, Think Design Deliver examined the present models in South Australia and across Australia and New Zealand, they proposed the idea of developing an integrated transport and land use planning model (Government of South Australia 2013). The development of bid-rent land use models and integration with transport models that consider behavioural and environmental aspects are needed. A modelling framework was proposed by Meng et al. (2016) shown in Fig. 1, which demonstrates the further development of MASTEM.

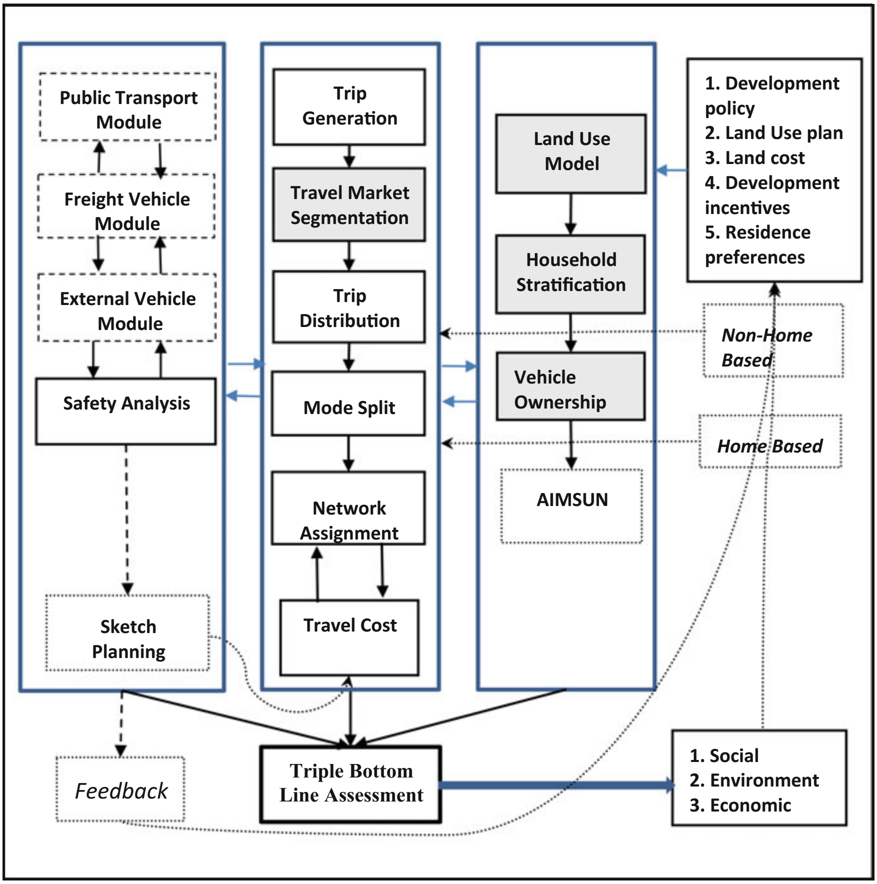


Fig. 1 Proposed Adelaide integrated transport and land use model. *Source* Meng et al. (2016)

The advantages of upgrading the current MASTEM model to an integrated transport and land use modelling system are to: create an interactive loop between transport and land use planning systems, minimize the forecast gap between land use and transport planning, reduce data collection costs while enhancing data quality ensuring efficient modelling output, and provide a land price and transport mode input into value capture for both short-and long-term strategic land use and transport planning.

5.2 Perth's PLATINUM

Perth, Western Australia, applied transport models in two departments, Planning and Main Roads, which created increased competition and duplication of effort. The modelling work has been used for cost-benefit evaluations of transport and land use projects. There has been limited integration between land use and transport models for strategic plans (Taplin et al. 2015). The recently conducted model assessment highlighted of the following issues:

- There was a broad level of support shown for the development of one integrated strategic level transport model for the Perth region;
- The current suite of transport modelling outputs from current strategic models was generally considered to be fit-for-purpose;
- Land use inputs and feedback was an issue of concern and was considered a significant risk in the successful implementation of a new strategic level transport model;
- The need for mesoscopic traffic modelling was expressed, especially for the modelling of congested areas;
- State Government should take a lead role in developing mesoscopic modelling and microsimulation modelling expertise through a Centre of Excellence approach.

In order to utilize recent modelling advances in addressing the unique contextual and growing challenges of transport modelling in Perth, Australia, Biermann et al. (2015) proposed the Perth LAnd and Transport INtegrated Urban Model (PLATINUM) to provide design options for a new and responsive model system. PLATINUM describes the process, outcomes and unique design challenges of this review and design initiative with a particular focus on path dependency and the critical choices in moving from current modelling practices to a new model system. The proposed structure of PLATINUM can be seen in Fig. 2. Like the MASTEM of South Australia, Western Australia uses Cube Voyager for transport modelling, and the application of bid-rent theory for land use modelling is appropriate.

The proposed PLATINUM development would comprise the achievement of a five-step, tour-based multi-modal strategic transport model, providing a single integrated strategic level transport model for the Perth region, interacting between

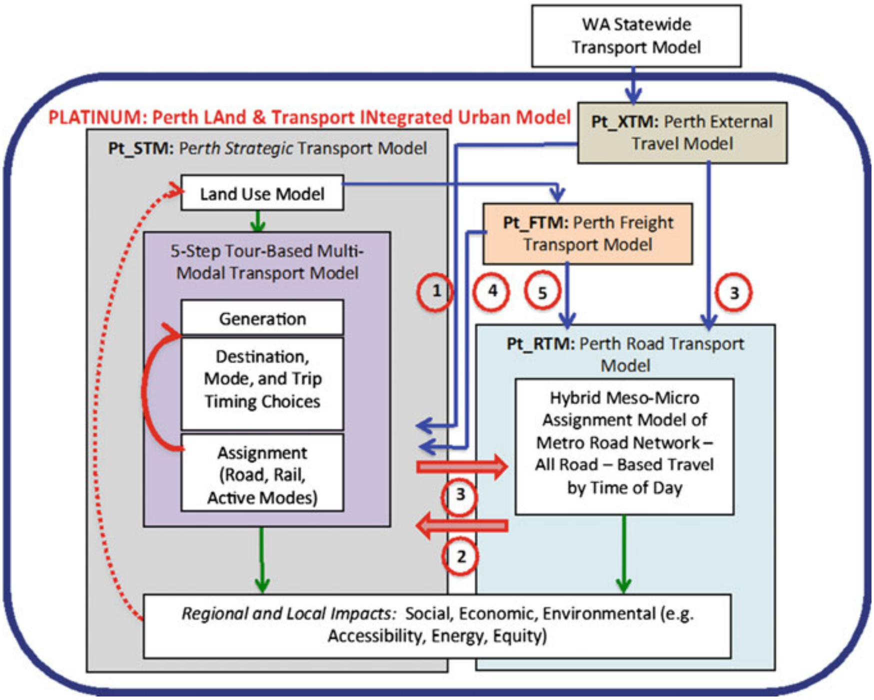


Fig. 2 Proposed structure of the proposed Perth Land and Transport INtegrated Urban Model (PLATINUM). *Source* Biermann et al. (2015)

transport and land use models. It could also provide an output to a regional impacts model and produce hybrid mesoscopic and microscopic simulations.

Both of the proposed systems require improved data, including RP and SP (experiment design applied) data as well as combining other potential sources discussed in Sect. 4.

6 Discussion and Conclusion

Transport and land use planning face challenges to include multi-policy objectives, such as social, economic and environmental objectives. The historical methods of transport modelling use simple estimated zonal activities and functions to analyse road capacity, safety aspects are no longer sufficient to simulate households' discrete travel preferences and the estimated impacts from complex social, economic and environmental policy objectives. The combination of bid-rent theory and random utility theory is capable of creating a dynamic link between changes in land use and travel mode choices to feed into an integrated estimation system for transport and land use policy making. There is a need for data base management that incorporates different forms of data sets, in addition to original RP data, newer data sets including SP data, blue tooth data, and/or qualitative data, for communication between transport and land use models. The combined theories are recommended for both case studies of Adelaide and Perth. The investigation of the shortcomings of the two case studies contributes to an understanding of the new theories and could achieve an optimal solution.

Taylor (1991, p. 169) commented: 'there is no one universal model. Different problems and applications require different models because the level of detail needed in model output and the demands for valid input data vary between applications'. When used as a key component of decision-support systems, transport models are expected to be capable of helping planners resolve often competing energy, environmental, fiscal, social and economic goals, as well as integrating transportation planning decisions into broader and longer range analyses of land use. In addition, the modelling strategy should be determined largely by the questions being asked. Often models are more about disciplined and rigorous testing of data both RP and SP to provide information for society and policymakers. The modelling results are important to persuade politicians and convince a group with qualitative preferences that the decision theory used will assist the group in arriving at a decision, including intangible values such as comfort, desirability and other social effects (Saaty 1990). These intangibles have to be at the bottom of every interpretation, which needs relative scales to serve as a standard, such as the demands for travel into numbers of temporally and spatially explicit vehicular trip volumes and the impacts of a science of scaling based on mathematics, philosophy and psychology. Some transport models have focused to resolve some of these additional requirements in relation to sustainability, such as Kii and Doi (2005), and to special services, such as para-transit services by Bradley and Koffman (2012).

References

Alonso, W. (1964). *Location and land use*. Cambridge, MA: Harvard University Press.

Anas, A. (1983). Discrete choice theory, information theory and the multinomial logit and gravity models. *Transportation Research Part B: Methodological, 17*(1), 13–23. http://www.sciencedirect.com/science/article/pii/0191261583900231

Bhaskar, A., & Chung, E. (2013). Fundamental understanding on the use of Bluetooth scanner as a complementary transport data. *Transportation Research Part C: Emerging Technologies, 37,* 42–72.

Bhat, C. R. (1998). Accommodating variations in responsiveness to level-of-service measures in travel mode choice modeling. *Transportation Research Part A, 32*(7), 495–507.

Biermann, S., Olaru, D., Taplin, J. H., & Taylor, M. A. P. (2015). Pragmatic incremental or courageous leapfrog [Re] development of a land-use and transport modelling system for Perth, Australia. In S. Geertman et al. (Eds.), *Planning Support Systems and Smart Cities* (pp. 489–506). New York: Springer.

Bowman, C., & Ambrosini, V. (2000). Value creation versus value capture: Towards a coherent definition of value in strategy. *British Journal of Management, 11*(1), 1–15.

Bradley, M. A., & Koffman, D. (2012). *Improving ADA Paratransit Demand Estimation: Regional Modeling*. Transportation Research Board.

Chaaraoui, A. A., Climent-Pérez, P., & Flórez-Revuelta, F. (2012). A review on vision techniques applied to human behaviour analysis for ambient-assisted living. *Expert Systems with Applications, 39*(12), 10873–10888.

Chang, J. S. (2006). Models of the relationship between transport and land-use: A review. *Transport Reviews, 26*(3), 325–350.

Chang, J. S., & Mackett, R. L. (2006). A bi-level model of the relationship between transport and residential location. *Transportation Research Part B: Methodological, 40*(2), 123–146.

Citilabs. (2015). http://www.citilabs.com Mountain View. California, USA.

Domencich, T. A., & McFadden, D. (1975). *Urban travel demand-a behavioral analysis*. North-Holland & American Elsevier. Oxford and New York. http://emlab.berkeley.edu/~mcfadden/travel/front.pdf

Earnhart, D. (2002). Combining revealed and stated data to examine housing decisions using discrete choice analysis. *Journal of Urban Economics, 51*(1), 143–169. http://www.sciencedirect.com/science/article/pii/S0094119001922417

Ellickson, B. (1981). An alternative test of the hedonic theory of housing markets. *Journal of Urban Economics, 9*(1), 56–79.

Government of South Australia. (2013). *Setting directions and coordinating outcomes: Integrating transport*. http://www.thinkdesigndeliver.sa.gov.au/__data/assets/pdf_file/0005/139613/Setting_Directions_and_Coordinating_outcomes_Integrating_Transport.pdf

Gross, D. J. (1988). Estimating willingness to pay for housing characteristics: An application of the Ellickson bid-rent model. *Journal of Urban Economics, 24*(1), 95–112.

Hamin, E. M., & Gurran, N. (2009). Urban form and climate change: Balancing adaptation and mitigation in the U.S. and Australia. *Habitat International, 33*(3), 238–245. http://www.sciencedirect.com/science/article/pii/S0197397508000659

Hanley, N., & Spash, C. L. (1993). *Cost-benefit analysis and the environment*. Edward Elgar Cheltenham.

Hensher, D. A., Rose, J. M., & Greene, W. H. (2005). *Applied choice analysis: A primer*. Cambridge, UK: Cambridge University Press.

Holyoak, N., Taylor, M. A. P., Oxlad, L., & Gregory, J. (2005). Development of a new strategic transport planning model for Adelaide. *Papers of the 28th Australasian Transport Research Forum*, Sydney. http://patrec.org/atrf.aspx

Hunt, J. D. (1997). *A description of the MEPLAN framework for land use and transport interaction modelling*. University of Calgary.

Hunt, J. D., Kriger, D. S., & Miller, E. J. (2005). Current operational urban land-use–transport modelling frameworks: A review. *Transport Reviews, 25*(3), 329–376.

Iacono, M., Levinson, D., & El-Geneidy, A. (2008). Models of transportation and land use change: a guide to the territory. *Journal of Planning Literature, 22*(4), 323–340.

Kii, M., & Doi, K. (2005). Multiagent land-use and transport model for the policy evaluation of a compact city. *Environment and Planning B: Planning and Design, 32*(4), 485–504.

Kleinhans, R. (2004). Social implications of housing diversification in urban renewal: A review of recent literature. *Journal of Housing and the Built Environment, 19*(4), 367–390.

Lee, J. D. B. (1973). Requiem for large-scale models. *Journal of the American Institute of Planners, 39*(3), 163–178.

Lerman, S. R. (1976). Location, housing, automobile ownership, and mode to work: A joint choice model. *Transportation Research Record, 610,* 6–11.

Lerman, S. R., & Kern, C. R. (1983). Hedonic theory, bid rents, and willingness-to-pay: Some extensions of Ellicksons results. *Journal of Urban Economics, 13*(3), 358–363.

Louviere, J. J., Hensher, D. A., & Swait, J. D. (2000). *Stated choice methods: Analysis and applications*. Cambridge, UK: Cambridge University Press.

Martínez, F. (1996). MUSSA: Land use model for Santiago city. *Transportation Research Record: Journal of the Transportation Research Board, 1552*(1), 126–134. http://dx.doi.org/10.3141/1552-18 http://trb.metapress.com/content/u35602wp7uw367m3/fulltext.pdf

Martinez, F. J. (1992). The bid—choice land-use model: An integrated economic framework. *Environment and Planning A, 24*(6), 871–885.

McFadden, D. (1974a). The measurement of urban travel demand. *Journal of Public Economics, 3*(4), 303–328. http://pigpen.utc.uic.edu/pigpen/kazuya/UPP560/Wk7/McFadden_The_Measurement_of_Urban_Travel_Demand.pdf

McFadden, D. (1974b). Conditional logit analysis of qualitative choice behaviour. In P. Zarembka (Ed.), *Frontiers in econometrics* (pp. 105–142). New York: Academic Press.

Medda, F. (2012). Land value capture finance for transport accessibility: A review. *Journal of Transport Geography, 25*(11), 154–161. http://www.sciencedirect.com/science/article/pii/S0966692312002116

Meng, L., Somenahalli, S., Allan, A., Pieters, J., Deng, X., Wilson, J., & Zuffery, C. (2016). Integrated transport and land use modelling for Metropolitan Adelaide. University of South Australia.

Meng, L., Taylor, M. A. P., & Scrafton, D. (2016). Combining latent class models and gis models for integrated transport and land use planning—A case study application. *Urban Policy and Research*, 1–25. http://dx.doi.org/10.1080/08111146.2015.1118372

Miyamoto, K., & Udomsri, R. (1996). An analysis system for integrated policy measures regarding land-use, transport and the environment in a metropolis. *Transport, Land-Use and the Environment* (pp. 259–280). New York: Springer.

Ortúzar, Jd D., & Willumsen, L. G. (2002). *Modelling transport* (3rd ed.). New York: Wiley.

Putman, S. (1983). *Integrated Urban Models.* London: Pio Limited.

Rosen, S. (1974). Hedonic prices and implicit markets: product differentiation in pure competition. *Journal of Political Economy, 82*(1), 34–55.

Roy, B. (1991). The outranking approach and the foundations of ELECTRE methods. *Theory and Decision, 31*(1), 49–73.

Saaty, T. L. (1990). How to make a decision: The analytic hierarchy process. *European Journal of Operational Research, 48*(1), 9–26. http://www.sciencedirect.com/science/article/pii/037722179090057I.

Sermons, M. W., & Seredich, N. (2001). Assessing traveler responsiveness to land and location based accessibility and mobility solutions. *Transportation Research Part D: Transport and Environment, 6*(6), 417–428.

Southworth, F. (1995). A technical review of urban land use–transportation models as tools for evaluating vehicle travel reduction strategies.

Suzuki, H., Cervero, R., & Iuchi, K. (2013). *Transforming cities with transit: Transit and land-use integration for sustainable urban development*. World Bank Publications.

Taplin, J., Taylor, M. A. P., & Biermann, S. (2015). *Transport modelling review*. Planning and Transport Research Centre (PATREC).

Taylor, M. A. P. (1991). Traffic planning by a “Desktop Expert”. *Computers, Environment and Urban Systems, 15*(3), 165–177.

Taylor, M. A. P., & Scrafton, D. (2003). *Travel demand modelling for metropolitan Adelaide report to the SA department of transport and urban planning*, Transport System Centre.

Thompson, W. R. (1965). *Preface to urban economics*. United States: Johns Hopkins Press.

Train, K. E. (2003). *Discrete choice methods with simulation*. Cambridge, UK: Cambridge University Press.

Waddell, P. (1993). Exogenous workplace choice in residential location models: Is the assumption valid? *Geographical Analysis, 25*(1), 65–82.

Waddell, P. (2002). UrbanSim: Modeling urban development for land use, transportation, and environmental planning. *Journal of the American Planning Association, 68*(3), 297–314. http://www.urbansim.org/pub/Research/ResearchPapers/UrbanSim-JAPA.pdf

Waddell, P., & Ulfarsson, G. F. (2004). Introduction to urban simulation: Design And Development of Operational.

Wegener, M. (1982). Modeling urban decline: A multilevel economic-demographic model for the Dortmund region. *International Regional Science Review, 7*(2), 217–241.

Wegener, M. (1994). Operational urban models state of the art. *Journal of the American Planning Association, 60*(1), 17–29.

Wilson, A. G. (1967). A statistical theory of spatial distribution models. *Transportation Research, 1*(3), 253–269.

Woolcock, M. (1998). Social capital and economic development: Toward a theoretical synthesis and policy framework. *Theory and society, 27*(2), 151–208.

Chapter 16
The Mode Most Traveled: Transportation Infrastructure Implications and Policy Responses

Tayo Fabusuyi and Robert C. Hampshire

Abstract Using the United States Census Public Use Microdata Sample (PUMS) dataset, we documented the severity of the disparity in commuting pattern across the contiguous US. The analysis was complemented by a more granular analysis with the Greater Pittsburgh area as the geographic area of focus. In addition to the locational variation in travel mode obtained using population estimates derived from the PUMS dataset, the dataset was utilized for a discrete choice model that generated detailed commuting profiles for the region's workforce, showing statistically significant differences not only by socio-economic attributes but more importantly, by commuters' place of abode. Policy levers that could address travel mode shift are discussed primarily with regards to changing population and its impact on transportation resources and the onset of fully autonomous vehicle in transportation networking companies' space—a subject of key topical interest given the choice of the city as the test bed for Uber's driverless ride sourcing services.

Keywords Travel mode · Commuters · Public Use Microdata (PUM) · Discrete Choice Model (DCM) · Marginal effects

1 Introduction

A disproportionate number of Americans drive to work alone. At the state level, the figure ranges from a low of 58% in New York to 85% in Alabama.[1] The disparity in commuting patterns is however, more pronounced within states. In California, the

---

[1] These figures including the subsequent ones for states and cities were all obtained by generating population estimates from the microdata sample set from the US Census using (2015) data.

T. Fabusuyi (✉) · R.C. Hampshire
Transportation Research Institute (TRI), University of Michigan, Ann-Arbor, MI, USA
e-mail: fabusuyi@umich.edu

R.C. Hampshire
e-mail: hamp@umich.edu

S. Geertman et al. (eds.), *Planning Support Science for Smarter Urban Futures*, Lecture Notes in Geoinformation and Cartography,
DOI 10.1007/978-3-319-57819-4_16

percentage of commuters who drive alone to work as a percentage of all commuters across the US Census public use microdata (PUM) area[2] ranges from 27% for PUM area code 2203 in San Francisco to 84% for PUM with area code 3302 in Fresno County. Finer segmentation of mode choice reveals negligible variation in the percentage of commuters who carpool although significant differences exist in the percentage of commuters that used the public transit system—a reflection of the differences in the availability of transit services across these geographical areas.

The enormity of this realization begs a host of questions. What factors explain the disproportionate proportion of Americans that drive alone and what sort of policy responses are required to effect a change in travel behavior? What are the transportation infrastructure implications of the observed travel mode behavior and in what way can we collectively, as a society, transition to a more sustainable situation? How critical will these issues be in the coming years given the increased trend in urbanization, the disruptive nature of innovative technologies and the linkages between travel mode and other societal objectives such as reducing pollution, congestion and greenhouse gas emissions?

Our research efforts speak to these questions. In addressing them, we use a two part empirical study that conducts a broad scan of travel behavior by computing population estimates for commuters' travel mode behavior across the United States (US) and for the Greater Pittsburgh area, generates detailed commuting profiles for the region's workforce. Policy levers that could address travel mode shift are discussed primarily with regards to changing composition of the region's workforce population and its impact on transportation resources and the onset of fully autonomous vehicle in transportation networking companies' space—a subject of key topical interest given the choice of the City of Pittsburgh as the test bed for Uber's driverless ride sourcing services.

The balance of the chapter is organized as follows. Section 2 addresses both inter and intra-state variations in commuters' travel mode across the US. The section uses the state of California as an example to showcase the significant differences in travel mode behavior even within states. The third section focuses on a fine grained analysis of the City of Pittsburgh workforce travel behavior. The analysis also includes the examination of the sensitivity of different segments of the workforce to travel mode choices given changes in the covariates of interest. The policy relevance of the analyses are discussed in Sect. 4. The last section recaps and offers guidance on how the study's approach could be replicated in other cities.

2 Locational Variation

In order to show the magnitude and the widespread variation in travel behavior across the US, we carried out a broad environmental scan of the travel behavior of commuters across the contiguous US and documented both inter and intra state

---

[2] A PUM area is a geographically designated enumeration unit by the US Census with a population in excess of 100,000 but below 200,000 residents.

variation in travel behavior. Our analysis utilized the 2015 US Census PUMS population records to generate population estimates of commuters' transportation modes. In calculating the estimates, we employ two types of weights: person weight and replicate weights. The person weight is required for the point estimates and both person weight and the replicate weights are needed to calculate the standard errors. Fay's variant of the Balanced Repeated Replication (BRR) method was utilized in calculating the standard errors (Fay 1995). Fay's approach, called the Modified Half Sample (MHS) improves on the BRR by addressing the problem of perturbed weights and decreased sample size using an adjustment factor called the Fay coefficient. This coefficient was set to 0.5 for the PUMS data. Building on the sampling variance:

$$\hat{V} = \frac{\sum_{i=1}^{N} (X_i - X)^2}{N}, \tag{1}$$

Fay's MHS variance equals:

$$\hat{V}_{mhs} = \frac{1}{(1-m)^2}\hat{V} = \frac{1}{(1-m)^2}\frac{\sum_{r=1}^{N} (X_r - X)^2}{N} \tag{2}$$

where $\boldsymbol{m}$ is the Fay's coefficient, $\boldsymbol{X_r}$ the replicate estimate and $\boldsymbol{X}$, the full sample estimate. Since the PUMS person records file has $\boldsymbol{N} = 80$ replicates and $\boldsymbol{m} = 0.5$, the expression above reduces to:

$$\hat{V}_{mhs} = \frac{\sum_{r=1}^{80} (X_r - X)^2}{20} \tag{3}$$

Table 1 shows the point estimates of the percentage of drivers who commute to work unaccompanied relative to all commuters for the contiguous US. Excluded from the analysis are all US territories and the states of Hawaii and Alaska. Across the 48 states analyzed, the percentage of commuters who drive solo relative to all commuters varies from a low 58% in New York to 85% in Alabama. Ten each, of

Table 1 Percentage who drive to work alone—*left* (best), *right* (worst)

State	%	State	%
New York	57.5	Alabama	85.2
Massachusetts	70.7	Mississippi	84.4
Oregon	71.4	Tennessee	83.4
Montana	71.6	Ohio	83.0
Washington	72.8	Indiana	82.9
California	72.9	Michigan	82.5
New Jersey	72.9	Oklahoma	82.4
Maryland	74.0	Arkansas	82.0
Illinois	74.2	West Virginia	82.0
Colorado	75.2	South Carolina	81.5

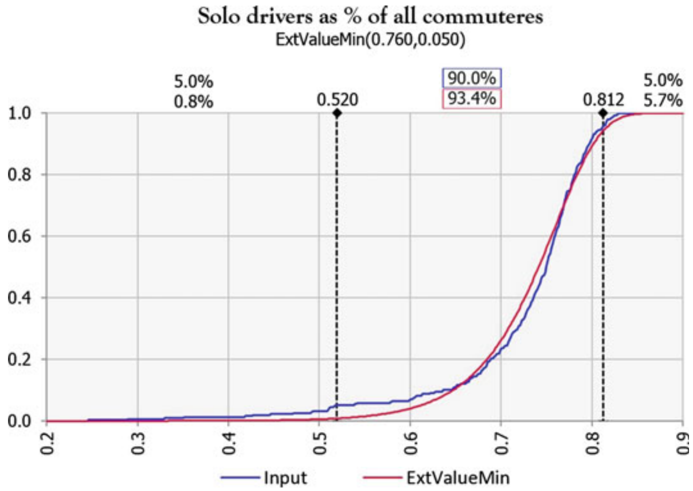


Fig. 1 Solo drivers as a percentage of all commuters

the best and worst performing states are listed in Table 1. New England and states from the coastal areas fare better compared to states from the South and the heartlands that are disproportionately represented at the other end of the spectrum.

The disparity in commuting pattern is however more pronounced within states as shown in Fig. 1. Focusing on California and using a PUM area as the unit of analysis, we obtained point estimates of commuters who drive alone to work as a percentage of all commuters across PUM area in California ranging from a low of 27% for PUM area code 2203 in San Francisco to a high of 84% for PUM with area code 3302 in Fresno County. The charts were obtained by fitting point estimates generated for each PUMS area to a distribution function. The best fit, chosen based on the Akaike or the Bayesian information criteria measures (Vrieze 2012), was the extreme value distribution. The charts provide the feasible space of the possible realization of percentages of individuals who drive solo relative to the total commuting population for PUMS areas. In our analysis for California, only four PUMS areas out of a total of 233 have less than 30% unaccompanied drivers relative to all commuters ratio. All these PUMS are in the San Francisco Bay area.

3 Travel Mode Population Estimates

The locational variation analysis sets the stage for a more detailed analysis on the Greater Pittsburgh area with a focus on the City of Pittsburgh given that it is the region’s workhorse. Our approach to the travel mode analysis examines commuters primarily, a decision informed by the City of Pittsburgh’s relatively high workforce to residents’ population ratio and the attendant problems related to traffic flow and parking spaces it creates. Of the 15 comparable cities analyzed in an earlier study (Fabusuyi and Hampshire, Needs Assessment for the Integrated Parking Application Project 2013), the City of Pittsburgh, bar none, has the highest workforce to resident population ratio. For every 100 residents, Pittsburgh has 92 workers while Tucson occupies the other end of the spectrum at 43 workers for every 100 residents. In addition, Pittsburgh's workforce population of 278,959 (United States Census Bureau Center for Economic Studies 2015) is predominantly made up of out of city residents by a 3:1 ratio.

We begin by examining data on the means of transportation and vehicle occupancy for both the City of Pittsburgh and Allegheny County, the surrounding county from which the city's workforce predominantly reside. We subsequently abstract from the results obtained by making the assumption that the commuting pattern of employees who work in the City but are not resident there are no different compared to the figures obtained for workers in the Greater Pittsburgh area excluding Pittsburgh. In the same vein, we have made the assumption that the home to work travel pattern of workers who live and work in the city is not any different compared to the proportionate figures for workers who reside within the City of Pittsburgh.

Table 2 provides estimated magnitudes and the associated errors at the 90% confidence interval level. These figures were generated from the 2015 US Census PUMS population records (United States Census Bureau 2015). The PUMS dataset provides an excellent resource for understanding commuting patterns at sub-regional level, a feat that was not possible in the past given the relatively small sample of existing surveys. Of the total number of city employees who live in Pittsburgh, the analysis shows that about 86,700 commute to work either by car, truck or van.

Estimates and the associated margins of errors were also calculated for individuals who used the public transit system and those whose place of work is in close proximity to home. Finally, we have disaggregated the population that commute to work by car, truck or van by looking at vehicle occupancy. The analysis was done using three cohorts of vehicle occupancy—individuals who drive

Table 2 Journey to work relative to place of above ('000)

	City of Pittsburgh	Greater Pittsburgh (Excluding city of Pittsburgh)
Means of transportation	Population estimates and 90% confidence interval	Population estimates and 90% confidence interval
Car, truck or Van	86.7 ± 2.46	397 ± 4.09
Drive solo	75.0 ± 2.21	359 ± 4.07
2 person carpool	10.2 ± 1.06	32.6 ± 1.71
3 or more	1.60 ± 0.33	5.16 ± 0.71
Public transit system	26.1 ± 1.37	27.1 ± 1.42
Walked/worked at home	31.1 ± 2.18	39.0 ± 2.45

alone; 2 person carpools and 3 or more person carpools. For Pittsburgh residents, 86% of those who drove did so unaccompanied compared to 90% for the same subset of the working population for the rest of the Greater Pittsburgh area.

Using these proportionate representations, we estimate that 208,000 commute-related vehicles ply the city's roads on any workday. The estimate was obtained by dividing the number of vehicles by the occupancy number while taking a conservative view by assuming that maximum occupancy for any vehicle is three. Our analysis reveals that a change in the city's workforce composition that achieves parity between in-city and out of city resident commuters will reduce the number of vehicles put on the road on any working day by close to 20,000. This could be achieved through an improvement in the quality of the school district and a more favorable city's income and property tax rates.

4 Travel Mode Commuting Profile

The travel mode population estimates are complemented by a more granular analysis that generates commuting profile based on contributory factors for the identified Pittsburgh's workforce population segments—city and non-city residents. In determining the contributory factors that explain travel mode choice by commuters, we borrow from the typical discrete choice models that are based on random utility theory (Manski and Lerman 1977) using the expression below:

$$V_{ij} = \beta X_i + \in_{ij} \tag{4}$$

V_{ij} represents the indirect utility function, and X_i represents a vector of the individual's characteristics. The individual will choose the travel mode for which V_{ij} is the highest. Therefore, the probability that an individual i chooses mode j will be:

$$\begin{aligned} P_{ij} &= Pr(V_j > V_k) \quad \forall j \neq k \\ &= Pr(\beta_j X_i - \beta_k X_i) > \in_{ik} - \in_{ij} \end{aligned} \tag{5}$$

The expression above constitutes the basic premise of the Discrete Choice Model (DCM). The pioneering work on DCM was McFadden's (1974) seminal article. It is assumed that rational individuals are exercising an option out of a set of alternatives, each with a series of attributes from which the individuals derives or enjoys some utility. Implicit in this assumption is that the utility is derived from a deterministic function and measurable. However, there are uncertainties and to reflect this reality, probabilities are used to describe travel mode preferences. In calculating these probabilities, there is an observable portion that could be characterized by the attributes of the travel mode; the commuters' characteristics and the interactions between the modes' attributes and commuters' characteristics. The unobservable portion that capture the uncertainties is subsumed underneath the error term which is assumed to have some well-behaved randomness that is independently and identically distributed with a Gumbel distribution. Given this assumption, $\left(\in_{ik} - \in_{ij}\right)$ will have a logistic distribution. If;

$$V_{ij} = \begin{cases} 1 & \text{for } V_{ik} \leq V_{ij} \\ 0 & \text{otherwise} \end{cases} \tag{6}$$

and given the assumptions of the error term, the parameters of the utility model could be estimated using a multinomial logistic model as shown below:

$$\Pr\left(V_{ij}\middle|_j\right) = \frac{\exp(\beta_j X_i)}{\sum_{i=0}^{j-1} \exp(\beta_j X_i)} \tag{7}$$

An appreciable volume of literature within the body of work on commuters' travel mode choice revolves primarily around driving unaccompanied. Ferguson (1997) identified economic factors responsible for this: more cars per capita due to an increase in average wealth; a decrease in gas prices; and an increase in the education level of the average worker. Bhat and Sen (2006), in a model of work mode choice, found that income, number of vehicles per worker, work duration and employment density are all significant variables in the decision to drive solo. Other studies, with strong neighborhood characteristics themes such as Thakuriah et al. (2005) and Waddell et al. (2002) incorporate land use policies and job location decisions.

A number of these studies have been carried out using PUMS data or by utilizing PUMS data in combination with other datasets. Examples include the 2000 PUMS data that was employed by Blumenberg and Shiki (2007) to examine the travel mode choices of the foreign-born population of California. PUMS data has also been used to show differences in commuting pattern across gender (Krizek et al. 2004), (Weinberger 2007); in the analysis of access to job opportunities (Hu and Giuliano 2011); and for land use policies (Haas et al. 2006).

Our analysis for the present study is based on the population records for the 2015 1 year US Census PUMS dataset merged with household records. Variables employed for the analysis include commuter related variables—Economic well-being, Sex, Race, Education attainment, Geographical Location, Pre-teen kids; trip and mode related variables—travel duration, time of travel, travel mode choice and interaction (including squared) terms: The economic wellbeing, measured relative to the federal poverty level of each state analyzed, was dropped given that it is highly correlated with education attainment. The observed travel mode choice, which is the dependent variable, is reclassified into four broad categories: Non-motorized and bi-pedal options; Public Transit; Car-Pool; and Drive Alone.

We empirically test what determines travel mode choice by running a multinomial logistic regression. However, for conciseness we only present the marginal

Table 3 Marginal effects of selected variables on travel mode choice

	City residents		Non-city residents	
	dy/dx[a]	p-value	dy/dx	p-value
Prob (Non-motorized travel mode) City-resident = 0.138, Non-city resident = 0.038				
Non-motorized				
Travel Time	−0.101	(0.000)***	−0.030	(0.000)***
Household vehicle	−0.060	(0.000)***	−0.022	(0.000)***
Education attainment	−0.064	(0.060)*	−0.014	(0.105)
Prob (Public-transit travel mode) City-resident = 0.204, Non-city resident = 0.061				
Public-transit				
Travel time	0.203	(0.000)***	0.108	(0.000)***
Household vehicle	−0.088	(0.000)***	−0.036	(0.000)***
Education attainment	0.257	(0.149)	0.140	(0.261)
Prob (Car-pool travel mode) City-resident = 0.088, Non-city resident = 0.085				
Car-pool				
Travel time	0.024	(0.111)	0.035	(0.023)**
Household vehicle	−0.011	(0.017)	−0.025	(0.000)***
Education attainment	−0.030	(0.339)	−0.016	(0.571)
Prob (Drive solo travel mode) City-resident = 0.570, Non-city resident = 0.815				
Drive solo				
Travel time	−0.125	(0.000)***	−0.113	(0.000)***
Household vehicle	0.158	(0.000)***	0.082	(0.000)***
Education attainment	−0.163	(0.188)	−0.110	(0.276)

[a] Marginal change represents a change of one standard deviation at the mean
*Significant at the 0.10 level, **at the 0.05 level and ***at the 0.01 level

estimates in Table 3. The findings show that irrespective of the commuter's residence, a standard deviation increase at the mean for travel time increases the commuter's preference for using the public transit option though the change in magnitude is almost twice for city residents compared to non-city resident commuters. The same change in travel time is also associated with a decrease in preference for both the non-motorized and driving solo mode options irrespective of the commuter's place of abode. Excluding the travel mode for driving solo, an increase in household vehicle ownership leads to a decrease in the preference for all other travel modes though the coefficient for car-pooling is not significant for city residents. A marginal change (Long and Freese 2014), equivalent to one standard deviation increase at the mean for years of formal education, which also proxies the wealth effect, leads to statistically significant decrease in the preference for the non-motorized or car-pooling travel options and an attendant statistically significant increase in driving solo for both commuter types.

We further show the differences between city and non-city residents by examining the marginal effects not only at the mean, but by graphing the probabilities of a commuter exercising specific travel mode options based on the control variable of interest. This allows us to determine how responsive these individuals are to modifying their travel mode preferences as a result of a marginal increase in an explanatory variable. The chart, presented in Fig. 2, provides a more readable option and shows the stark contrasts by where commuters are resident by stacking on the same graph the responsiveness of each of the broadly defined group to changes in the explanatory variables. We explore a dimension of the variation by comparing individuals who are city residents to those who are not across all samples to ascertain if there are differences in sensitivities to determinants of travel mode choice using travel time, years of schooling and household vehicle ownership as the explanatory variables with the other variables held at the mean. However for brevity, we only show the results of the analysis with regards to travel time.

Figure 2a–d provides the commuting profile of the City of Pittsburgh working population with respect to the travel time with other regressors held at their mean values. Starting from the top left hand side and moving in a clockwise direction, the first two charts provide a condensed view of the travel mode profiles across the mode options with city residents on the left and non-city residents on the right.

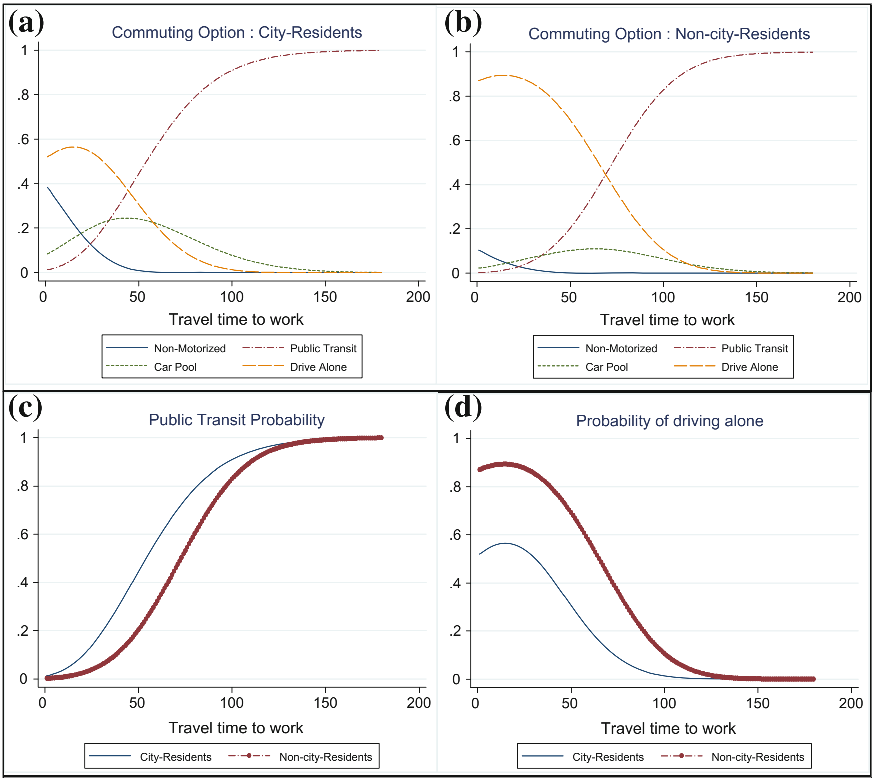


Fig. 2 (**a**–**d**) (clockwise, starting from the *top left*) Commuting profile for city and non-city residents with respect to travel duration

A couple of observations with regards to Fig. 1a–b seems apt. From mere eyeballing, the travel mode options are dominated primarily by both public transit and driving solo, particularly for non-city resident folks. Irrespective of the duration of the commute, the cumulative probability of these two options is typically in excess of 85%. In addition, relative to non-city dwellers, an appreciably higher proportion of city residents use both the non-motorized and car-pooling options, more so, for travel time less than one hour. The non-motorized and car-pooling options barely register a blip for non-city residents.

A more detailed outlook in Fig. 2c–d shows that the preference for public transit by city residents dominates that of non-city residents. However, the reverse is the case for the probability of driving alone with the preferences across the two cohorts converging for commute duration in excess of two hours. At all realization of the commute duration, a non-city resident has a higher probability of driving solo compared to a city resident though it would appear that the difference observed in the travel mode preference is driven more by shifters, more so for the first two hours of commute time, as compared to differences in the travel time coefficient estimates given the similar gradient of the curves—an observation that is lent further credence from the marginal effect figures from Table 3.

5 Policy Relevance

Most of the transportation challenges related to peak traffic flows and dearth of parking spaces within the City of Pittsburgh could be traced to two sources—events and work related. Instead of having an overarching plan, often driven by a regional transportation strategy, that seeks to optimize the whole transportation ecosystem, we make a case for an adaptable, demand side policy prescription. Not only do such policies come with a cheaper price tag but more importantly, if properly designed, could be effective in surgically targeting the system's binding constraints. We have classified the policy recommendations into two sections—those related to leveraging existing legacies and those that are private public partnership driven programs. Although informed, in part, by the Pittsburgh environment, these recommendations are applicable in other cities. Having said this, they will be most effective if they are properly modified to capture the local realities of the environment in which they will be implemented.

5.1 Leveraging Existing Legacies

The city at present has a predictive parking app, ParkPGH (Fabusuyi et al. 2013), (Fabusuyi et al. 2014) and one of the key insights we obtained from the series of discussions we had with stakeholders is how best to leverage the parking app in order to improve its effectiveness with regards to shifting the populace towards utilizing a multi-modal transportation system. The mode shift will not only influence how individuals demand parking spaces but more importantly, impact their travel demand pattern. This is achieved by allowing drivers to proactively plan their trips and explore the options available to them. A patron going to the Cultural District to see a matinee show in a week's time could use the long term predictive component to calculate the probability of finding a parking space. In a similar light, an individual who is heading downtown from Oakland in an hour or two could use the short term module to make a decision whether to drive or head to the East busway station to catch a bus. However, the benefits of the predictive module go beyond the demand side. On the supply side, garage operators could use the predictive information to better manage their facilities. For example, a predicted higher than normal demand for parking spots could allow a garage operator to artificially increase the facility's capacity by making provisions for valet parking. Further downstream, the information provided by the predictive module could be used to dynamically price parking spaces.

Another feasible option is relaying the information provided by the integrated parking application project to the public using variable message signs (VMS). This strategy could be implemented at very low cost but with high impact. Using information obtained from the city's workforce composition that shows that more than 210,000 out of city residents commute to Pittsburgh on any work day, we could target this population using the major transportation arteries. Figure 3 shows the City of Pittsburgh's workforce heat map overlaid with the City's major transportation routes. In deciding on where the VMS could be strategically placed,

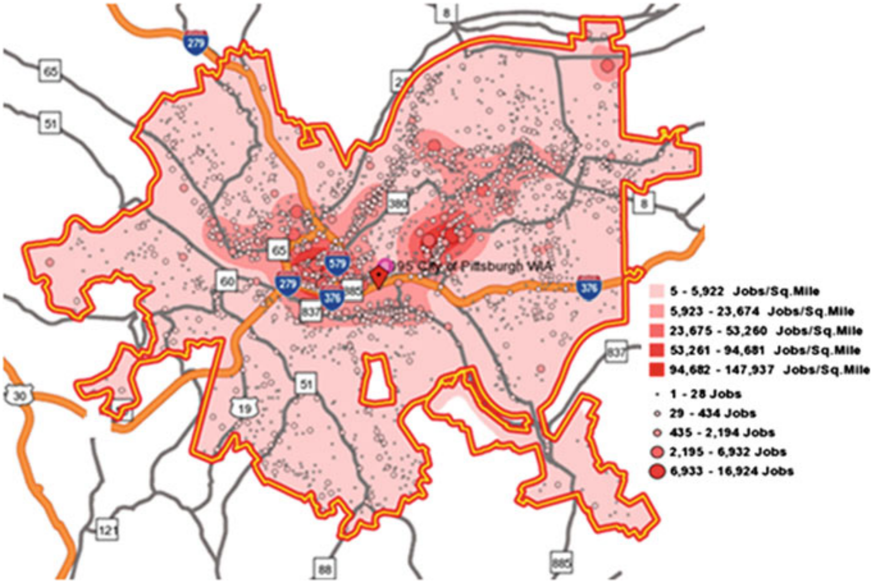


Fig. 3 Heat map of the City of Pittsburgh overlaid with major transportation routes

we used data from the US Census longitudinal employer household dynamics (US Census Bureau 2014) interactive tool that showed that close to 60,000 commuters use Interstate 376 to get to work while Route 28 and Interstate 279 account for approximately 70,000 of the commuting population on any work day. This provides insight on potential routes to use in displaying parking availability information.

An example of the insight could be a commuter coming from the North Hills[3] via 1–279 or Route 28. Assuming the capacity downtown is already maxed-out, the VMS could display a message saying "*Parking spaces downtown full. Proceed to the North Shore*". Commuters could subsequently drive to the North Shore, park at one of the garages and take the *T* Connector to downtown. This mode of thinking could be extended city-wide using fringe parking facilities that function as Park & Ride outlets. There are discussions in the nascent stage that may better facilitate this —for example, the lojacking of port authority buses and extending the T Connector to the South Shore. These developments along with displaying ParkPGH parking information through VMS not only has the potential to address parking situation, it could also go a long way towards reducing the heavy traffic often observed in some parts of the city.

5.2 Innovative Public Private Partnership (3P) Programs

Of late, there has been a number of transportation related programs implemented using public private partnerships. Examples of these programs with minimal footprint include "*first mile, last mile*" arrangements between cities and Transportation Network Companies (TNCs)—the partnership between Uber and the Town of Summit in New Jersey being one of many. However, in Pittsburgh more cutting edge technology is being piloted with potential of upending urban mobility. Developments of this nature underscores the need to rethink what the near future portends for travel behavior, traffic flow and demand for parking spaces particularly in urban areas in light of the disruptive technologies that drive them.

It is safe to assume that the advent of peer-to-peer mobility juxtaposed with driverless vehicles will radically change the prevailing landscape. As these innovations become more mainstreamed, the reduction in car ownership and increased ride sharing could lead to significant number of parking spaces being repurposed for totally different economic activities, substantially altering the urban landscape. Having said this, it is not entirely unreasonable to argue that this development may exert a contradictory effect given the potential for increased urban Vehicle Miles Travelled (VMT).

Apart from the leading TNCs making investment in these frontier technologies, more incremental products such as car-pooling, whose effectiveness has improved

---

[3] The North Hills refer collectively to Pittsburgh's northern suburbs and is made up of approximately 40 townships and boroughs.

considerably in the past year due to better matching and routing algorithms have the potential of influencing individuals' travel mode preferences, an impact that will scale non-linearly with the network size. As a critical mass of vehicles become self-driving and the public increasingly embraces travel behavior that is peer-to-peer mobility driven, we leave it to the reader's imagination how this transformation could influence the demand for parking spaces and the menu of options and the quality of offerings afforded to consumers. It also underscores the need to revisit the need for long term strategic plans whose designs are premised on the assumption that the underlying causal system that existed in the past will remain invariant into the future. The literal use of the phrase—may you live in interesting times, could not be more apt.

6 Conclusion

Using the 2015 US Census Public Use Microdata (PUM) Sample dataset, we conducted a broad scan of travel behavior by computing population estimates for commuters' travel mode behavior for the United States and found appreciable variation across geographical areas measured either across or within states. Within the continental United States, the percentage of commuters who drive solo relative to all commuters varies from a low 58% in New York to 85% in Alabama. However, the disparity in commuting pattern is even more pronounced within states. For example, the percentage of commuters who drive alone to work as a percentage of all commuters across PUMS area in California ranges from 27% for PUM area code 2203 in San Francisco to 84% for PUM with area code 3302 in Fresno County. Finer segmentation of mode choice reveals negligible variation in the percentage of commuters who carpool although significant differences exist in the percentage of commuters that used the public transit system—a reflection of the differences in the availability of transit services across the geographical areas.

Given that transportation policies are decided at local levels, the research effort was complemented by a more granular analysis using the Greater Pittsburgh area as a test bed. An appreciable degree of the empirical analysis is directed at commuters and the rationale for this is the need to focus on daytime parking when most of the peak demands were observed, a direct result of the composition of the city's workforce and the associated commuting habits. Pittsburgh's workforce to residential population ratio is 0.92, the highest of all the cities analyzed. On any workday, Pittsburgh's daytime population increases to 463,000. This net gain of 155,000 is as a result of workers commuting to the city and is equivalent to more than 50% increase in the city's overall population.

In addition to the population estimates derived from the PUMS dataset, the dataset was utilized for a discrete choice model that generated detailed commuting profiles for the region's workforce, showing a stark difference not only by socio-economic attributes but more importantly, by abode location, providing credence to the population estimates earlier derived. The pressure that this puts on city parking is enormous, and is expected to increase given Pittsburgh's favorable workforce growth trend and this realization underscores the fact that a supply side response may not be viable given the magnitude of the financial constraints involved in increasing parking supply.

Our analysis examines policy levers that could address travel mode shift with regards to changing workforce composition and its impact on transportation resources, particularly given the onset of autonomous vehicle in the transportation networking companies' space—a subject of key topical interest given the choice of the city as the test bed for Uber's driverless ride sourcing services. Our findings question the use of long term regional transportation plans, that are typically biased towards supply side policies related to the provision of transportation infrastructure and instead, make the case for more adaptable, demand side policy prescriptions that could incentivize the public to exercise more socially optimal travel modes. Particularly noteworthy is the ease with which the approach could be replicated in other cities and the use of US Census data provides a common data source that allows for comparative analysis.

References

Bhat, C., & Sen, S. (2006). Household vehicle type holdings and usage: An application of the multiple discrete-continuous extreme value (MDCEV) model. *Transportation Research Part B, 40*(1), 35–53.

Blumenberg, E., & Shiki, K. (2007). Transportation assimilation: Immigrants, race and ethnicity, and mode choice. In*86th Annual Meeting of the Transportation Research Board.*

Fabusuyi, T., & Hampshire, R. (2013). *Needs assessment for the integrated parking application project*. Pittsburgh: Carnegie Mellon University/University of Pennsylvania University Transportation Center.

Fabusuyi, T., Hampshire, R. C., & Hill, V. (2013). Evaluation of a smart parking system. *Transportation Research Record: Journal of the Transportation Research Board, 2359*(1), 10–16.

Fabusuyi, T., Hampshire, R., Hill, V., & Sasanuma, K. (2014). Decision analytics for parking availability in downtown Pittsburgh. *Interfaces, 44*(3), 286–299.

Fay, R. (1995). *VPLX: Variance estimation for complex surveys*. Bureau of US Census: Program Documentation.

Ferguson, E. (1997). The rise and fall of the American carpool: 1970–1990. *Transportation, 24,* 349–376.

Haas, P., Makarewicz, C., Benedict, A., Sanchez, T., & Dawkins, C. (2006). *Housing and transportation cost trade-offs and burdens of working households in 28 Metros*. Chicago, IL: Center for Neighborhood Technology.

Hu, L., & Giuliano, G. (2011, January 23–27). Beyond the inner city: A new form of spatial mismatch. In *Proceedings of the 90th Annual Meeting of the Transportation Research Board.*

Krizek, K., Johnson, P., & Tilahun, N. (2004, November 18–20). Gender differences in bicycling behavior and facility preferences. In *Conference Proceedings 35 Research on Women's Issues in Transportation.*

Long, S., & Freese, J. (2014). *Regression models for categorical dependent variables using stata* (Third ed.). College Station, TX: Stata Press.

Manski, C. F., & Lerman, S. R. (1977). The estimation of choice probabilities from choice based samples. *Econometrica: Journal of the Econometric Society, 45*(8), 1977–1988.

McFadden, D. (1974). The measurement of urban travel demand. *Journal of Public Economics, 3* (4), 303–328.

Thakuriah, V., Sriraj, P., Soot, S., Liao, Y., & Berman, G. (2005). Activity and travel changes of job access transportation service users: Analysis of a user survey. *Transportation Resarch Record: Journal of the Transportation Research Board, 1927*, 55–62.

U.S. Census Bureau. (2014). *Quarterly Workforce Indicators Data. Longitudinal-Employer Household Dynamics Program*. Retrieved from http://lehd.ces.census.gov/data/#qwi

United States Census Bureau. (2015). *Public use microdata sample (PUMS) dataset*. Retrieved from http://www.census.gov/acs/www/data_documentation/pums_data/

United States Census Bureau Center for Economic Studies. (2015). *Longitudinal Employer-Household Dynamics*. Retrieved May 13, 2014 from http://lehd.ces.census.gov/

Vrieze, S. I. (2012). Model selection and psychological theory: A discussion of the differences between the Akaike Information Criterion (AIC) and the Bayesian Information Criterion (BIC). *Psychological Methods, 17,* 228–243.

Waddell, P., Outwater, M., Bhat, C., & Blain, L. (2002). Design of an integrated land use and activity-based travel model system for the puget sound region. *Transportation Research Record: Journal of the Transportation Research Board, 1805*, 108–118.

Weinberger, R. (2007). Men, women, job sprawl and journey to work in the Philadelphia Region. *Public Works Management and Policy, 11*(3), 177–193.

Chapter 17
An Integrated Demand and Carbon Impact Forecasting Approach for Residential Precincts

Nicholas Holyoak, Michael Taylor, Michalis Hadjikakou and Steven Percy

Abstract Estimation of the demand of an urban precinct, related to Electricity, Transport, Waste and Water (ETWW), is a necessary step toward the delivery of quality living environments where daily activities can be conducted in a sustainable manner. A forecasting model that concurrently links demand in all four aforementioned domains to carbon emissions can assist planning agencies, infrastructure providers, operators and private developers to deliver low-carbon urban precincts in the future. Integration of modelling methodologies delivers improved ability, accuracy and flexibility when compared to typical forecasting approaches. This chapter details the outcomes of recent research efforts on the development of an integrated ETWW demand estimation tool with detailed scenario forecasting abilities. Focusing on the residential components of the precinct, modelling outputs provide detailed estimations of household demands and resulting carbon impacts across the four domains. Impacts of non-residential land uses including high-value industry, retail, commercial and open space are also considered and reported on. Model users can estimate the carbon impact of resident population changes, various household structure types, carbon-friendly technologies and climate change for precinct locations across Australia. In addition, the tool accounts for interactions

---

N. Holyoak (✉)
School of Computer Science, Engineering and Mathematics, Flinders University,
Tonsley, SA, Australia
e-mail: Nicholas.Holyoak@flinders.edu.au

M. Taylor
School of Natural and Built Environments, University of South Australia, Adelaide,
SA, Australia
e-mail: Michael.Taylor@unisa.edu.au

M. Hadjikakou
Sustainability Assessment Program, School of Civil and Environmental Engineering,
University of New South Wales, Sydney, NSW, Australia
e-mail: M.Hadjikakou@unsw.edu.au

S. Percy
Department of Electrical and Electronic Engineering, The University of Melbourne,
Parkville, VIC, Australia
e-mail: Percy@student.unimelb.edu.au

S. Geertman et al. (eds.), *Planning Support Science for Smarter Urban Futures*, Lecture Notes in Geoinformation and Cartography,
DOI 10.1007/978-3-319-57819-4_17

with external infrastructure such as transport networks, off-site waste disposal, water supply locations and grid-based energy supply. Forecasting abilities of the model are demonstrated through case-study applications that reflect of ‘what-if’ type scenario investigations, important to policymaking and planning for future urban development. The user is ultimately able to explore combinations to achieve a low-carbon precinct development.

Keywords Precinct · Demand · Energy · Transport · Waste · Water

1 Background

Forecasting the future demands associated with residential precincts is a necessary process to deliver adequate services and resources whilst minimising the subsequent carbon impacts, expressed as Carbon Dioxide equivalent (CO_2-e), during the everyday activities of the population. Accurate forecasting processes need to account for not only the physical attributes of the built environment and technologies but also the nature of residential population types. Household demands associated with the Energy, Transport, Waste and Water (ETWW) domains have significant impacts on the overall carbon production associated with the precinct as a whole. This is especially relevant as interactions between these core domains occur whilst residents conduct activities within and from the home. Planning agencies, private developers, infrastructure providers and operators all stand to benefit from a detailed, accurate and integrated demand forecasting approach based on readily available input data sources. A forecasting tool based on this approach will assist in the delivery of residential precincts with lower carbon production into the future.

A number of forecasting and software tools already exist in the individual ETWW domains with a range in application scale, operational ease and purpose. Newton et al. (2013) detail a study into design assessment tools for precincts, concluding that most existing demand estimation procedures in assessment tools “are rudimentary and lack transparency (in relation to algorithms used, model assumptions and baseline data)” and identified a need to “provide more advanced and scientifically validated models for use in precinct assessment tools”. The ETWW model seeks to address these issues.

Electricity demand forecasting has been summarised in numerous review articles including Torriti (2014) and Ahmad et al. (2014). The unique climates and behaviours in different geographical locations means that location specific models need to be developed. In Australia, tools such as the CSIRO, Housing Stock model (Ren et al. 2013) is capable of simulating residential demand, although this tool is limited by requiring highly detailed data for demand simulations, this data is often not available for a new development. As result a new tool has been developed in this project and is discussed in detail by Percy et al. (2015). In the water domain, tools such as Innovyze (Sourghali and Pugh 2016) and SimulAlt demand-supply water simulation model (Government of South Australia 2011) establish water demand forecasts, whilst established strategic transport demand models such as MASTEM (Holyoak et al. 2005) and software packages like Cube (Citilabs 2011) provide modelling and simulation potential. Few household-level municipal waste production forecast software models exist with most approaches based on unique research applications.

Many of these forecasting tools and approaches draw on common data input requirements such as socio-demographic and household variables, even if their forecasting methods differ. Despite there being many individual domain models there exists no integrated modelling framework developed to capture the interactions that exist between these domains with respect to demand and subsequent carbon impact. As a result, the CRC for Low Carbon Living research program 2 addresses this problem.

This chapter provides an overview of outcomes from a research effort into forecasting for integrated demands and carbon impacts of a precinct in the energy, transport, waste and water (ETWW) domains. A major contribution of this research is the development of an integrated demand estimation approach that allows for the accurate estimation of the core ETWW demands and subsequent carbon impacts at a household and at a precinct level. The approach also identifies commonalities in data requirements and model formulation between the four forecasting domains. In this way overall carbon impacts of urban developments or redevelopments can be assessed more accurately, effectively and efficiently. Resulting demand forecasting can account for the integrated impacts of solar energy generation and battery storage, increased water recycling and rainwater use, alternative transport fuels including electric vehicles and strategies to encourage increased recycling behaviour and the transport of waste. Climate change effects are also considered directly through future year temperature and precipitation estimates and indirectly through changes to the water supply mix or seasonal needs for energy and water. This research is funded by the CRC for Low Carbon Living Ltd supported by the Cooperative Research Centres program, an Australian Government initiative.

2 Modelling Process and Components

This modelling framework applies forecast techniques to estimate carbon and associated impacts from urban precincts. For an accurate assessment of the ultimate carbon impacts of the precinct, model applications not only need to consider the spatial location of the precinct but also the physical 'built' attributes and the population that reside and conduct activities within it. Physical attributes of the precinct with respect to support infrastructures, the boundary definition or size of the precinct and location within Australia are required in preparation for the development of detailed input data sets.

Operation of the model involves definitions for precinct variables, the operation of internal and external routines, application of data management and display

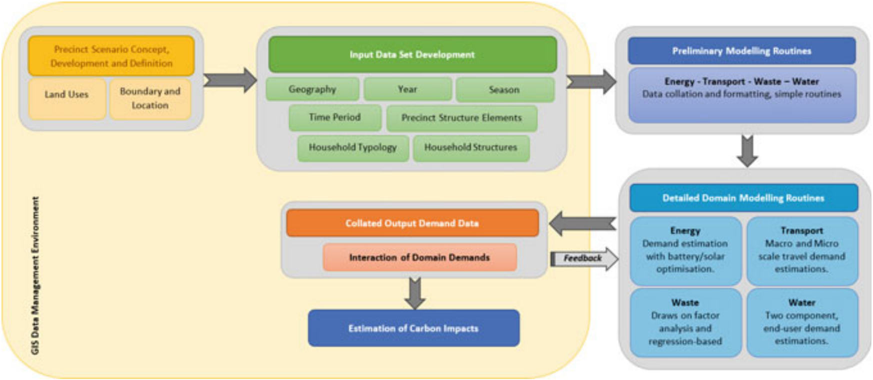


Fig. 1 ETWW model operational flowchart

environments and the development of output summaries as depicted in Fig. 1. Research conducted in the individual ETWW domains has produced much of the model 'engine' with integration between domains and feedback processing loops. It also utilises a GIS environment which is useful in the management of data and for processing and display purposes associated with input and output data archives, including the final demand and carbon impact results.

Precinct scenario definition is the first step in the ETWW model development and operation with the need for details on the precinct 'concept' including spatial attributes such as the physical size and location, allocation of land uses and connections to transport networks. Strategic planning information for precinct developments over time, such as master-plan resources and policy or economic development strategies can be utilized in the initial forecast scenario definitions. Scenario consideration is essential for the model to recognise key interactions and demand forecasting parameters that are delivered to external modelling routines.

Following on from this, input data can then be assembled and fed into preliminary and detailed domain modelling processes.

Feedback routines allow for inter-domain interactions to occur with final collated outputs providing a basis for the estimation of carbon and cost impacts. Connections to Geographic Information System (GIS) operations assist with necessary precinct definition, data management and output prsesentation operations.

3 Input Data Development

Modelling processes in the ETWW tool require a compilation of common sets of input data components required to operate the individual forecasting routines in the energy, transport, water and waste domains. Some data may be specific to individual domains (such as the transport network configuration), with other core inputs (such as number of household residents), having multiple domain applications. Recognising that the main focus of the ETWW tool is residential forecasting, greatest attention is paid to defining the household in detail with other simplified inputs for non-household related land uses that are regarded as precinct structure elements including green space, road networks, commercial and other land uses. Timing components including the forecast year/s, the season and forecast period are defined allowing for recognition of potential climate change. Defined resident population typologies align with Mosaic household typologies developed by Experian (2013) and household structures relate to the physical attributes of the household, including floor space allocation, number of bedrooms and solar generation capacity.

4 Forecasting Processes

Preliminary modelling processes perform elementary routines associated with data preparation and support procedures for the detailed domain modelling applications. Along with these simple routines are more involved forecast processes for the demands of non-residential land uses. Simplified principles for the domain modelling development and application are provided herein with greater detail for all modelling processes identified in Holyoak et al. (2016).

4.1 Non-residential Land Uses

Energy consumption for non-residential land use bases forecast estimates on the developed floor area dedicated to the land use type. A range of activity types including retail, commercial and education are recognized in this process with resources such as those provided by Commonwealth of Australia (2012) and the US Energy Information Administration (2016), assist in developing these demand forecasts. Solar production potential is derived from the allocated roof area dedicated to solar PV production and PV performance characteristics.

Water demand estimates are estimated in a similar manner with forecasts derived from floor area dedicated to land use activity types. Consumption characteristics from Sydney Water (2016) provide Australian-based demand estimates for this non-residential domain. Waste generation for the precinct is estimated with the use of resources developed by the Department of Sustainability, Environment, Water, Population and Communities (2013) for a range of activity types and waste types. Following on from waste volume estimates, energy and carbon production associated with waste treatment is forecast with the assistance of Zero Waste SA (2012) and DOE (2014). Transport domain forecasts for both residential and non-residential land uses are estimated simultaneously with the use of external Strategic Transport Modelling (STM) routines, as detailed in following sections.

4.2 Energy

Electricity use in the residential sector is a major contributor to CO_2 emissions. The time varying magnitude of electricity demand in a home is dependent on many factors, such as: outdoor temperature, appliance ownership and the demographic composition of the precinct (Torriti 2014). Demand forecasting for the energy domain utilises machine learning (statistical) models which involve training an algorithm to generalise forecast processes to a known dataset. The resident and demand datasets are normally obtained from smart-meters and resident surveys. Once the algorithm is trained, a new input dataset can be provided to the model to simulate an electricity demand. Percy et al. (2015) and Holyoak et al. (2016) detail model formulation and data requirements of the energy model, these include: demographic, appliance ownership, building type, occupancy, and outdoor temperature. These inputs are defined within the common repository of data inputs for all ETWW forecast processes.

Hourly demand forecasting is necessary to investigate how solar and battery systems can be used to reduce the grid imported energy, emissions and the resultant impacts on the electricity network (Kavgic et al. 2010; Suganthi and Samuel 2012). Hourly electricity demand profiles will be aggregated to provide the desired resolution for total kilowatt-hour (kWh) values to be interacted with other ETWW domains. Resulting CO_2-e impacts are estimated with the Scope 2 emission factors (DOE 2014) which directly relate grid-based energy supply to carbon impact.

4.3 Transport

Transport demand forecasting in urban regions is a well-researched field with widely applied behavioural modelling techniques utilised for strategic planning purposes (Ortúzar and Willumsen 2011; Holyoak 2003). Forecast models such as the Metropolitan Adelaide Strategic Transport Model (Holyoak et al. 2005) and the Sydney Strategic Transport Model (NSW BTS 2011) have capabilities in representing behavioural change through numerous estimation techniques. When connecting with these models (Fig. 1) the ETWW forecasts are provided with strategic-level transport demands. Precinct-level demand estimations from the STM are based on the precinct structure definition, and are linked to the greater metro region represented in the STM during the forecast process. Estimates of travel kilometres performed by precinct residents recognise multiple modes, peak period effects including congestion, travel on various road types and travel performed both within and beyond the precinct. Holyoak et al. (2016) provides greater detail on this process with resulting transport demands by private and public motorized modes and alternative forecast modes such as electric vehicles based on the repository of population, residential and other land use data common across all forecast domains. An advantage of utilising existing STM's in the forecasting process is the provision of both residential and non-residential travel demand estimates for the precinct used in subsequent carbon impact estimation routines.

For the transport domain, research reported by Iankov (2016) has determined detailed CO_2-e estimation routines involving the development of generic emission rates for vehicle traffic loads that are highly applicable to Australian conditions. This research has also determined the uptake of fuel efficient technologies, including hybrid electric vehicles, plug-in hybrid electric vehicles, battery electric vehicles and fuel cell vehicles in the future light vehicle fleet, useful in forecasting scenario assessment.

4.4 Water

The right choice of water demand forecasting model depends on several factors such as the specific setting, the spatial and temporal scale, and the nature and quality of the available dependent variables (Donkor et al. 2014; House-Peters and Chang 2011). For the ETWW model, the need for a long-term forecast (20-year horizon) able to consider climate, household characteristics, water supply mix and electricity mix in addition to possible interventions, meant that a multivariate statistical model was the ideal type of water demand model. Additionally, in order to accurately quantify water-related energy and carbon emissions necessitates an end-use forecasting component, as hot water use and rainwater contribution/offset have a significant impact on overall water-related energy. Using historical (for the period 2011–2015) panel (longitudinal) data for mains water, rainwater and hot water use in addition to monthly weather data (average maximum temperature and total monthly rainfall) and household characteristics derived from survey data, three linear mixed models were developed to forecast monthly total water demand, hot water demand and rainwater contribution (Holyoak et al. 2016). Recent literature provides support for linear mixed models (panel data approaches) combining fixed and random effects as these tend perform better than multiple linear regression models with only fixed effects (Arbués et al. 2003; Polebitski and Palmer 2010).

A figure representing energy use for water supply depends greatly on the water supply mix in any given locality, with the best available data for each main city used to arrive at the best possible estimate (Cook and Gregory 2012; Marchi et al. 2014). Note also that the water supply source mix for Australian cities also tends to be climate dependent, with demand in drier years being met through increasing reliance on non-conventional water resources such as desalination and water reuse schemes (Cook and Gregory 2012). Relating water demand to energy use and subsequent carbon impact looks to Scope 2 emission factors (DOE 2014) which directly relate grid-based energy supply to carbon impact.

4.5 Waste

Waste generation forecast estimates for the residential precinct components are estimated in a similar manner to the non-residential with acquired residential survey data and waste removal datasets supporting precinct estimation techniques. Waste volume estimates, energy and carbon production associated with waste treatment is forecast with the assistance of Zero Waste SA (2012) and DOE (2014). Household production of wastewater is recognised as part of water domain estimates.

5 Forecast Domain Integration

Domain forecasting processes draw on a common set of assembled input data, with database format including spatial dimensions and potential links to GIS mapping for ease of interpretation and representation. Initial outputs produced by the external forecasting routines are classified as 'first-pass' output and are used for initial demand estimations and the determination of interaction data necessary for inter-domain connections. First-pass data define the overall consumption and production demand profile of the precinct, focussing on households as the residential precinct component.

Demand estimations identified to exert influence on each other are very much dependent on the scenario parameters and applied through the application of information feedback routines. This is an important and significant component of this modelling process. Feedback routines between the collated data allow for demand interactions and their influence the forecasting process. Re-estimations of domain forecasts will then account for the influence of other domains on consumption and production profiles to reflect scenario definitions. The ETWW model structure allows for relationships that can potentially exist between the domains as interacting precinct demand forecast scenarios. It is possible to represent and assess these in terms of their resultant carbon impact through the ETWW model as scenarios that specify technological/built environment and resident activity interaction types between the domains identified in Table 1.

One example of an interaction between forecast domains is that which exists between the transport and energy in an electric vehicle scenario. Transport demands that include the use of electric vehicles must first be established in order to estimate the electrical energy required to fully or partially charge the electric vehicle batteries required for a day's travel. This additional energy requirement from the precinct household can then be incorporated into the energy demand model with supply of this energy possible from mains or solar produced power. Revised demand profiles then bring about the need for model re-estimations, with updates of modelling inputs supplied by the feedback routine.

Table 1 Scenario types and domain interactions

Scenario interaction option	Interacting domains
Electric vehicle ownership and use	Transport-energy
Hot water use	Water-energy
Evaporative cooling	Water-energy
Rainwater tank water use	Water-energy
Wastewater	Waste-water
Activities from home	All domains
Water consumption	Water-energy
Recycling activity	Waste-transport-energy
Water supply	Water-energy
Waste removal	Waste-transport
Energy use	Energy
Solar panels	Energy
Battery storage	Energy
Grid energy generation	All domains

In addition to the scenario interaction types, the structure and development of domain modelling routines allow for the representation of the following technologies and attributes of precinct structure, both at the household and precinct scale:

- Solar electricity generation,
- Battery electricity storage,
- Energy efficient devices,
- Energy supply from renewables,
- Water saving devices,
- Water capture and wastewater re-use,
- Alternative hot water systems,
- Water-efficient green areas,
- Waste recycling techniques and technologies,
- Public transport and non-motorised network alternatives.

Scenario definitions allow the user to specify selected technologies, activities and interaction context but also, the model structure and input data types also make it possible to assess other external and internal influences on carbon production. The use of Mosaic household resident types can allow for the assessment of a different resident household population. Climatic conditions can also be varied for the future forecast year to assess low, likely and high degrees of change to average temperature and precipitation, again with or without changes to the included technologies and policy strategies.

Performance of various technologies and policy strategies can be investigated under different usage and climatic conditions. Modelling scenarios can help to determine which combination may be offer the best policy and technology solution in terms of demand and carbon impact for a future precinct population. Forecast demands from the detailed domain models are collated and assembled as precinct consumption and production estimates. Again, the focus is on the households and household typologies with other land uses also accounted for in a more aggregate fashion. Following this process, final demand profiles can be submitted to carbon estimation routines.

6 Tonsley Precinct Application

Adelaide's Tonsley precinct, a location situated approximately 11 km South-West of Adelaide CBD in South Australia is chosen for the case study scenario applications. Strategic precinct or masterplan information (Government of South Australia 2013) is used to firstly develop the land use allocations in the precinct as illustrated in Fig. 2.

6.1 Forecasting Scenario Development

There are two forecast scenarios for the year 2035 with specific interaction attributes included to demonstrate model operation and domain interaction.

Scenario 1 represents a baseline condition for the 2035 mixed-use precinct structure with the entire residential area developed containing 862 households in the North-Western sector of the precinct (Fig. 3) with associated attributes (Table 2).

All house structures in Tonsley have comparable floor area, with varying distribution of floor space and notably PV panels per household. Residence type 1 are built to a height of 3 floors with the entire single house structure occupying all floors. Such residential structures are typical of those in the in the Lights View development in metropolitan Adelaide. Residence type 2 are built to a height of 4 floors with entire single house structures existing on two floors in a similar manner to residential structures in the Luminaire development in Bowden, Adelaide. Residence type 3 are taller structures built to a height of 6 floors with entire single house structures existing over two floors in a similar manner to the Park Central residential structures in Bowden, Adelaide. A complete build-out of other land uses includes (Table 3):

- Commercial,
- Educational,
- High Value Industry,
- Open Space,
- Car parking,
- Mixed use,
- Retail,
- No Designation,
- Roof space

Road, cycle and walk networks are included with connections to public transport and the forecast represents 24 hour demand forecasting for a typical weekday in the month of October. The scenario also applies Scope 2 DOE (2014) emissions rates for grid energy supply, and utilises current waste dump and recycling locations. In

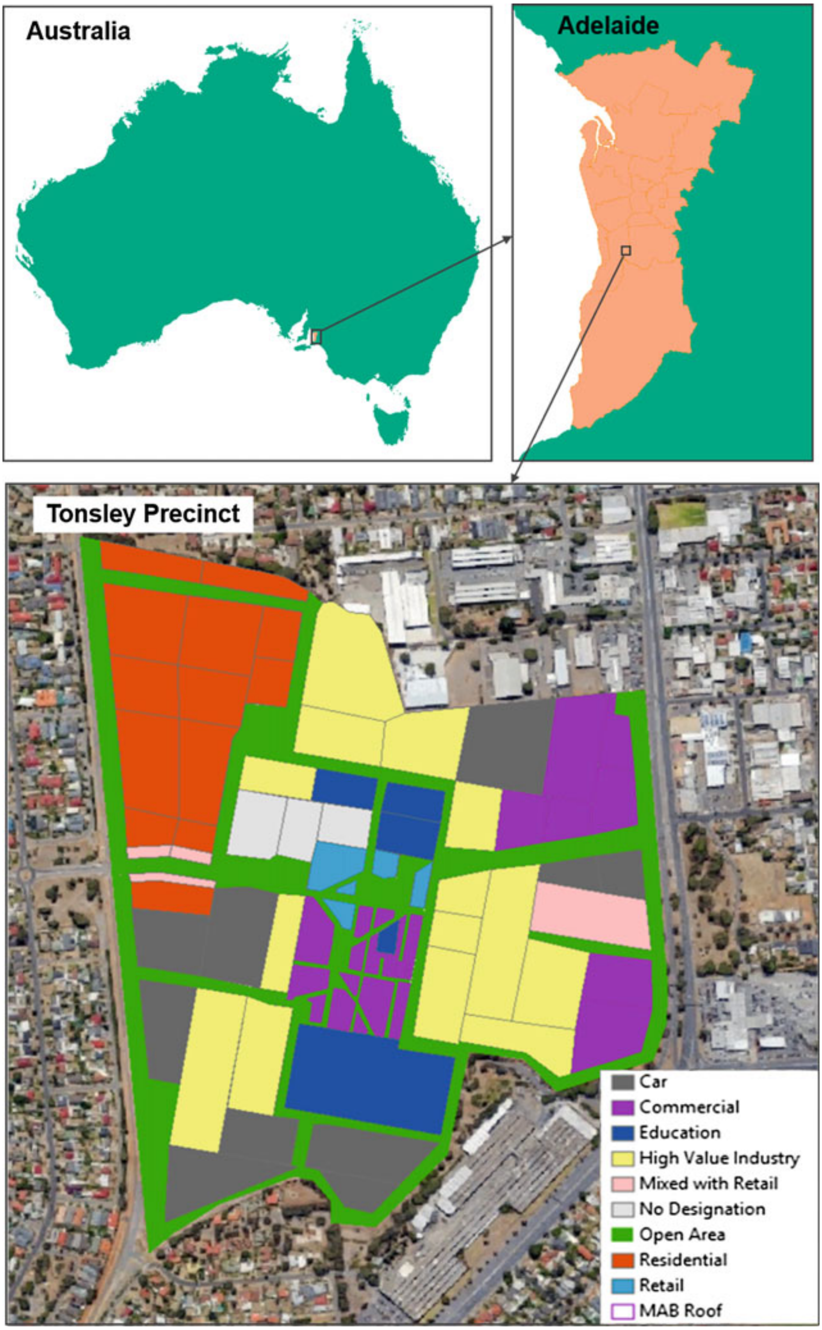


Fig. 2 Configuration of Tonsley land uses according to available strategic precinct information

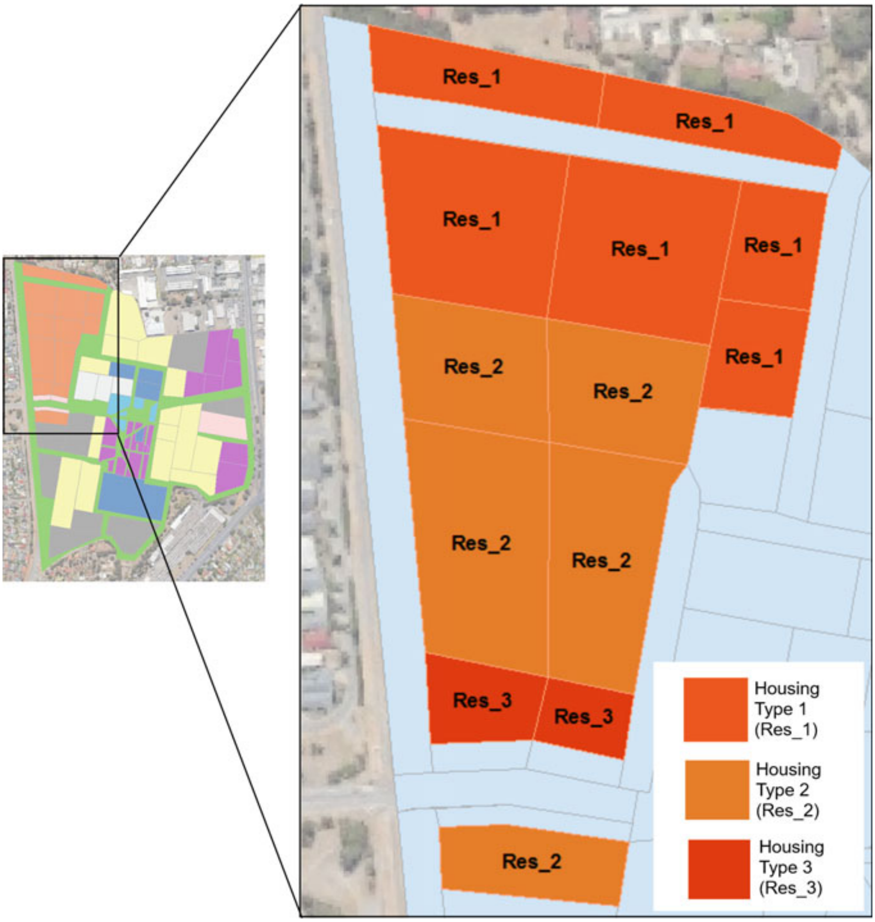


Fig. 3 Detail of the Tonsley residential development components

this base condition, no scenario options (Tables 4 and 5) are applied. Total land area is of the entire site, including green areas, roads and public space is 601,363 m^2.

Resident typologies applied to both Tonsley precinct development scenarios are presented with the relevant Mosaic Codes in the following Table. Mosaic household resident typologies (Experian 2013) provide the ETWW model with user data with the ability to represent the household resident type, selected as one of 49 unique segments, each with a representative Mosaic identification code. These typologies classify individual Australian households based on a range of socio-demographic and lifestyle attributes (Table 3).

Table 2 Resident housing structure types with associated attributes

Attribute	Housing type 1	Housing type 2	Housing type 3
Residence type code	Res_1	Res_2	Res_3
Reference building	Lights view	Luminaire	Park central
Residence footprint	44.5 m^2	140 m^2	130 m^2
Floors	3	1	1
Total floor area	151 m^2	145 m^2	130 m^2
Bedrooms	2	2	2
Bedroom area	18%	22%	25%
Living area	28%	27%	30%
Kitchen area	11%	12%	12%
Wet area	5%	6%	6%
Green area	2%	4%	3%
Carpark area	15%	17%	14%
Other area	19%	12%	10%
Rainwater storage	1	1	1
PV panels	4	4	2
Cooker, fridge	1, 1	1, 1	1, 1
Aircond, waterheater	1, 1	1, 1	1, 1
Washer, dryer	1, 1	1, 1	1, 1
Shower, toilet	1, 1	1, 1	1, 1

Note Residence Type Codes relate to those identified in Fig. 3

Table 3 Scenarios 1 and 2 mosaic resident typologies

Mosaic ID	Mosaic resident type description
C10	Stylish pursuits
C11	Inner city aspirations
C12	Wireless and wealthy
C13	Professional views
C14	Leased lifestyles
H30	Cultural fusion
I34	Roaring twenties
I35	University diversity
K38	Sensible seniors

For scenario 1, the total precinct resident population is 1923 and residential land area allocation 89,982 m^2.

Scenario 2 mirrors the Scenario 1 conditions detailed in the previous model application with the same land uses and resident population, however it also allows for a number of scenario option inclusions applied to the individual residential zones (Fig. 4). Scenario options chosen for inclusion in the forecasting process may

Table 4 Tonsley residential land use electric vehicle and activities performed from home parameters

Zone	Electric vehicles			Activities from home		
	EV type	Trip purpose	% Travel by EV	Work	Shopping	Education
1.	VW e-Golf	Commute	50	N	N	Y
2.	None	None	0	Y	N	N
3.	None	None	0	Y	N	N
4.	VW e-Golf	Commute	50	N	N	Y
5.	VW e-Golf	Commute	50	N	N	Y
6	None	None	0	Y	N	N
7.	VW e-Golf	Commute	50	N	N	N
8.	VW e-Golf	Commute	50	N	N	N
9.	VW e-Golf	Commute	50	N	N	N
10.	VW e-Golf	Commute	50	N	N	N
11.	VW e-Golf	Commute	50	N	N	N
12.	None	None	0	Y	N	N
13.	None	None	0	Y	N	N

Table 5 Tonsley residential land use water use, energy consumption and recycling activity parameters

Zone	% Rainwater use	% Greywater recycled	Water consumption (%)		Energy consumption (%)	
1	20	15	17	Decrease	0	–
2	20	15	0	–	15	Decrease
3	20	15	0	–	15	Decrease
4	20	15	17	Decrease	0	–
5	20	15	17	Decrease	0	–
6	20	15	0	–	15	Decrease
7	20	15	17	Decrease	0	–
8	20	15	17	Decrease	0	–
9	20	15	17	Decrease	0	–
10	20	15	17	Decrease	0	–
11	20	15	17	Decrease	0	–
12	20%	15	0	–	15	Decrease
13	20%	15	0	–	15	Decrease

be identified to reflect the objectives of urban policy or economic development strategies and are completely flexible for the user's needs.

Tables 4 and 5 present the parameters for the scenario option inclusions applied to the residential zones in Fig. 4.

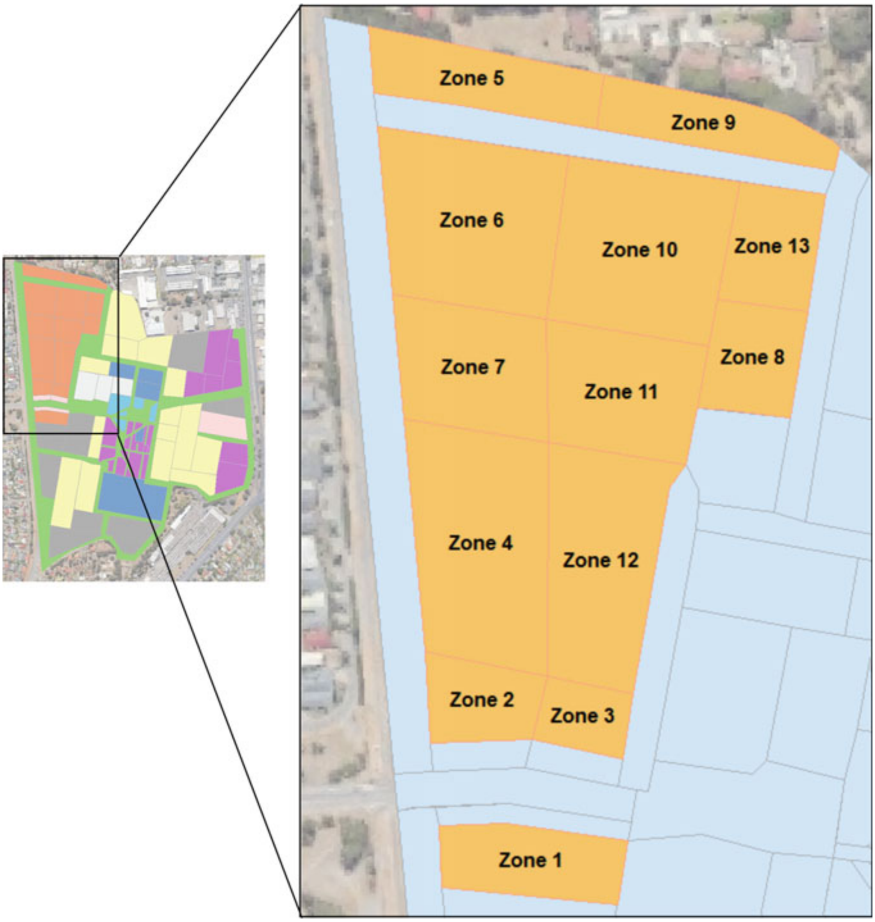


Fig. 4 Tonsley residential land use and zoning ID's

Scenario parameters detailed in Tables 4 and 5 provide the ETWW forecast with information to apply for the following activities and interactions:

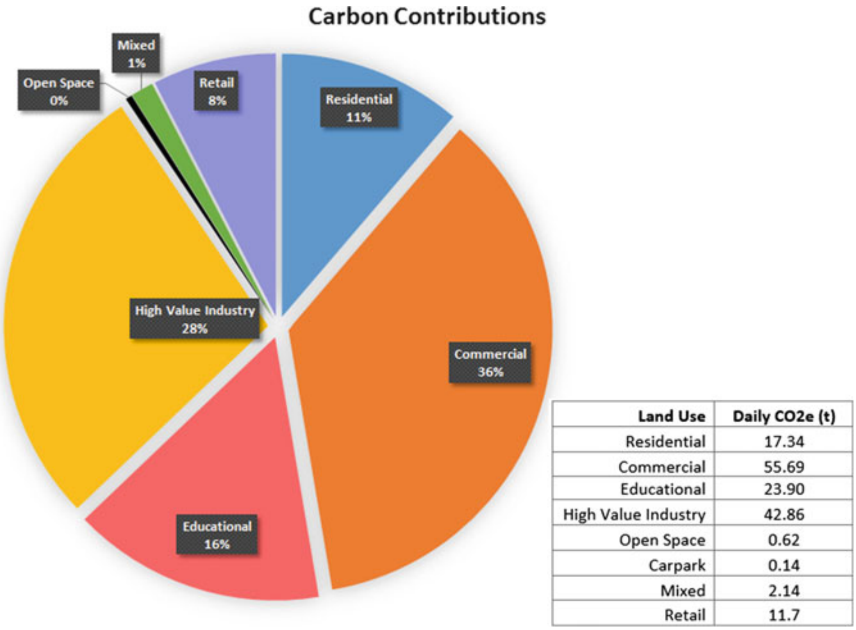
- electric vehicle travel: transport and energy domain interaction,
- work, education and shopping at home location: all domain interaction,
- changes to rainwater use: water and energy domain interaction,
- changes to grey-water recycling: water and waste domain interaction,
- changes to water and energy consumption: water and energy domains respectively,
- changes to household waste recycling: transport and waste domain interaction.

6.2 Forecasting Scenario Results

Forecasting processes within the model produce a range of detailed outputs and results, hence for ease of interpretation and clarity of expression, this chapter will only focus on a synthesis of selected outcomes. Firstly, the scenario 1 baseline condition produces forecasts of carbon contributions from all land uses for the year 2035 represented in Fig. 5.

Non-residential land uses generate the majority of carbon emissions with commercial and high-value industry with a combined proportion of 64%, the largest component of the built environment and land use allocation at Tonsley. Carbon is generated across all the domains of energy, water transport and waste as employees undertake everyday activities associated with their work. Residential carbon impact is 11% of the total emissions which is due to the relatively small proportion of land use. We will focus the remainder of the analysis on this residential precinct component.

Analysing the daily CO_2-e of the residential land uses, Scenario 1 produces a total of 17.3 tonnes CO_2-e as a base condition for the 862 households, composed of three different house structure types and a resident population from a total of 9



Land Use	Daily CO2e (t)
Residential	17.34
Commercial	55.69
Educational	23.90
High Value Industry	42.86
Open Space	0.62
Carpark	0.14
Mixed	2.14
Retail	11.7

Fig. 5 Scenario 1 baseline carbon impact contributions from land use types

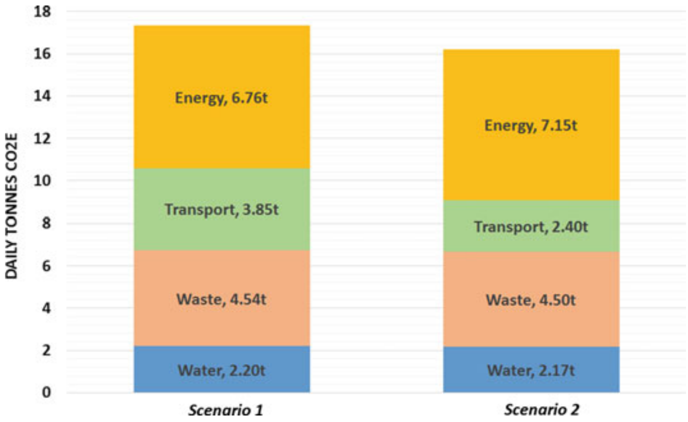


Fig. 6 Total daily residential-only carbon impact of scenarios 1 and 2

Mosaic classification of resident types (Fig. 6). Scenario 2 sees a significant overall reduction in CO_2-e production to 16.2 daily tonnes. The use of electric vehicles has reduced the impact of transport in terms of tailpipe emissions but has increased the demand for electrical energy from the household. An overall reduced water demand and increased rainwater use has contributed to a reduction in CO_2-e generated by mains-supplied water however the use of rainwater pumps also adds to the household electricity demand. An increased grey-water use has reduced the amount of waste as waste-water. Activities performed from the home reduce the emissions from transport but add to the other 3 domain carbon productions, offsetting some of the gains made from other influences. Figure 7 provides the total daily CO_2-e for all precinct land uses resulting from the scenario 2 forecast.

GIS functionality combined with the ETWW model forecast data provides the user with the ability to define the CO_2-e attributable to each land zone as presented in Fig. 7. Greatest CO_2-e production is associated with commercial and education land uses, predominantly on the Southern and Eastern sides of the precinct. The residential components produce a range of total CO_2-e however this is reduced in comparison to most commercial and HVI land uses. The lowest impact is from open and public spaces.

A more detailed analysis of CO_2-e, by domain, is possible for all land use types across Tonsley with the following figure illustrating the results for the residential components.

From Fig. 8 we can see that in most zones, CO_2-e production from the energy domain dominates, often closely followed by the waste proportion with CO_2-e associated with landfill and energy use for recycling purposes. Transport emissions

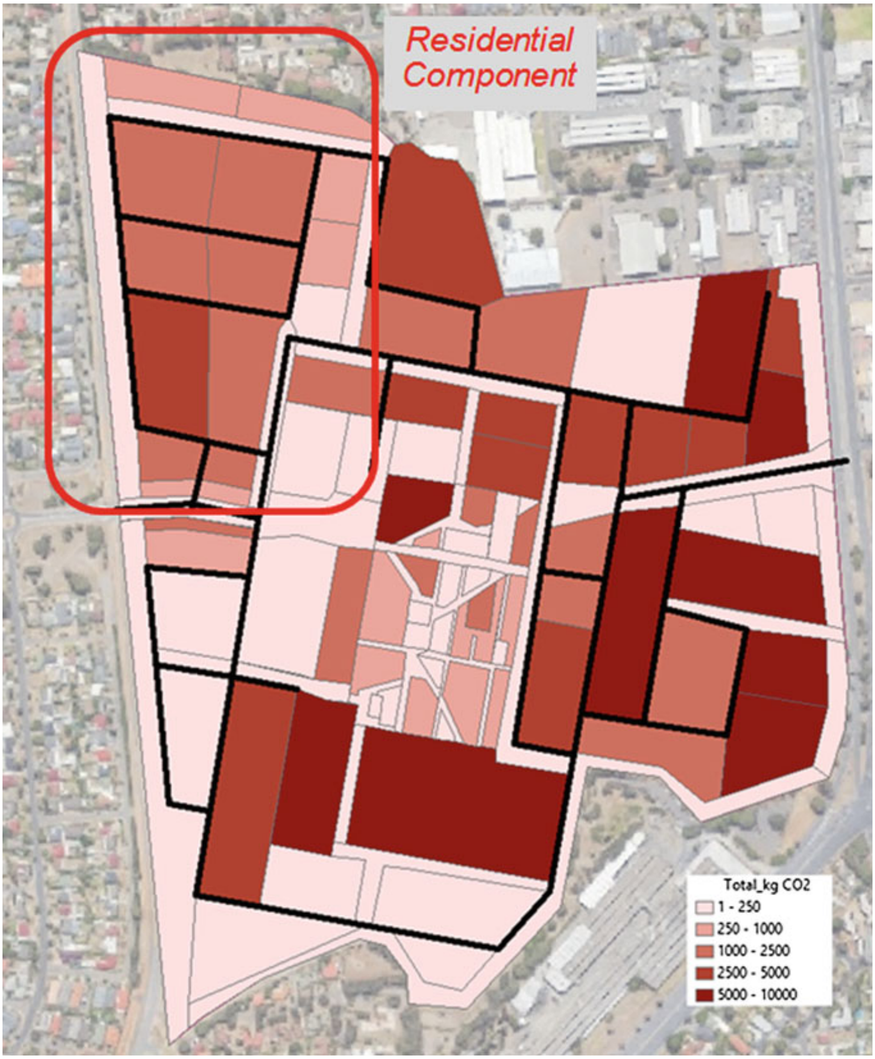


Fig. 7 Carbon impact of Scenario 2 as daily carbon for all precinct land uses

are lower which is a direct result of the influence of the electric vehicle contributing to energy CO_2-e rather than transport. Transport proportions are also from reduced overall transport from activities performed from the home, a behaviour that increases daily household emissions in other domains for the residences.

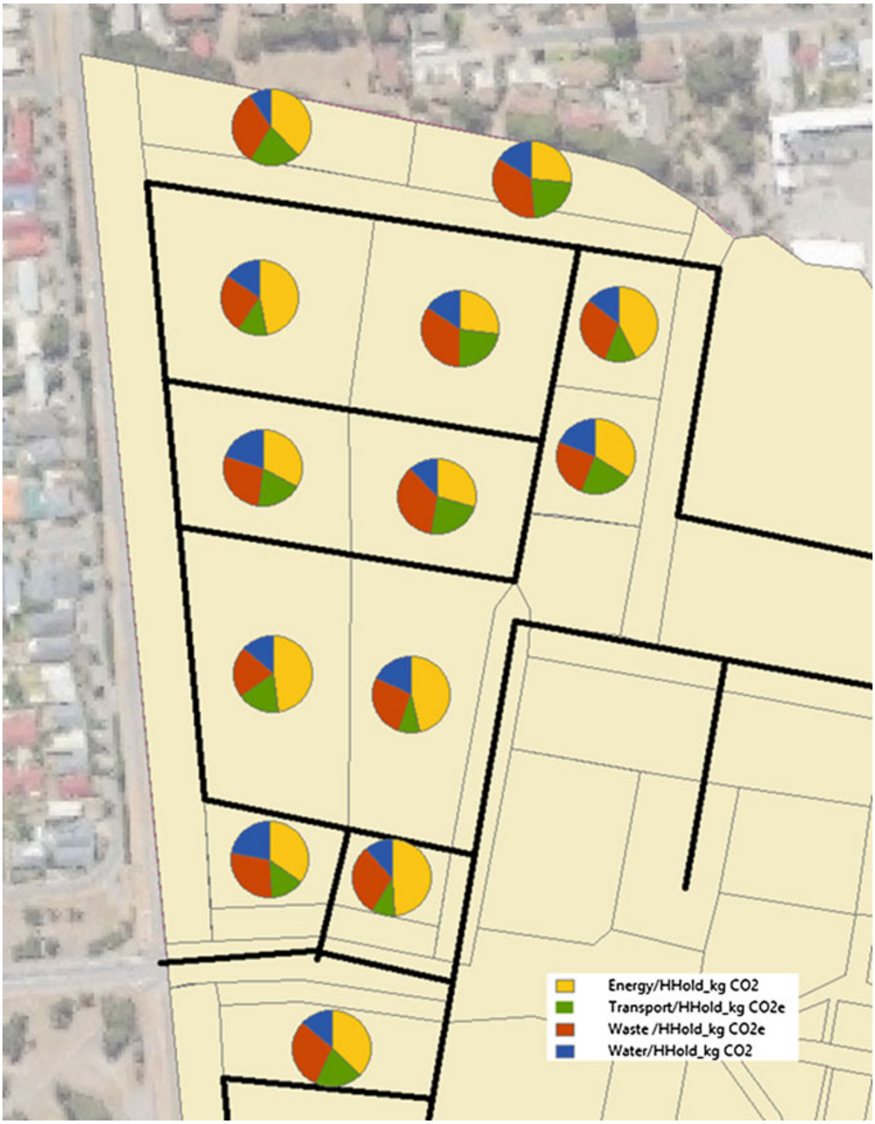


Fig. 8 Carbon impact of Scenario 2 daily carbon proportions for all domains in residential zones

7 Conclusions

This chapter has outlined an integrated ETWW demand and carbon forecasting approach for residential precincts. This tool is useful for planners, policy makers and other agencies to design carbon efficient residential precincts. The tool allows for forecast population changes and associated demand and carbon impact estimations. Forecasting approaches described in this chapter estimate energy, transport, waste and water demands of precinct developments in an integrated manner. The model inputs allow for complex scenarios containing different population types, the built environment, technologies as well as external influences (such as the impacts of climate change or changes in the water and electricity supply mix). Demand modelling within the domains draws on newly developed and existing forecast approaches to strengthen the accuracy and ability of the model to integrate demand and carbon estimates across the four domains.

Forecasting has been demonstrated with the successful application to a future year case study scenarios applied to the Tonsley Precinct in Adelaide, Australia. Our findings demonstrate that the application of the model is possible at both generalised and detailed scales with comparative results of all three scenarios illustrated. Detailed analysis with results presented in a spatial perspective utilising GIS capabilities further demonstrate the model abilities as a flexible and accurate approach to integrated demand forecasting at the precinct scale.

References

Ahmad, A. S., Hassan, M. Y., Abdullah, M. P., Rahman, H. A., Hussin, F., Abdullah, H., et al. (2014). A review on applications of ANN and SVM for building electrical energy consumption forecasting. *Renewable and Sustainable Energy Reviews, 33,* 102–109.

Arbués, F., Garcıa-Valiñas, M. Á., & Martınez-Espiñeira, R. (2003). Estimation of residential water demand: A state-of-the-art review. *The Journal of Socio-Economics, 32,* 81–102.

Citilabs (2011). Discover Cube 5.0. Revision 50-006-0. Citilabs Inc.

Commonwealth of Australia (2012). *Baseline energy consumption and greenhouse gas emissions, commercial buildings in Australia Part 1—Report, COAG National Strategy on Energy Efficiency*. Canberra: Department of Climate Change and Energy Efficiency.

Cook, S. H. M., & Gregory, A. (2012). *Energy use in the provision and consumption of urban water in Australia: An update*. CSIRO Water for a Healthy Country Flagship: Water Services Association of Australia.

de Dios Ortúzar, J., & Willumsen L. G. (2011). *Modelling Transport, 4th Edition*, New York: Wiley.

Department of Sustainability, Environment, Water, Population and Communities (2013). *A study into commercial & industrial (C&I) waste and recycling in Australia by industry division*. Canberra: Government of Australia.

DOE (2014). *National greenhouse accounts factors*. Canberra: Department of the Environment, Commonwealth of Australia.

Donkor, E., Mazzuchi, T., Soyer, R., & Roberson, A. J. (2014). Urban water demand forecasting: Review of methods and models. *Journal of Water Resources Planning and Management, 140,* 146–159.

Experian. (2013). Experian Mosaic Guide. http://www.experian.com.au/consumer-segmentation/mosaic-segments.html. Accessed April 21, 2016.

Government of South Australia (2011). *Eyre Peninsula demand and supply statement*. Adelaide: Department for Water, Government of South Australia.

Government of South Australia (2013). Tonsely: Site Strategies. https://tonsley.com.au/content/uploads/2016/04/Tonsley-Site-Strategies.pdf. Accessed November 2, 2016.

Holyoak, N. (2003). *The formulation and development of a policy sensitive analysis tool for the evaluation of travel demand management measures*. Ph.D. Thesis.

Holyoak, N., Taylor, M. A. P, Hadjikakou, M., Percy, S., Iankov, I., & He, H. (2016). *Integrated energy transport waste and water demand forecasting and scenario planning for precincts: Final report*. Research Program 2, CRC for Low Carbon Living (In Press).

Holyoak, N., Taylor, M. A. P., Oxlad, L., & Gregory, J. (2005). Development of a new strategic transport planning model for Adelaide. In *28th Australasian Transport Research Forum* (*ATRF*), Sydney: Australia, CD-ROM.

Iankov, I. (2016). *Greenhouse gas emission rates for traffic loads applicable to Australian roads.* Ph.D. Thesis.

House-Peters, L. A., & Chang, H. (2011). Urban water demand modeling: Review of concepts, methods, and organizing principles. *Water Resources Research, 47,* 15.

Kavgic, M., Mavrogianni, A., Mumovic, D., Summerfield, A., Stevanovic, Z., & Djurovic-Petrovic, M. (2010). A review of bottom-up building stock models for energy consumption in the residential sector. *Building Environment, 45*(7), 1683–1697.

Marchi, A., Dandy, G., & Maier, H. (2014). *Financial costs, energy consumption and greenhouse gas emissions for major supply water sources and demand management options for metropolitan Adelaide*. Technical Report Series No. 14/12, Adelaide: Goyder Institute for Water Research.

Newton, P., Marchant, D., Mitchell, J., Plume, J., Seo, S., & Roggema, R. (2013). *Design performance assessment of urban precincts from a carbon, sustainability and resilience perspective: a scoping study Version 3.0 Exposure Draft*. Research Project RP2001: Scoping study for precinct design and assessment tools, Research Program 2, CRC for Low Carbon Living.

NSW BTS (2011). *Sydney strategic travel model modelling future travel patterns: Technical documentation*. Sydney: NSW Government.

Percy, S., Aldeen, M., & Berry, A. (2015). Residential precinct demand forecasting using optimised solar generation and battery storage. In *IEEE PES Asia-Pacific Power and Energy Engineering Conference*. Brisbane: Australia.

Polebitski, A., & Palmer, R. (2010). Seasonal residential water demand forecasting for census tracts. *Journal of Water Resource Planning and Management, 136*(1), 27–36.

Ren, Z., Foliente, G., Chan, W. Y., Chen, D., Ambrose, M., & Paevere, P. (2013). A model for predicting household end-use energy consumption and greenhouse gas emissions in Australia. *International Journal of Sustainable Building Technology and Urban Development, 4*(3), 210–228.

Sourghali, V., & Pugh, A. (2016). The vision and the journey for predictive modelling. In *Australia's International Water Conference & Exhibition*. Melbourne: Australia.

Suganthi, L., & Samuel, A. A. (2012). Energy models for demand forecasting—A review. *Renewable and Sustainable Energy Reviews, 16*(2), 1223–1240.

Sydney Water (2016). Benchmarks for Water Use. https://www.sydneywater.com.au/SW/your-business/managing-your-water-use/benchmarks-for-water-use/index.htm. Accessed August 3, 2016.

Torriti, J. (2014). A review of time use models of residential electricity demand. *Renewable and Sustainable Energy Reviews, 37,* 265–272.

US Energy Information Administration (2016). *Commercial Buildings Energy Consumption Survey: 2012 Energy Usage Summary*. http://www.eia.gov/consumption/commercial/reports/2012/energyusage/. Accessed June 9, 2016.

Zero Waste, S. A. (2012). *Optimum compaction rate for Kerbside Recyclables, Zero Waste SA and local government research and development scheme*. Adelaide: Zero Waste SA.

Chapter 18
Open Data and Human-Based Outsourcing Neighborhood Rating: A Case Study for San Francisco Bay Area Gentrification Rate

Eleanna Panagoulia

Abstract The past decade has experienced a staggering rise of data–aided analysis that facilitates understanding the impact of socio-economic flux and socially oriented activities towards the quality and livability of space. Evaluating urban environments is not only important from the planners' perspective, but has larger implications for the residents themselves. In this chapter we argue that the livability of a city or a neighborhood is not necessarily described by conventional, authoritative data, such as income, crime, education level et cetera, but ephemeral data layers, related to human perception, can be more effective in capturing the dynamics of space. Implementing methods that are considered disassociated with urban analytics, we attempt to go beyond the conventions in understanding the dynamics that drive socio-economic phenomena and construct lived space. Our objective is to create methodologies of anticipating and evaluating urban environment by re-patterning different datasets and taking advantage of their combinatory potential.

Keywords Data aided analysis · Neighborhood rating · Open data · Human based outsourcing

1 Introduction

Urban design practice has been significantly influenced by the development of tools and platforms that have set the scene for new ways of understanding place and space. Current data streams have allowed planners to view the city as a constantly transforming and unpredictable environment. This chapter will focus on the development of alternative urban computing methodologies that are non-deterministic and attempt to provide new insight in mapping the complexity of the urban environment.

E. Panagoulia (✉)
College of Environmental Design, University of California, Berkeley, CA 94720, USA
e-mail: eleannapan@gmail.com

S. Geertman et al. (eds.), *Planning Support Science for Smarter Urban Futures*, Lecture Notes in Geoinformation and Cartography,
DOI 10.1007/978-3-319-57819-4_18

The research builds on the term of mapping as James Corner defines it. Corner suggests ways in which mapping acts may emancipate potential and reveal hidden, invisible layers (Corner 1999). Under this scope, we create a case study that focuses on mapping the gentrification rate in the San Francisco Bay Area; a phenomenon that establishes rapidly in the area; hence it is considered a challenge to visualize due to its dynamical and complex character. This phenomenon is a subject of debate, as there is extended conflict and consensus whether it is beneficial or not to the broader community. Gentrification recalibrates terms such as safety, affordability, aesthetics et cetera towards upgraded standards that may be regarded as improvement on the surface, but have a negative effect on lower income society. Gentrification alters not only the social fabric, but also the physical makeup of a neighborhood, such as its identity, local culture, indigenous characteristics and traditions preserved by the local residents. In this chapter we are attempting to break this complexity down into its constituent parts and find points of leverage to map and visualize urban development. We implemented a data—driven process utilizing multiple databases that offer opportunities to author urban data through subjective observation and crowd sourced survey techniques. We formulated an accumulative analysis that consists of three methods that operate at different scales, regional and local, in an attempt to show, through the lens of new and old ideas, how the city can be better understood nowadays. In order to provide an informative framework for our research on data-driven mapping methodologies, we will analyze the groundwork of some fundamental topics and problematic that influenced our approach on data and design, by providing key terminology and by analyzing precedent studies on the field. As mentioned before, this research operates at multiple scales, including that of neighborhood. In the following section we will analyze terms such as neighborhood, gentrification and displacement and attempt to provide an understanding of their interrelation. Finally, we will emphasize on the role of data in mapping processes and its contribution to the current state of the art.

2 Key Terminology

2.1 Neighborhood and Neighborhood Change

The notion of neighborhood is one that planners and scholars usually presuppose as consistent; however, its role in the urban environment has been questioned and debated upon in the past. The neighborhood has come to be understood as the physical building block of the city for both “social and political” organization (Sampson 2011), and thus, combines physical and non-physical attributes. Early scholars described neighborhoods as defined, closed ecosystems, characterized by their physical elements, such as size, density, demographics et cetera that would get disrupted by external factors, such as new residents. Based on these theories, neighborhood change was a natural process of population relocation and competition for space, until a state of new equilibrium is established. These ideas about neighborhood presented a deterministic model, where neighborhoods can be categorized based on simplified criteria such as their residents' financial status et cetera. However, neighborhoods are not introverted, autonomous clusters and the mechanisms of neighborhood change do not rely on exclusively external factors. According to Jane Jacobs, nowadays people identify a neighborhood by a landmark in the city because it has become intimate from daily use or encounter (Jacobs 1961). For her the key that creates the notion of a neighborhood is diversity and identity. She argues that people tend to avoid visiting places that do not represent any variation either in function or aesthetics (Jacobs 1961). Although the modern way of living has urged people to be more mobile than before, for example, their place of work does not coincide with their place for entertainment or their home, people tend to care about the district that surrounds their home if it meets the certain criteria that fit their lifestyle. The stability of a neighborhood relies on its capacity to absorb opportunities and sustain its diverse character. The term neighborhood can be described as an instance of organized complexity (Jacobs 1961), a network of numerous connections, where transformations can occur unexpectedly. Apart from a territorially bounded entity, neighborhoods embody series of overlapping social networks, where a diverse mix of people and processes has its own self-organizing dynamic.

2.2 Gentrification and Displacement

Gentrification is one category of neighborhood change and is broadly defined as the process of improving and renovating previously deteriorated neighborhoods by the middle or upper class, often by displacing low-income families and small businesses. The first documented use of the term "gentrification" (Glass 1964) describes the influx of a "gentry" in lower income neighborhoods. Owens identifies 9 different types of neighborhoods that are experiencing upgrading: minority urban neighborhoods, affluent neighborhoods, diverse urban neighborhoods, no population neighborhoods, new white suburbs, upper middle-class white suburbs, booming suburbs and Hispanic enclave neighborhoods (Owens 2012). Gentrification does not only rely on a singular cause, as it may emerge when more than one condition is present. It is a complicated process that does not rely on binary and linear explanations. Early studies identified two main categories that cause gentrification: private capital investment for profit-seeking and people flow that refers to individual lifestyle preferences. Gentrification does not result in negative effects, as it can also be regarded as a tool for revitalization. When revitalization occurs from existing residents, who seek to improve their neighborhood conditions, the result can be constructive in enforcing the neighborhood stability. This condition is called incumbent upgrading or "unslumming" as Jane Jacobs defines it (Jacobs 1961). However, when revitalization causes displacement of current residents and a decline in neighborhood diversity, then neighborhoods gradually become segregated by income, due in part to macro-level increases in income inequality as well as decline of job opportunities (Freeman 2004). Hence, neighborhood stability is compromised because the opportunities have been narrowed down to a very limited range of financial status and lifestyle. Displacement is identified as the biggest negative impact of concern resulting from neighborhood revitalization and gentrification. Displacement occurs when any household is forced to move from its residence, usually because of eviction and unaffordable rent increase. However, tracking unwilling displacement can be challenging to categorize, as researcher have faced limitations regarding data availability and data comprehension.

3 Precedent Studies on Gentrification Detection

There have been several precedent studies that aimed in identifying gentrification rate and its consequences in several American cities since the late 1970s. In this section we will briefly depict some main methods previous researchers used, as well as their strengths and weaknesses. Early researchers analyzed gentrification under a binary, rather simplified scope, under solely macro-level capital accumulation or micro-level sociological processes of individual preferences. Yet their methods did not take into consideration politics, as they viewed the process as a natural neighborhood succession, where property changes hands and residences get displaced. Also, their surveys suffered from data limitation, short span timeframes and a canvas that did not convey the details and the complexity of the real situation. Research on gentrification and displacement waned in the late 1980s and early 1990s, as researchers became to study gentrification both as a revitalization process, as well as a consequence for displacement. They shared methods of the previous literature, combined now with more access to detailed datasets, allowing for the introduction of more advanced statistical techniques in an attempt tease out the independent effects of gentrification on residential displacement. Many of these studies also pay much closer attention to the impacts of displacement on neighborhood scale rather than studying displacement of the general population. A main method, common in many surveys, suggested to proxy gentrification as an increase in the number of educated professional and to proxy displacement as a decrease in the number of residents from the following vulnerable groups: working class, unskilled labor, renters, unemployed, people of color, elderly and single parent households (Lees et al. 2010). Yet the outcome produced “noisy” data that suggested that a more qualitative research was needed. More recent analyses span at larger timeframes to get a better understanding of resident movement in and out of gentrifying neighborhoods. All surveys suffered from the fact that the results masked a great deal of heterogeneity between urban areas and even within the Census tracts. This resulted from deficiencies in the data sets and short time-scale of the analysis, factors that designated the low predictive capacity of the models and the insufficiency to fully understand neighborhood dynamics, which remain ambiguous and conflicting. Although varied in their approaches, questions and results, one consistent finding across these studies is that movers in gentrifying tracts were more likely to be higher income, college educated and younger. This came down to depicting certain categories as indicative that the process of gentrification was already underway: (a) shift in tenure, (b) influx of households interested in urban living, and (c) increase in high income serving amenities such as music clubs, coffee shops, galleries, et cetera (d) rise of educational level. It is important to note that the above categories summarize quantitative data sources only. Even when data sets allow tracking of individual households, they do not provide a sufficient response to measure displacement. For instance, the reason for a household to move to a different neighborhood may rely on subjectivity, which is hard to quantify. Moreover, data on many of the drivers and impacts of gentrification and displacement are not regularly gathered, hence they may not capture all the changes even in the categories they represent. It is therefore important to explore the implications of the data limitations and to consider qualitative sources of information to better understand the drivers and impacts of neighborhood change.

4 Recent Computational Tools—The Role of Data

In the early 2000s several urban analytics models incorporated computational tools that introduced automation, in order to simulate relationships among the urban space. Tools are divided to the ones focusing on representing the movement of individuals and households into spatial patterns of settlement tend to be specified through "agent-based models," also referred to as "multi-agent systems," and to the ones focused on capturing inter-related patterns of change among spatially fixed entities, such as housing units or entire neighborhoods, tend to be specified through cellular automata. Urban simulation models are guided by a set of specified rules that simulate decision making, that perform in a simplified environment disconnected from real facts, thus they may not capture complex gentrification dynamics. One explanation for this is the difficulty of adequately incorporating the breadth of social theory needed to account for the range of gentrifying mechanisms. For instance, even the simulation of the relationships that occur in a park of a business district neighborhood during day and nighttime, quickly becomes a complicated problem to simulate. These models are constrained by their inability to theoretically ground mechanisms of neighborhood change and translate them into a set of rules. They are limited by a lack of empirical detail, both in their specifications of agent attributes, as well as in their specification of neighborhood choice and parcel change mechanisms. As cities are becoming more instrumented and networked, more data is being generated about the urban environment and its residents, allowing urban designers to access the local scale fabric of the city, opening up new research directions for understanding the city (Sassen 1998). Going beyond traditional data sources, such as Census, which is fairly static and updated only every 10 years, we encourage designers to engage with other types of data that capture the ephemeral side, such as, people's desires, trends et cetera. It is important for designers and planners to recognize the opportunities for making better sense of public space through technology. One of the key benefits of adopting a data-driven approach to urban analytics surveys is the ability to see a combination of datasets in context with each other, and to detect temporal and spatial patterns. The following section describes the case study that attempts to visualize neighborhood change and gentrification in the San Francisco Bay Area.

5 Case Study

5.1 Introduction

As mentioned in the main introduction, this case study will focus on visualizing the gentrification rate in the San Francisco Bay Area. The case study involves a combination of three different methods in an attempt to provide a holistic understanding of the flux in the urban environment. This case study will use a series of maps at different, suitable scales to visualize all the data collected from all the three methods. We employed James' Corner principle in combining data sets in a creative way that could uncover realities previously unseen even across exhausted, over studied grounds, such as the Bay Area (Corner 1999). In order to get a better understanding of the overlapped data sets, we first created a geo-located 3D space in the software Processing, were multiple data sets can be displayed at the same time. The visual communication of the information was based on Tufte's principle regarding the clarity of information displayed on the map. He argues against using excessive decoration in visual displays of quantitative information. Tufte encourages the use of data-rich illustrations that presented all available data. When such illustrations are examined closely, every data point has a value, but when they are looked at more generally, only trends and patterns can be observed (Tufte 1990). In particular, changes of degree in a factor are displayed with a gradient of the same color, changes of type are displayed with different colors and the general vocabulary of visual styles is communicated with dots, lines and areas.

5.2 Authoritative Data Approach

The first method is based on a Census GIS data analysis to identify the areas that have altered their character the last 10 years, based on authoritative parameters associated with gentrification, such as tenure status, land value, income and employment rate. The Geographic Information System, or GIS, allows for very fast accumulation of Census data that represent multiple categories relevant to our study. However, for domain specific categories, such as population, income, educational level, transport et cetera surveys are conducted every few years, using a limited spatial and temporal sampling framework. As a first step, we identified all the green areas, parks et cetera in the entire Bay Area and excluded them from the calculations, as they would have compromised the results of the survey. The initial survey was done for the county of San Francisco based on an assumption that most changes would occur there. We created a series of maps that show a range of household income, a range of home value, owner occupied housing, vacant lots and the ratio of unemployed population to the total population. Soon it became apparent that most suitable scale for this kind of data set display is an urban scale, that of the entire Bay Area, because this data has low spatial resolution and hence, refers to large scale surveys, where comparison would make more sense. As a second stage of the process we re-collected data for the entire San Francisco Bay Area. The Census data that we collected consists of a combined data set from 2000 to 2012 that compares tenure, median household income, median home value and employment rate. Through calculations we generated the delta of these data sets respectively and remapped the values in a series of grey scale maps. The term delta stands for the difference/amount of change that was observed in every county of the Bay Area for every data set respectively. The amount of change was visualized in a series of grey scale maps that range from 0–255, where black color represents highest amount of change and white color, no change. The 4 maps that represent the amount of change in tenure, median household income, median home value and employment rate were weighted and overlapped on a single map that represents the amount of change of the combined data sets (Fig. 1). In order to enrich the process, we added an additional layer of information, that of artists' employment rate. Artists' community is considered highly associate with gentrification rate. Previous surveys in the field have established artists as agents of urban gentrification, for the reason that low-income artists tend to revalorize unproductive spaces, since they are affordable, and, as a result, increase the attractiveness of urban space. Artists make the first move into post-industrial, post-welfare neighborhoods. Soon they attract the hipster movement before, eventually, being displaced by them and their new middle-class neighbors. Both participate in the cycle of exploring, developing new potential sites for capital investment. Hence, the combined data set of the other categories is overlapped with artist employment rate Census data (Fig. 2). All the relevant data was collected from government websites in.csv format, then imported to Microsoft Excel for the calculations to be performed (delta calculation) and then re-exported in.csv spreadsheets that were imported in Grasshopper and visualized in the Processing model space created for this purpose.

5.3 Ephemeral Data Approach

The second method operates at a local level analysis, in San Francisco and Oakland respectively. The data resources for this research derive from open data platforms (data that is freely accessible), such as Google API, Google Places and collective,

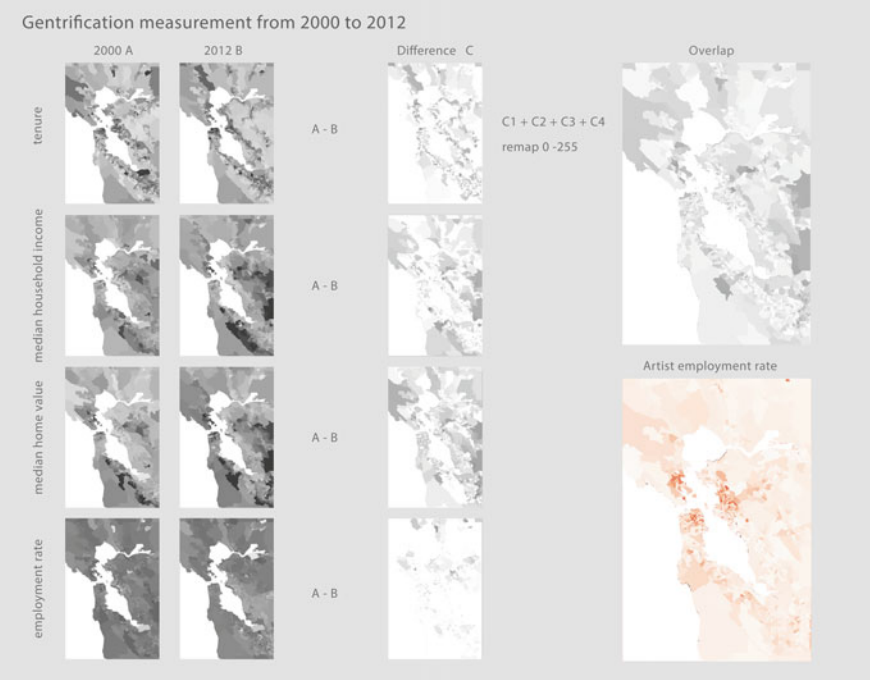
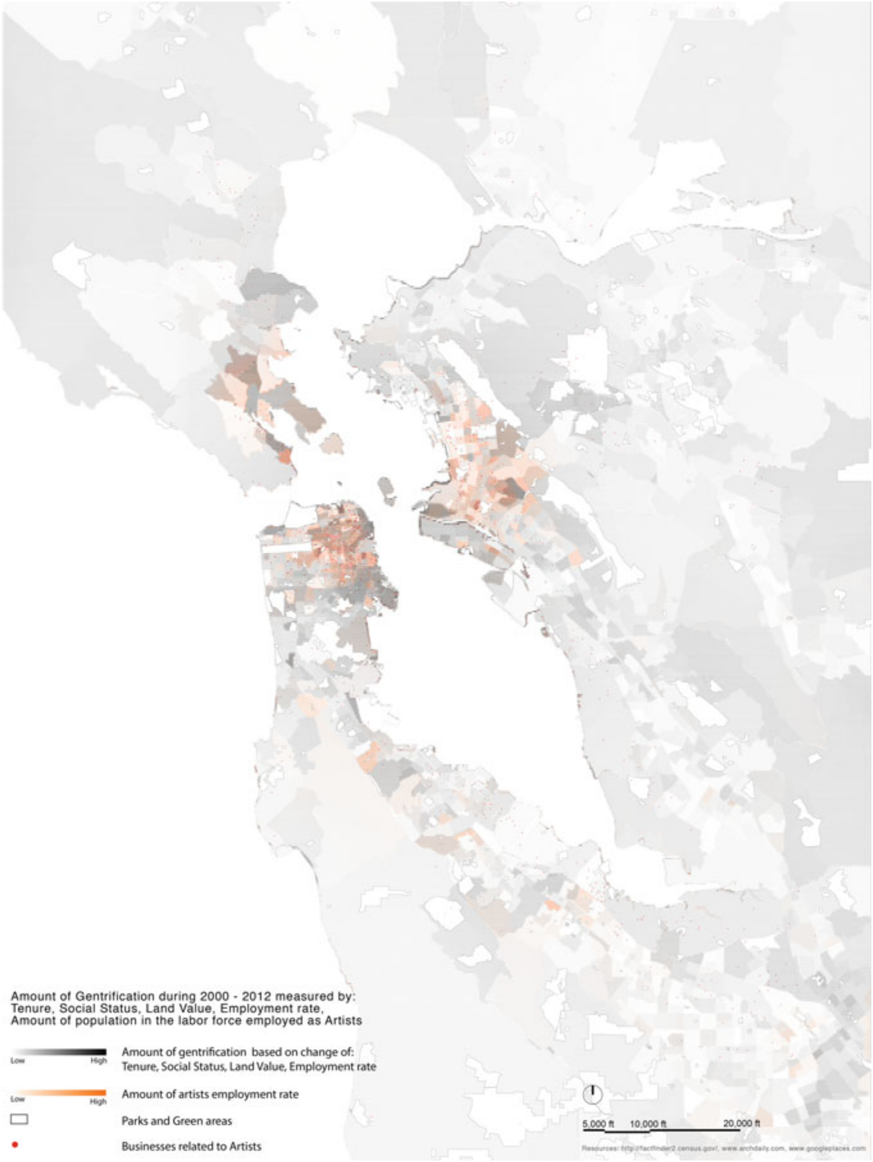


Fig. 1 San Francisco Bay Area, Census GIS data comparison of tenure, median household income, median home value and employment rate from 2000 to 2012 overlapped with artists' employment rate

open-data platforms where users post all kinds of requests (sell and buy, real estate et cetera), such as “craigslist.org”. Our database is articulated by tracing certain population categories that reflect potentialities about gentrification. The first category involves artists and their recent activity in the San Francisco Bay Area. The same logic as in the first method is applied in this method as well. The artist population is considered as the frontline of gentrification. The second category involves the homeless population rates in the same period. Gentrification rate is also highly associated with eviction rate, since it caters for an environment that is affordable only to higher-income clientele, leaving out those individuals and families who face eviction and live on the brink of homelessness, applying for shelter in those areas. In gentrified areas low-income families soon face a significant rise in rent cost, combined with reduces chances of job advancements (Wolch et al. 1993). The main difference of this method in comparison to the previous one is that the data accumulation derives from open data platforms by defining an equivalent keyword query. Although we are dealing with the same group of people (artists), the data come from an entirely different type of source. We argue that for the artist community particularly, this data source describes more effectively the activity of this group, as most of the people are freelancers or unemployed, however they



Resources: http://factfinder2.census.gov/, www.archdaily.com, www.googleplaces.com

Fig. 2 San Francisco Bay Area, Census GIS data comparison from 2000 to 2012 overlapped with businesses related to artists from Google Places

actively pursue real estate for their studio or advertise artwork exhibitions et cetera This activity would be completely masked by the Census data set, however it is revealed at this stage of the process, since Google places and "craigslist.org" allow for every request is geo-located. In detail about the method itself, using Google API and “craigslist.org”, we performed multiple requests at a daily basis, in order to collect all the necessary data. The keyword queries were related to temporal requests and offers regarding real estate for artists’ studios, gallery spaces, events, artists’ resources, artwork sale, exhibitions, FAQ et cetera. Regarding the homeless population queries, those involved shelters, community amenities, technology stations, hygiene stations, food supply stations et cetera. The data accumulated was formatted in.csv format same as with the Census data process and visualized as nodes on the same context (Figs. 3 and 4).

5.4 Empirical Data Approach

The third method operates at neighborhood level. This method embraces an empirical data approach, where human perception and subjectivity are considered a qualitative source of data that can unveil qualities that the other processes overlook. In order to allocate a group of people for crowd sourcing, we utilized a human-based outsourcing platform called Amazon Mechanical Turk. Amazon Mechanical Turk is a crowdsourcing Internet marketplace, operated by Amazon, enabling individuals to coordinate the use of human intelligence to perform tasks that computers are currently unable to do. It is an on-demand large sample of users that executes large assignments over a given period of time. In our case, a large group was given two different sets of questions. The first set targets human subjectivity, where the users were asked subjective questions in order to rate certain neighborhoods based on Google Street View viewpoints. This research takes advantage of human subjectivity when it comes to rating an area based on personal interpretation of safety, affordability and infrastructure condition, qualities that vary significantly even among neighboring blocks, however the amount or the frequency of variation may have a significant role (Fig. 6). The second set targets the collection of detail features (e.g., the presence of: expensive loft housing, abandoned buildings, industrial buildings, bikes, public stairs et cetera) that are encountered in the areas of interest using the same Google Street View viewpoints (Fig. 5). These features are time consuming to collect manually therefore; this tool is proven convenient as it succeeds in collecting this information in short time. The areas of interest were Tenderloin in San Francisco and Emeryville in Oakland. Tenderloin was chosen because despite the fact that it is adjacent to already gentrified areas, it has different character whereas, Emeryville was chosen because it is transforming from a crime area into an urban, entertainment and commercial attractor point. The questions were submitted to Amazon Mechanical Turk through a template in.json format. The questions were structured in a way that the answers would be easy to process and to visualize, such as numerical (scale 1–10), binary (yes/no) or choice (tick the box), while we avoided completely answers in a form of text. The answers we received were in.json format so we transformed them into.csv format and then imported to Grasshopper and Processing same in the previous two methods.

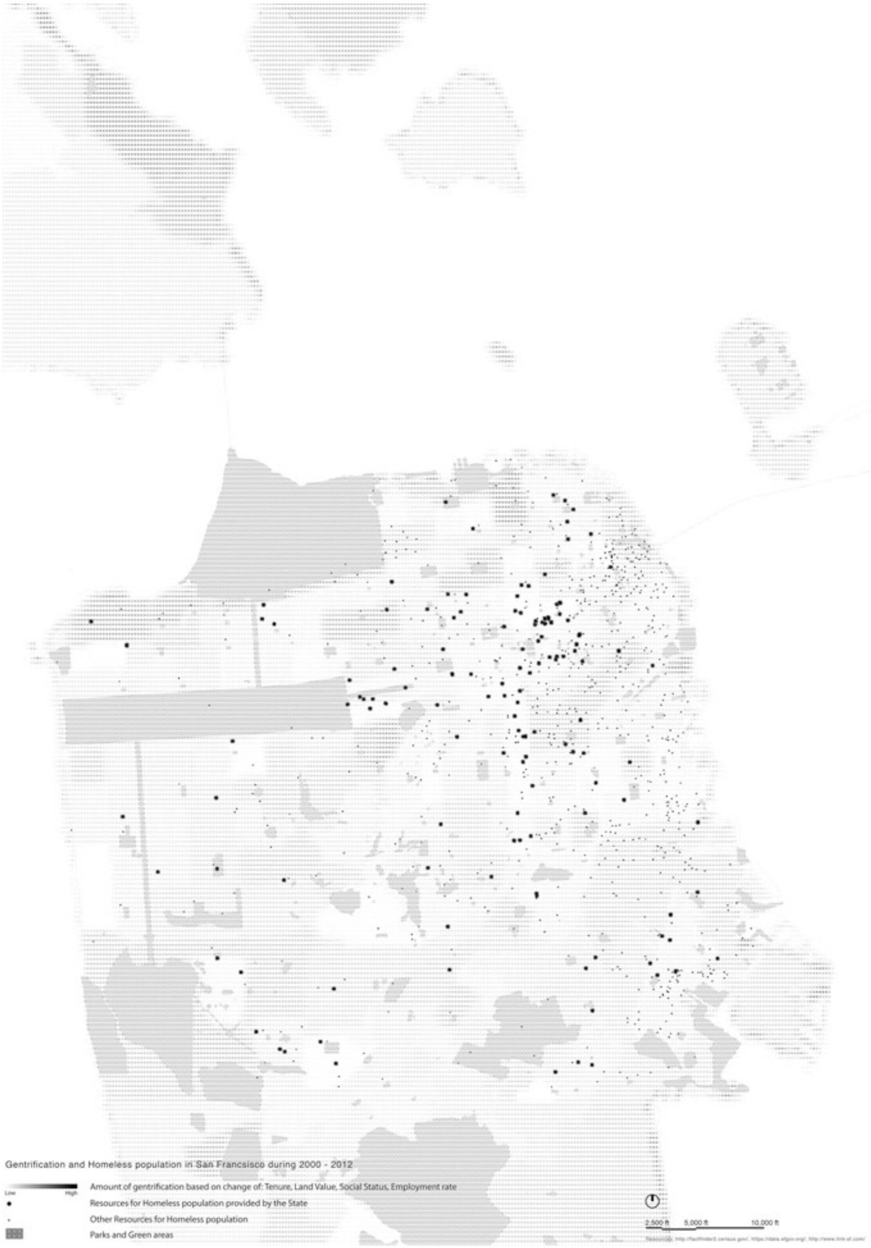


Fig. 3 San Francisco Bay Area, Census GIS data comparison from 2000 to 2012 overlapped with homeless population public services

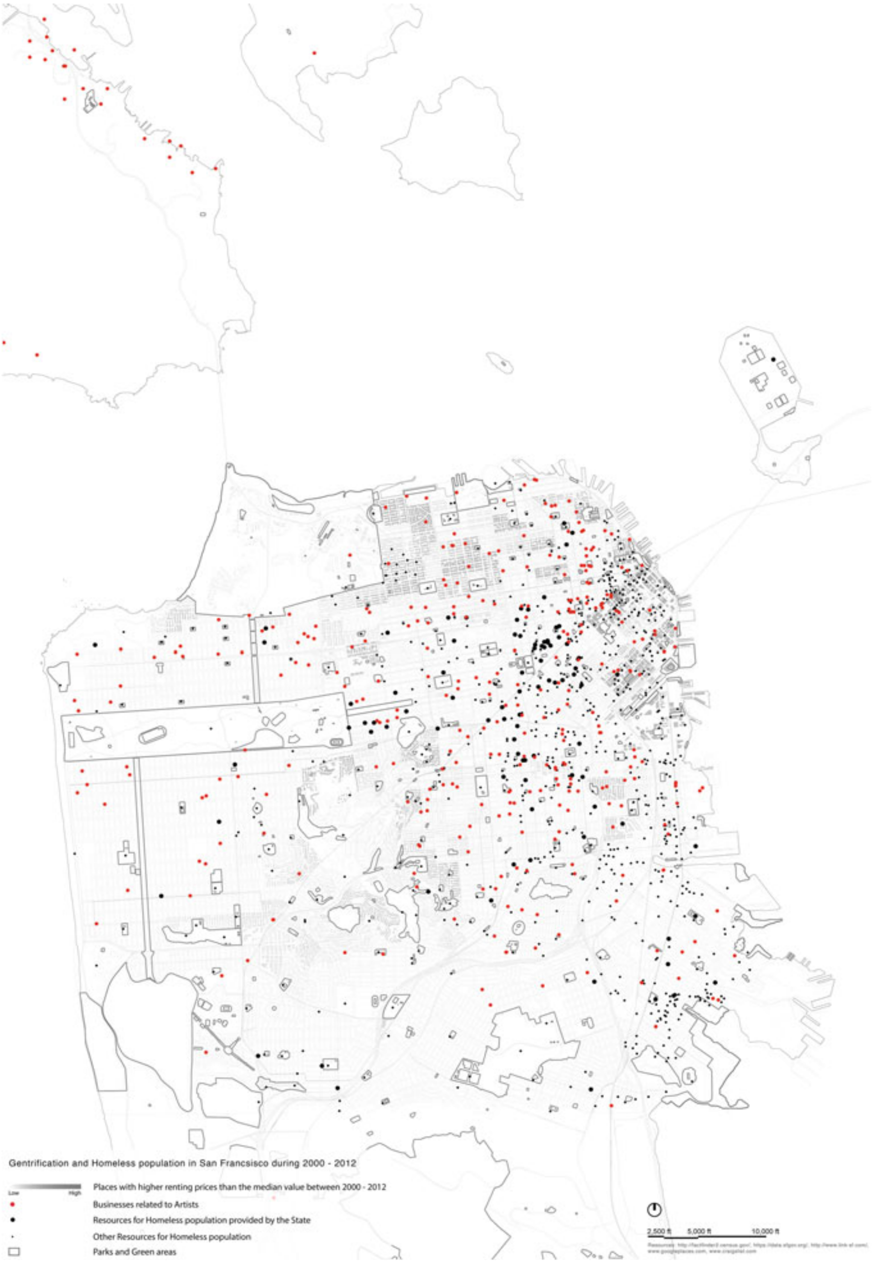
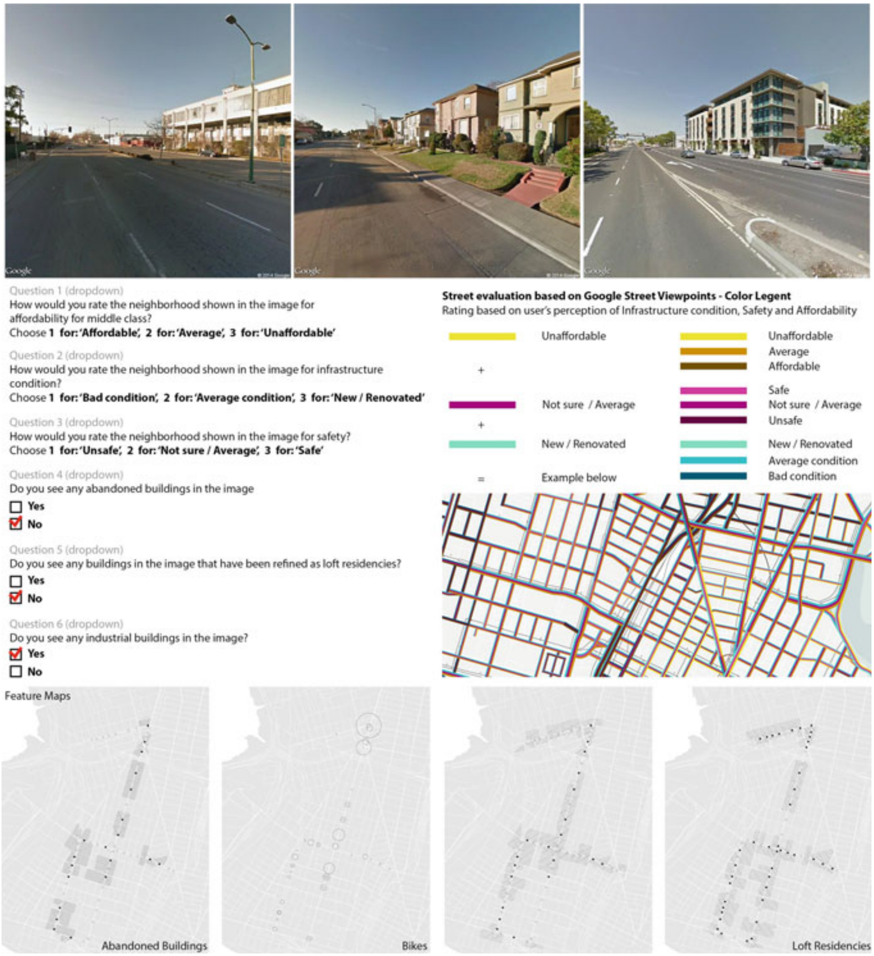


Fig. 4 San Francisco Bay Area, Census GIS data comparison from 2000 to 2012 overlapped with businesses related to artists from Google Places and homeless population public services



Question 1 (dropdown)
How would you rate the neighborhood shown in the image for affordability for middle class?
Choose **1 for: 'Affordable', 2 for: 'Average', 3 for: 'Unaffordable'**

Question 2 (dropdown)
How would you rate the neighborhood shown in the image for infrastructure condition?
Choose **1 for: 'Bad condition', 2 for: 'Average condition', 3 for: 'New / Renovated'**

Question 3 (dropdown)
How would you rate the neighborhood shown in the image for safety?
Choose **1 for: 'Unsafe', 2 for: 'Not sure / Average', 3 for: 'Safe'**

Question 4 (dropdown)
Do you see any abandoned buildings in the image
☐ **Yes**
☑ **No**

Question 5 (dropdown)
Do you see any buildings in the image that have been refined as loft residencies?
☐ **Yes**
☑ **No**

Question 6 (dropdown)
Do you see any industrial buildings in the image?
☑ **Yes**
☐ **No**

Fig. 5 Amazon mechanical turk submitted questionnaire (*left*) and features maps (*bottom*)

5.5 *Evaluation*

The results of the three surveys were overlapped and weighted in order to produce a series of maps at different scales that visualize gentrification in the Bay Area. Each method presents certain advantages. The Census data analysis provides an overview of the context over a significant time span (2000–2012) and helps us understand major socio-economic shifts. The open data analysis depicts the ephemeral layer of relationships that take place in the urban environment, which is impossible to be described by authoritative data, however it is more relevant to the actual conditions. The third method enriches the process with user personal feedback about ranking the environment of a neighborhood. The project aims to provide a calibrated

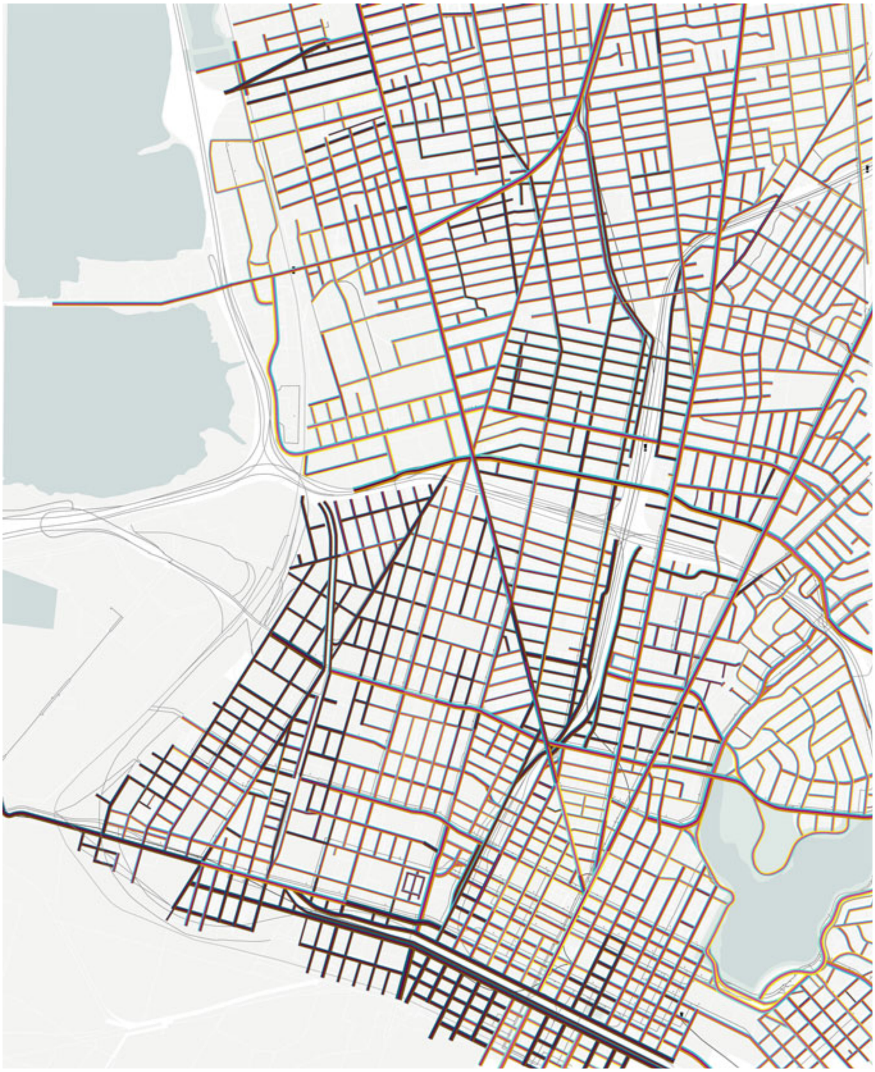


Fig. 6 Amazon mechanical turk street rating

understanding of the multiple grains of constructed space through top down and bottom up methods, as well as to offer a tool of visualizing dynamical characteristics of the urban environment. Our research balances the traditional census data analysis with more dynamic layers of collective platforms and crowdsourcing. Whichever method is considered more or less descriptive of the reality, it is worth examining all the conduits and corridors available to us, by which this change is being delivered. Looking at urban issues through maps can give us several hints about spatial and social transformations, in which we can think upon, as visualized information provokes feedback, either logical or emotional (Corner 1999). Throughout this entire process we can assess certain findings:

1. Based on the Census data search, nearly half of Bay Area census tracts are undergoing some form of neighborhood transformation and displacement.
2. The data accumulated from the ephemeral data research depict a significant artists' movement regarding art studio rent requests, artwork sale and creative services in general in the entire Bay Area and especially in San Francisco and Oakland. As it is also evident from the maps, Oakland has historically been overshadowed by the San Francisco arts scene; however, in combination with the staggering rise of rent in San Francisco, we can anticipate that the artist movement will intensify in East Bay in a short timeframe.
3. Studying Oakland at a local street view scale, we can assess that the area is undergoing disperse development that presents high contradictions related to infrastructure condition, affordability and safety. The results from the crowd-sourcing survey vary significantly in building block scale; therefore; any sense of continuity of the same character because of proximity is not necessarily a criterion to rely upon (Fig. 7).
4. Moreover, certain re-developed areas have uniform functional identity, such as Emeryville, as they present excessive duplication of the most profitable uses (malls, restaurants), while San Francisco and Oakland downtowns present excessive duplication of financial functions, (bank district).
5. We notice significant contradictions on the results of the crowed sourced research regarding infrastructure condition, safety and affordability perception of the participants. Some of the findings depict areas of new development (last 3–4 years) that are yet islanded off because the surrounding area is significantly undermined. However, this contradiction reveals certain dynamics regarding the future, further re-development of the area, as well as the areas that accumulate similar features (Figs. 8 and 9).

This new establishment of relationships is replacing almost entirely the previous condition of gradual displacement and gentrification. It evolves rapidly, and although it looks more orderly, visually, as many areas are undergoing significant upgrading, this aesthetic ordering might not have a social correlation. Social structure and social stability are inversely proportional to visual order. This condition is known to be establishing in Oakland, which was significantly undermined in the past few years, however the challenge is not only to identify the problem, but also to find the ways to analyze by mapping its characteristics it and communicate it visually to its extents. Understanding the shifts of urban space and finding the patterns that drive them is a big challenge. We support that close engagement with technology leads us to explore numerous research methods, which have a way of contributing to meaningful connections inside data networks. We find inspiration in the combination of the traditional ways of space categorization by investigating the relationship of home value, income, transportation et cetera with a bottom-up, participative approach in which individuals provide more ephemeral social

Fig. 7 Amazon mechanical turk neighborhood rating: Neighborhood infrastructure evaluation (*left top*), Safety (*right top*), Affordability (*right bottom*), Infrastructure and Safety comparison in *grey* scale to reveal contradicting characteristics (*left bottom*)

elements of neighborhoods. We believe that the composite association between them leads to a more informed decision-making and a more qualitative image of the city that reflects subjective aspects of urban planning (Batty 2013). As some of the above methods open the possibility to operate at a fine spatial scale, examining the city building by building, they provide the context for a more fine-grained understanding of neighborhood characteristics, conflicts and relationships that

Fig. 8 Oakland, artists activity and high priced real estate from ephemeral data research

reveal the heterogeneous characteristics of the city. Although it is impossible to predict precisely how and where changes will occur in the future, new combinations of data can create new knowledge and capacity for discovery that often comes from unlikely places. Throughout the entire survey the key aspect that brings all the results together is open data (accessible public data that are licensed to be reused). In order for our process to have a meaningful insight, it required putting data in context with other data, compare different timeframes and different scales, as accessible data by itself does not necessarily help us better understand, and interact

Fig. 9 Oakland, artists activity and high priced real estate overlaid with neighborhood infrastructure and safety comparison from mechanical turk study result

with, our cities. Open data allow for evidence-based decisions, analyze patterns and solve complex problems. We believe that the key to improve policymaking is engaging people to collaborate and use information to become more active in society. This would be a first step towards the equalization of power between citizens and stakeholders and the collaborative constructions of urban space.

6 Future Work

Future development of the project would be to find ways to enrich the process with user feedback data that will improve decision-making. One way to achieve that is the incorporation of social media feeds, such as Facebook and Twitter that would refine the tool by adding the feedback of targeted users and potential residents of the area. Social media is making feelings, thoughts and intentions about the city explicit and thus, creates new opportunities to improve the existing mapping tools, as most social media is geo-located. Almost all the main social network providers allow access to data feeds via an Application Interface (API), so the user data can be collected, filtered and open up the possibility of a real-time view of the city. In the years to come, it is vital to understand that as technology improves, the amount of data increases and designers should problematize on the cases where data provides unique understandings they couldn't have had otherwise or cases where it creates confusion that hinders designers' perception. The main challenges would be to identify whether we have enough data to create assumptions, whether we have the right type of data to support our claim and whether we can visualize urban space in ways that are perceived by everyone.

References

Batty, M. (2013). *The new science of cities*. Cambridge, Massachusetts: The MIT Press.

Corner, J. (1999). *The agency of mapping: Speculation critique and invention*. London: Reaktion Books.

Freeman, L. (2004). Gentrification and displacement: New York City in the 1990s. *Journal of the American Planning Association, 70*(1).

Glass, R. (1964). *Aspects of change*. London: MacGibbon & Kee.

Jacobs, J. (1961). *The death and life of great American cities*. New York: Vintage Books.

Lees, L., Slater, T., & Wyly, E. (2010). *The gentrification reader*. Oxon: Routtledge.

Owens, A. (2012). *Neighborhoods on the rise: A typology of neighborhoods experiencing socioeconomic ascent*. City & Community.

Sampson, J. (2011). *Great American city: Chicago and the enduring neighborhood effect*. Chicago: The University of Chicago Press.

Sassen, S. (1998). *Globalization and its discontents*. New York: New Press.

Tufte, E. (1990). *Envisioning information*. Connecticut: Graphics Press LLC.

Wolch, J., & Dear, M. (1993). *Malign neglect, homelessness in an American city*. San Francisco: Jossey—Bass Publishers.

Chapter 19
CityDash: Visualising a Changing City Using Open Data

Christopher Pettit, Scott N. Lieske and Murad Jamal

Abstract In an increasingly urbanised world, there are pressures being placed on our cities, which planners, decision-makers, and communities need to be able to respond to. Data driven responses and tools that can support the communication of information, and indicators on a city's performance are becoming increasingly available and have the potential to play a critical role in understanding and managing complex urban systems. In this research, we will review international efforts in the creation of city dashboards and introduce the City of Sydney Dashboard, known as CityDash. This chapter culminates in a number of recommendations for city dashboards' implementation. The recommendations for city dashboards include: consolidated information on a single web page, live data feeds relevant to planners and decision-makers as well as citizens' daily lives, and site analytics as a way of evaluating user interactions and preferences.

Keywords Open data · Smart cities · Visualisation · Dashboard · Real-time data

1 Introduction

In an era of big data, smart cities, Internet of things (IoT) and data analytics, the concept of the dashboard has emerged as way of visualising city performance as driven through city data. In some respects, dashboards have risen through the open

---

C. Pettit (✉) · M. Jamal
City Futures Research Centre, University of New South Wales, Sydney 2052, Australia
e-mail: c.pettit@unsw.edu.au

M. Jamal
e-mail: m.jamal@unsw.edu.au

S.N. Lieske
School of Earth and Environmental Sciences, University of Queensland, Brisbane 4072, Australia
e-mail: scott.lieske@uq.edu.au

S. Geertman et al. (eds.), *Planning Support Science for Smarter Urban Futures*, Lecture Notes in Geoinformation and Cartography,
DOI 10.1007/978-3-319-57819-4_19

government data movements being experienced globally. As noted by Kitchin et al. (2015a), urban or city dashboards provide one mechanism to collate, process, visualize, analyse, and share data, and they are becoming increasingly common. In fact, dashboards can be considered as an information output produced through the constructs of the smart city (Mattern 2014). Following ARUP (2010), we construe a smart cities' communication platform as consisting of: (1) "an increasing volume of real-time and other data"; (2) a data "repository and clearinghouse"; (3) analytical tools; and (4) "Public-facing products and services" (p. 24). This vision specifically links real-time data with public engagement.

The idea of a digital dashboard is a metaphor based on an automobile dashboard. The term dashboard invokes the displays of information seen in the instrument panels of automobiles and airplanes (Batty 2015; Mattern 2015). The dashboard metaphor is used in a variety of ways to communicate the idea of consolidation and presentation of data and information. Another way of considering city dashboards is as a city monitor. Batty (2015) characterises dashboards as moving from mechanical to digital monitors. However, like many things stemming from the automobile industry, the term dashboard seems to have stuck. This is in some ways rather unfortunate as the notion of a dashboard implies there is a driver—someone in control of the system. There is an inherent disconnect between dashboards and the controls of a mechanical system versus dashboards and controls in complex systems. In the case of urban systems, control may or may not be desirable. To the extent at which control of urban systems is desirable in practice; this control may be aspirational rather than actual.

Despite these conceptual limitations, it is clear dashboards allow us to document, assimilate, and display urban data. As such they potentially play a role in enabling better understanding of urban systems. This is important as we need many tools in the armoury to help us plan for better built environments, and manage increasingly stressed urban systems in a world that is expected to have more than 60% of the its population living in cities by 2030 (United Nations 2014). City dashboards, thus have an important role in the provision of real-time data to planners, decision-makers and citizens who can assist in making our cities more resilient and better able to respond to 'shocks' to the urban system.

In this chapter, we will provide a review of the role of city dashboards in communicating city data, and how they might be used more broadly as a type of planning support system to aid in the planning, management, and monitoring of urban systems. We provide an international review of city dashboards and related initiatives, particularly in the context of open data, which is an integral component of a public facing dashboard. Next, we present our work producing the City of Sydney Dashboard and discuss its purpose, architecture, and future development. Finally, we provide a set of recommendations on how dashboards can play an important role in assisting in city planning and citizen engagement.

2 Background

Dashboards may be defined as a means of collecting together and displaying a number of indicators through a common graphical interface. For Few (2006), a "dashboard is a visual display of the most important information needed to achieve one or more objectives; consolidated and arranged on a single screen so the information can be monitored at a glance" (p. 34). Just as a car dashboard provides critical information needed to operate the vehicle at a glance, indicator dashboards provide key information for running companies (Rivard and Cogswell 2004) or cities. Information is typically communicated through gauges, traffic light colours, meters, arrows, bar charts, graphs, maps, and other visual artefacts (Few 2006; Kitchin et al. 2015b).

Beyond the simple dashboards in the first automobiles, the next historical stage of dashboards arose through control room style establishments. There are a number of examples of control rooms with dashboards including the Royal Air Force Fighter Command from the Battle of Britain, the National Aeronautics and Space Administration's Mission Control Center (Mattern 2015), and the Cybersyn Project, which was a decision support system and control room for managing the Chilean economy under the Allende government in the 1970s (Batty 2015; Mattern 2015). Contemporary urban examples of dashboards as control rooms include Baltimore's CitiStat and the Centro de Operações Rio designed by IBM.

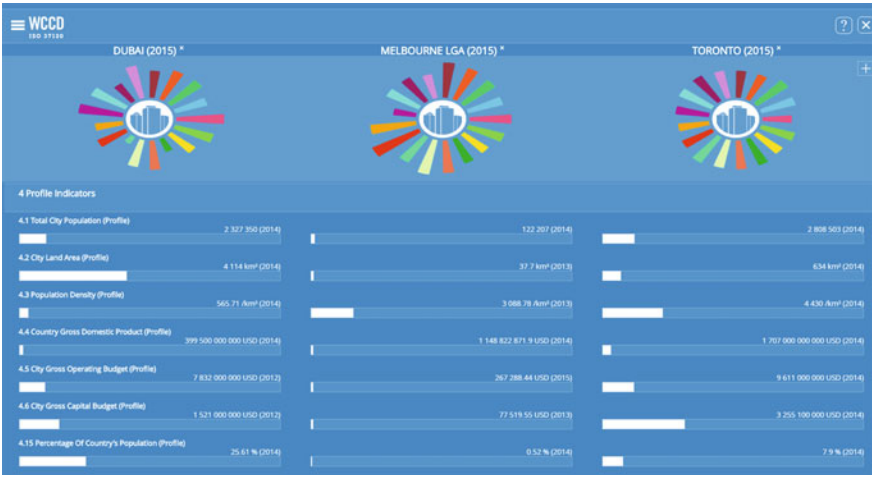
The City of Baltimore developed CitiStat, which has become a widely emulated effort to improve municipal performance and accountability through both data integration and display (Henderson and Center 2003). CitiStat also provides indicators and metrics that enable quantitative assessment of city departments. Systems based on CitiStat have been set up on numerous cities and states (Kitchin et al. 2015a; Mattern 2015). The Centro de Operações Rio has a focus on emergency services but also collects, integrates, and analyses trends and patterns in information from 30 municipal agencies in Rio de Janero, Brazil (Prefeitura do Rio de Janeiro 2010; Singer 2012; Mattern 2014; Batty 2015; Kitchin et al. 2015a) summarize the features of control rooms including walls of computer screens presenting data visualisations.

Yet in more recent times, we have seen the emergence of a number of online dashboards which started off as static website with indicators of performance supported by static images and maps like that of the World Council of City Data's Open Data Portal discussed in Sect. 3. However, with the advent of web services and data stores, we have seen the latest incarnation of city dashboards. The latest generation of dashboards can support the interactive visualisation of real-time data aggregated from online datastores also known as clearinghouses. The next section of the chapter takes an international perspective in providing a concise review of the current state of play of city dashboards.

3 Review of City Dashboards

The World Council on City Data (WCCD) provides data, maps, and a dashboard for over 30 cities through a website and portal infrastructure. Data are provided directly by the participant cities who submit reports that are compliant to ISO 37120, a recently created ISO standard for measuring and monitoring city service and quality (ISO 2014). ISO 37120 provides a comprehensive list of over 100 city indicators which ultimately allow the comparisons between cities. The WCCD open data portal requires cities to manually upload their data into the WCCD data store. Data are then visualized against the 17 themes for which there are over 100 indicators displayed in static bar charts. Figure 1 shows data acquired from the WCCD dashboard for cities Dubai, Melbourne, and Toronto based on reports from 2015. Such a dashboard might be of use to city planners, citizens and decision-makers wishing to compare the performance between cities.

The Dublin Dashboard has been developed by Maynooth University through the Programmable City Initiative (www.dublindashboard.ie). The developers of the Dublin Dashboard describe it as a website that is "*extensive, open*" and "*analytical*" (Kitchin et al. 2015a, p. 6). While they highlighted the use of real-time information, this is only one of a myriad of features, which includes extensive data, interactive data visualisations and maps, indicators and trends, service locations, functionality for reporting problems to the city government, as well links to Dublin themed apps (e.g. parking, airport, cycle planning). The site uses open data and is publicly accessible (Kitchin et al. 2015a). The Dublin dashboard is in fact a library of dashboards connected to a number of data modules (Kitchin et al. 2015a). The vision for the Dublin Dashboard is for the site to be a tool for users to interact with organized data including filtering and analysis. The Dublin Dashboard team



4 Profile Indicators

	DUBAI (2015) *	MELBOURNE LGA (2015) *	TORONTO (2015) *
4.1 Total City Population (Profile)	2 327 350 (2014)	122 207 (2014)	2 808 503 (2014)
4.2 City Land Area (Profile)	4 114 km^2 (2014)	37.7 km^2 (2013)	634 km^2 (2014)
4.3 Population Density (Profile)	565.71 /km^2 (2014)	3 088.78 /km^2 (2013)	4 430 /km^2 (2014)
4.4 Country Gross Domestic Product (Profile)	399 500 000 000 USD (2014)	1 148 822 871.9 USD (2014)	1 707 000 000 000 USD (2014)
4.5 City Gross Operating Budget (Profile)	7 832 000 000 USD (2012)	267 288.44 USD (2015)	9 611 000 000 USD (2014)
4.6 City Gross Capital Budget (Profile)	1 521 000 000 USD (2012)	77 519.55 USD (2013)	3 255 100 000 USD (2014)
4.15 Percentage Of Country's Population (Profile)	25.61 % (2014)	0.52 % (2014)	7.9 % (2014)

Fig. 1 WCCD metrics for Dubai, Melbourne, and Toronto's 2015 performance (2015)

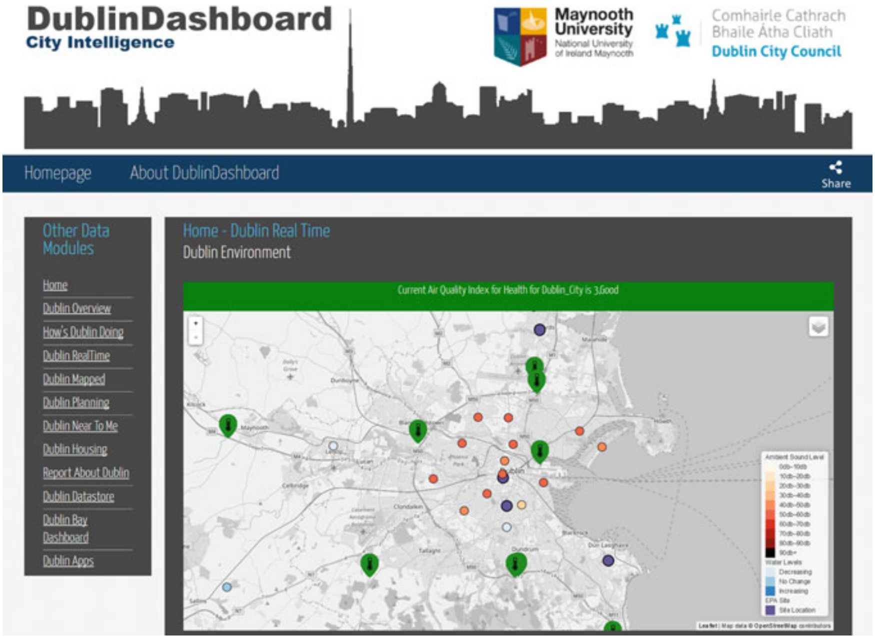


Fig. 2 Dublin Dashboard—air quality monitoring index for health using real-time environmental information (Maynooth University 2016)

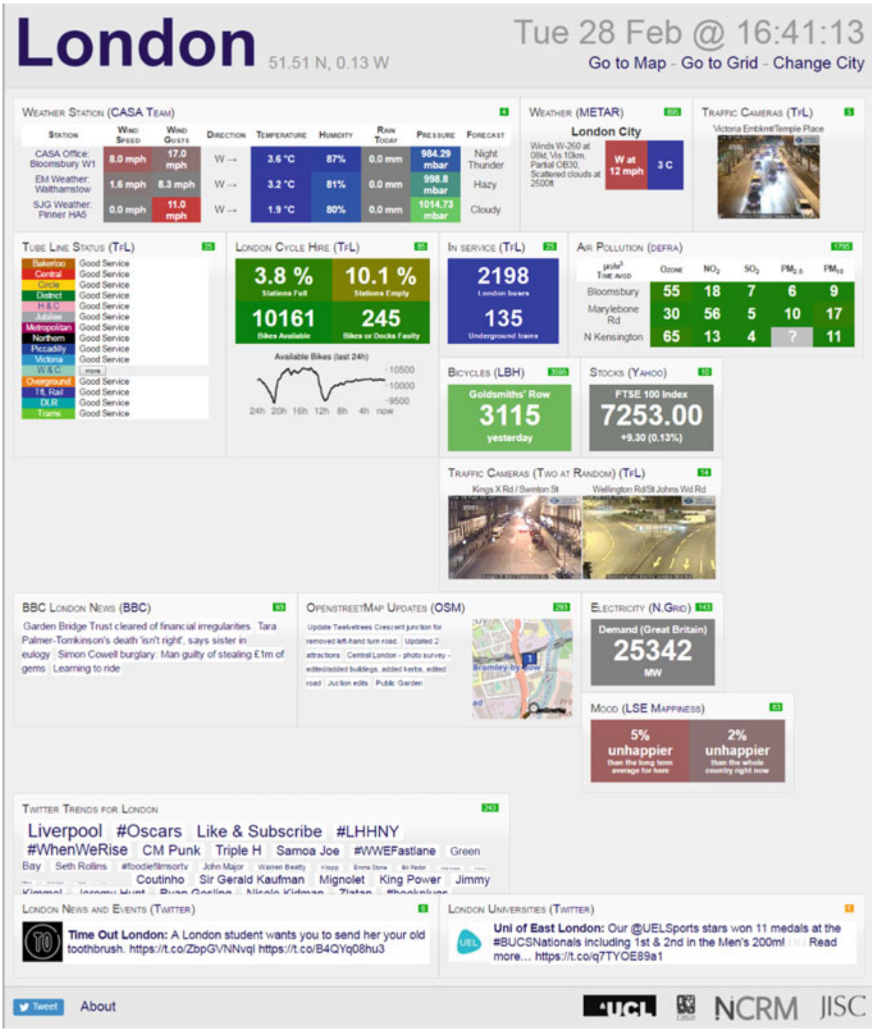
highlights the ability of users to explore and interpret data without those users requiring specialized analytical skills. Visualisations from the site may also be exported for sharing or use in documents, and the data itself may be exported for specialised analysis. Within this dashboard suite, the user can choose to evaluate how Dublin is performing against a series of indicators, or connect to real-time data points being collected through sensors and web services as shown in Fig. 2. Within Dublin Dashboard, users can also explore map layers and see what is going on in city planning, including the current planning applications being assessed by Council. These features provide the means for answering a number of questions about the city including how is the city performing? What is happening now in Dublin? And how does Dublin compare with other cities (Kitchin et al. 2015a)? This treasure trove of dashboards even provides accessibility metrics and housing data including housing monitors and vacancy rates. With such a vast collection of dashboards, it would seem that the tool caters for a wide range of audiences from city planners, to health officials, environmental officers and citizens alike.

There is a group of dashboards that emphasises the use of open data feeds to display real-time data, primarily focused within a single screen or web page. Batty (2015) describes the *city dash* presentation of dashboards as a technical exercise in aggregating and displaying live data feeds. A well-known example of the style is the CityDashboard, a data-driven website that presents real-time metrics for various cities in the United Kingdom including Birmingham, Brighton, Cardiff, Edinburgh, Glasgow, Leeds, London, and Manchester. Each live metric of the city is presented as a single widget on the main page of the website and is updated at various intervals without the need for manual refreshing. The moveable widgets include links to a number of open data feeds. The platform was originally built for the City of London as a proof of concept that these sorts of systems could provide the everyday citizen with an overview of the short term 'daily' dynamics within the city (Gray et al. 2016). From Mattern (2015), the combination of weather data, public transportation status, traffic cameras, news, and twitter trends is an effort to communicate the "*pulse*" of the city.

As described by Gray et al. (2016), the key to the CityDashboard is the increasing availability of open data feeds. The design emphasis is guided by data availability, frequency of update, and potential interest to citizens. In incorporating data into the dashboard, the creators also consider whether the data are available for multiple cities and if the data are collected ethically (Gray et al. 2016). Citizens are the key user group. Batty (2015) notes each widget may have its own interpretation by each individual user without needing detailed analysis. Behind the scenes, the dashboard is collecting and storing all the information in displays, thus providing a rich longitudinal database of a number of key city metrics that can be used for other research projects. The CityDashboard also offers a grid and map view of the data, but there is an apparent user preference for the Dashboard view displayed in Fig. 3. Gray et al. (2016) note that the map is relatively underutilised in practice. The one additional click required to access the map from the main page appears to be the barrier. Gray et al. (2016) speculate this may be due to users not noticing the link to the map on the main page and suggest further research. To an extent, the one-click barrier between data and map would seem to have implications for dashboards designed across multiple web pages. Yet, this could be a subject for empirical usability investigations.

Kitchin et al. (2015b) posit that dashboards enable visualisation of mixes of real-time and trend data, and provide the public and decision-makers both up-to-date and trend information on urban systems. This aligns exactly with Kitchin et al.'s goal for city dashboards, which is to measure and monitor elements of urban systems. This goal of the creators of the Dublin Dashboard is more ambitious than the citydash perspective. The Amsterdam City dashboard (http://citydashboard.waag.org/), though indicated as being under construction at the time of this writing, is similar to the Dublin dashboard in that a previous investigation suggests that it also presents real-time data along with longer term trends and analytical tools (Batty 2015, p. 31).

The State of Michigan's Open Michigan Mi Dashboard (https://midashboard.michigan.gov/) presents information as data and indicators within categorised widgets—a variant of Tufte's small multiples (a series of similar scale graph, charts or maps), that allows direct comparisons within a single page (Tufte 2001). The categories used in the dashboard include economic strength, health and education, value for government money, quality of life, and public safety. From the data and



Station	Wind Speed	Wind Gusts	Direction	Temperature	Humidity	Rain Today	Pressure	Forecast
CASA Office: Bloomsbury W1	8.0 mph	17.0 mph	W →	3.6 °C	87%	0.0 mm	984.29 mbar	Night Thunder
EM Weather: Walthamstow	1.6 mph	8.3 mph	W →	3.2 °C	81%	0.0 mm	998.8 mbar	Hazy
SJG Weather: Pinner HA5	0.0 mph	11.0 mph	W →	1.9 °C	80%	0.0 mm	1014.73 mbar	Cloudy

Winds W-260 at 08kt, Vis 10km, Partial OB30, Scattered clouds at 2500ft

Bakerloo	Good Service
Central	Good Service
Circle	Good Service
District	Good Service
H & C	Good Service
Jubilee	Good Service
Metropolitan	Good Service
Northern	Good Service
Piccadilly	Good Service
Victoria	Good Service
W & C	more
Overground	Good Service
TfL Rail	Good Service
DLR	Good Service
Trams	Good Service

µg/m³ Time avgd	Ozone	NO_2	SO_2	$PM_{2.5}$	PM_{10}
Bloomsbury	55	18	7	6	9
Marylebone Rd	30	56	5	10	17
N Kensington	65	13	4	?	11

Garden Bridge Trust cleared of financial irregularities Tara Palmer-Tomkinson's death 'isn't right', says sister in eulogy Simon Cowell burglary: Man guilty of stealing £1m of gems Learning to ride

Update Twelvetrees Crescent junction for removed left-hand turn road. Updated 2 attractions Central London - photo survey - edited/added buildings, added kerbs, edited road Juction edits Public Garden

Liverpool #Oscars Like & Subscribe #LHHNY #WhenWeRise CM Punk Triple H Samoa Joe #WWEFastlane Green Bay Seth Rollins #foodiefilmsortv John Major Warren Beatty Klopp Emma Stone Bi Parker Coutinho Sir Gerald Kaufman Mignolet King Power Jimmy

Time Out London: A London student wants you to send her your old toothbrush. https://t.co/ZbpGVNNvql https://t.co/B4QYq08hu3

Uni of East London: Our @UELSports stars won 11 medals at the #BUCSNationals including 1st & 2nd in the Men's 200m! Read more… https://t.co/q7TYOE89a1

Fig. 3 CityDashboard—real-time data aggregated and displayed for City of London (Centre for Advanced Spatial Analysis 2017)

indicators themselves, the Michigan dashboard allows links to charts and underlying data. Mattern (2015) notes there is little information on how data are derived.

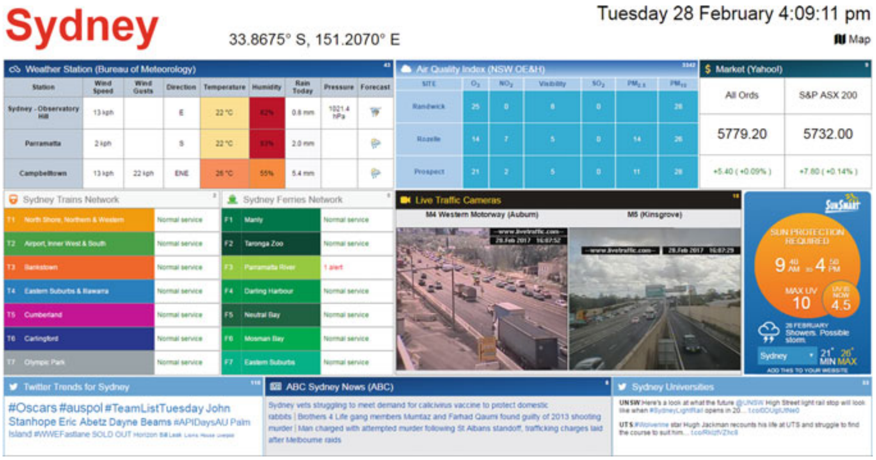
Data2GO.NYC (http://www.data2go.nyc) assimilates and makes accessible federal, state and local data for New York City. Data are presented in a number of categories including an index of human development, demographics, education, environment, food systems, health, housing and infrastructure, political engagement, public services, safety and security, as well as work, wealth and poverty. Their dashboard interface presents widget-like displays of data and indicators linked with a city map that allows brushing (dynamic linking) between charts and maps.

In creating the Dublin Dashboard, Kitchin et al. (2015a, p. 8) indicated that they sought to merge the single page live data immediacy of the London City Dashboard with the data clearinghouse functions of the London Datastore. The London data clearinghouse previously referred to themselves as a dashboard (formerly at http://data.london.gov.uk/london-dashboard; currently at https://data.london.gov.uk/). The London Datastore describes itself as, "*…a free and open data-sharing portal where anyone can access data relating to the capital*" (London Datastore 2016). San Francisco offers a similar data store, SF OpenData, which describes itself as "*…the central clearinghouse for data published by the City and County of San Francisco*" (https://data.sfgov.org/). SF OpenData also offers an API which would allow developers to communicate, receive and visualize data. Similarly, the Smart Nation Singapore initative (https://www.smartnation.sg/) offers assistance to Singaporean open data and the opportunity for developers to create their own city dashboards. A number of these are being developed as smart phone applications, with specific targeted application domains such as Health as in the example of HealthHub (https://www.healthhub.sg/). While such open data initiatives like those of San Francisco and Singapore are absolutely critical in supporting city dashboards, it is important to note that the platforms themselves do not constitute city dashboards.

The Dublin, Amsterdam and New York dashboards align well with the definition of a well-designed dashboard—one that both includes real-time data as well as information on historical trends (Few, cited in Mattern 2015). In contrast with the citydash perspective, the more integrated perspective with the extension of data visualisation to emphasize measuring and monitoring leans toward the idea of control. Analysis of these dashboards suggest a number of critical research directions including interface design for citizens (Mattern 2014), examination of both current and future urban digital communication platforms (Mattern 2014), and the need for more powerful data-based analysis of user interaction and interpretation of data (Kitchin et al. 2015b; Batty 2015). Also, research in developing live data feeds into a more aggregated, purpose-based evaluation of city performance as well as evaluation of city performance over time is especially relevant to citydash style dashboards (Batty 2015). Most generally, Kitchin et al. (2015a) argue for more dashboard research so as to establish a broader empirical base for dashboard research and allow additional comparison between dashboard development efforts. It is in this light that we now introduce the Sydney City Dashboard.

4 Sydney City Dashboard

After reviewing the state of play of existing dashboards and given there was not an authoritative dashboard for Sydney, we decided to build our own City Dashboard known as CityDash. CityDash is significantly influenced by London's CityDashboard as it was developed through the Centre for Advanced Spatial Analysis (CASA), University of College London (Gray et al. 2016).



Sydney 33.8675° S, 151.2070° E

Tuesday 28 February 4:09:11 pm

Map

Weather Station (Bureau of Meteorology)

Station	Wind Speed	Wind Gusts	Direction	Temperature	Humidity	Rain Today	Pressure	Forecast
Sydney - Observatory Hill	13 kph		E	22 °C	[illegible]	0.8 mm	1021.4 hPa	
Parramatta	2 kph		S	22 °C	[illegible]	2.0 mm		
Campbelltown	13 kph	22 kph	ENE	26 °C	55%	5.4 mm		

Air Quality Index (NSW OE&H)

SITE	O_3	NO_2	Visibility	SO_2	$PM_{2.5}$	PM_{10}
Randwick	25	0	6	0		28
Rozelle	14	7	5	0	14	26
Prospect	21	2	5	0	11	28

Market (Yahoo!)

All Ords	S&P ASX 200
5779.20	5732.00
+5.40 (+0.09%)	+7.80 (+0.14%)

Sydney Trains Network

T1	North Shore, Northern & Western	Normal service
T2	Airport, Inner West & South	Normal service
T3	Bankstown	Normal service
T4	Eastern Suburbs & Illawarra	Normal service
T5	Cumberland	Normal service
T6	Carlingford	Normal service
T7	Olympic Park	Normal service

Sydney Ferries Network

F1	Manly	Normal service
F2	Taronga Zoo	Normal service
F3	Parramatta River	1 alert
F4	Darling Harbour	Normal service
F5	Neutral Bay	Normal service
F6	Mosman Bay	Normal service
F7	Eastern Suburbs	Normal service

Twitter Trends for Sydney

#Oscars #auspol #TeamListTuesday John Stanhope Eric Abetz Dayne Beams #APIDaysAU Palm Island #WWEFastlane SOLD OUT Horizon Bill Leak Lions House [illegible]

ABC Sydney News (ABC)

Sydney vets struggling to meet demand for calicivirus vaccine to protect domestic rabbits | Brothers 4 Life gang members Mumtaz and Farhad Qaumi found guilty of 2013 shooting murder | Man charged with attempted murder following St Albans standoff, trafficking charges laid after Melbourne raids

Sydney Universities

UNSW Here's a look at what the future @UNSW High Street light rail stop will look like when #SydneyLightRail opens in 20… [illegible]

UTS #Wolverine star Hugh Jackman recounts his life at UTS and struggle to find the course to suit him… [illegible]

Fig. 4 Sydney City Dashboard (City Futures Research Centre 2017). *Source* http://citydashboard.be.unsw.edu.au/

The CityDash platform aggregates a number of data feeds including air quality, weather, sun protection, market information, multi-modal public transit, traffic cameras, news, and selected Twitter feeds (see Fig. 4). The front end architecture is based on React JS where each data widget represents a ‘React Widget’ which communicates with the back end using the Dashboard API (see Fig. 5 for System Architecture). The front end is also built upon an open source react-based grid layout framework called React Grid Layout which provides configurable layouts targeted for user device screen size, thus making it responsive across devices.

The back end architecture is based on the python-based Django Framework. On top of it sits the Dashboard API which handles all the requests coming from the front end (e.g. Bureau of Meteorology’s API et cetera), does the processing, and returns the data back in JSON file format. This combination of technologies allows open data feeds to provide a real-time city dashboard—the digital pulse of Sydney.

Google Analytics has been integrated into CityDash. (see Fig. 6). With this integration, we can learn more details about CityDash’s users and their activity on CityDash. Interacting with the Google Analytics web app we can, for instance, determine user session activity, geographical location, and event interactions such as clicking on navigational links and dashboard widgets. This will serve as a barometer for the success of the dashboard and will be monitored for usage patterns over time.

Similar to the London Dashboard, CityDash also has a map view (see Fig. 7). The Sydney map view is primarily focused on creating a transportation map which displays real-time locations of different modes of transportation including buses, trains, ferries and light-rail. The map uses the CityDash Dashboard API to retrieve relevant data for the different transportation modes. The technical architecture for the dashboard’s map view is shown in Fig. 8. On the back end, two new web

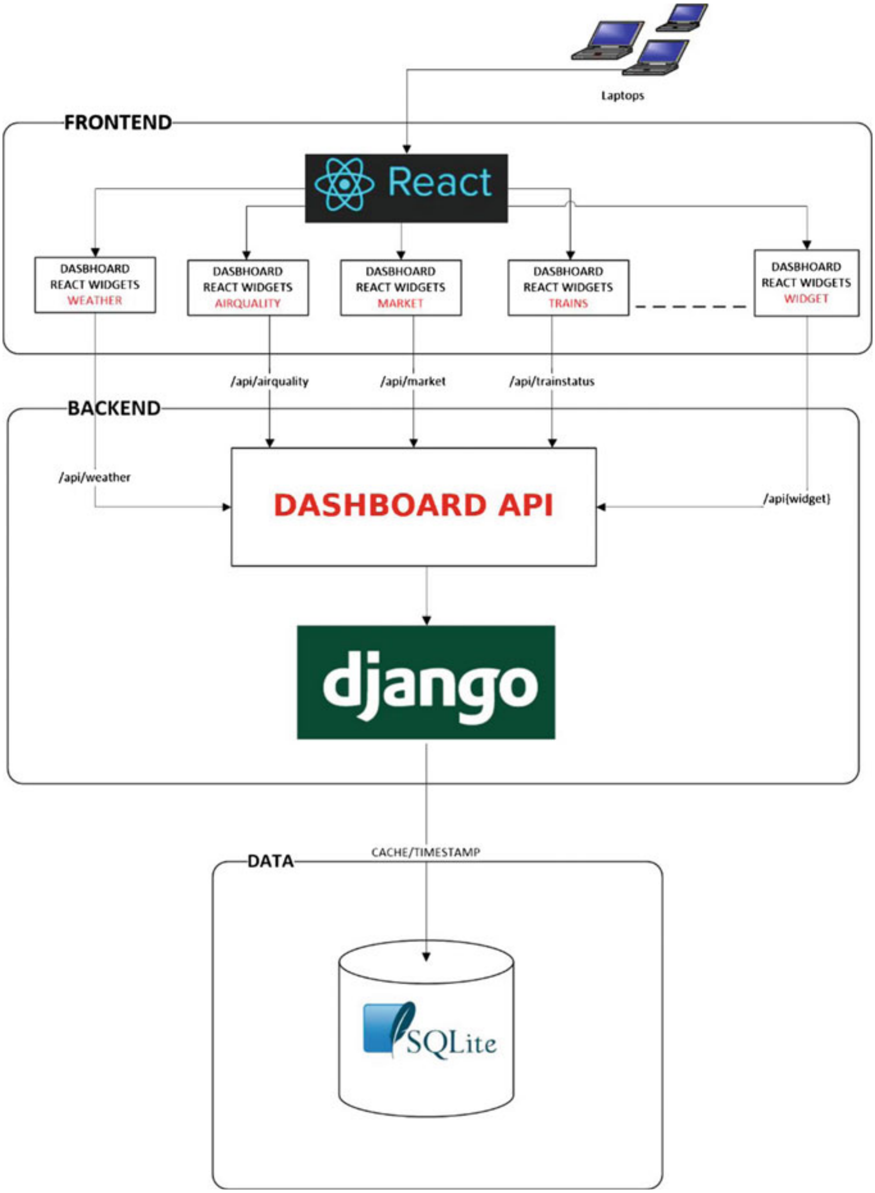


Fig. 5 Technical Architecture of CityDash

services have been introduced in the API. These services interact with the API from Transport for NSW (TfNSW) using Google GTFS technology to communicate and receive data. One service is scheduled to run on specific intervals, downloading updates for daily timetables, trips, and routes, and then processing data to the

Sessions 251

Users 111

Pageviews 489

Pages / Session 1.95

Avg. Session Duration 00:03:48

Bounce Rate 2.39%

% New Sessions 41.83%

Demographics
Language
Country
City

System
Browser
Operating System
Service Provider

Mobile
Operating System
Service Provider
Screen Resolution

	City	Sessions	% Sessions
1.	Saint Petersburg	89	35.46%
2.	Sydney	36	14.34%
3.	Samara	28	11.16%
4.	(not set)	22	8.76%
5.	Moscow	13	5.18%
6.	Minden	10	3.98%
7.	London	10	3.98%
8.	Rome	10	3.98%
9.	Zeltweg	9	3.59%
10.	Cologne	7	2.79%

view full report

Fig. 6 CityDash using metrics as provided through Google Analytics

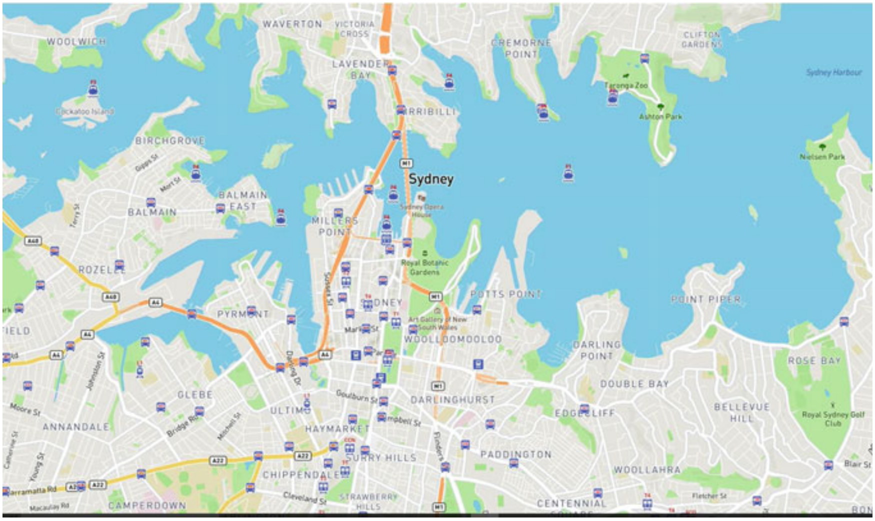


Fig. 7 CityDash Map View—real-time location of buses across Sydney

database while another service gets real-time vehicle positions for different transport modes.

On the front end, we are using mapbox-gl-js to apply symbology and visualize real-time vehicle positions. The front end calls the relevant dashboard API web service every 20 s to get the vehicle position updates, while the web service itself calls the TfNSW API every 20 s to get updates. Each of these "calls" from the CityDash widgets have their own poll intervals. Table 1 lists the widgets and their

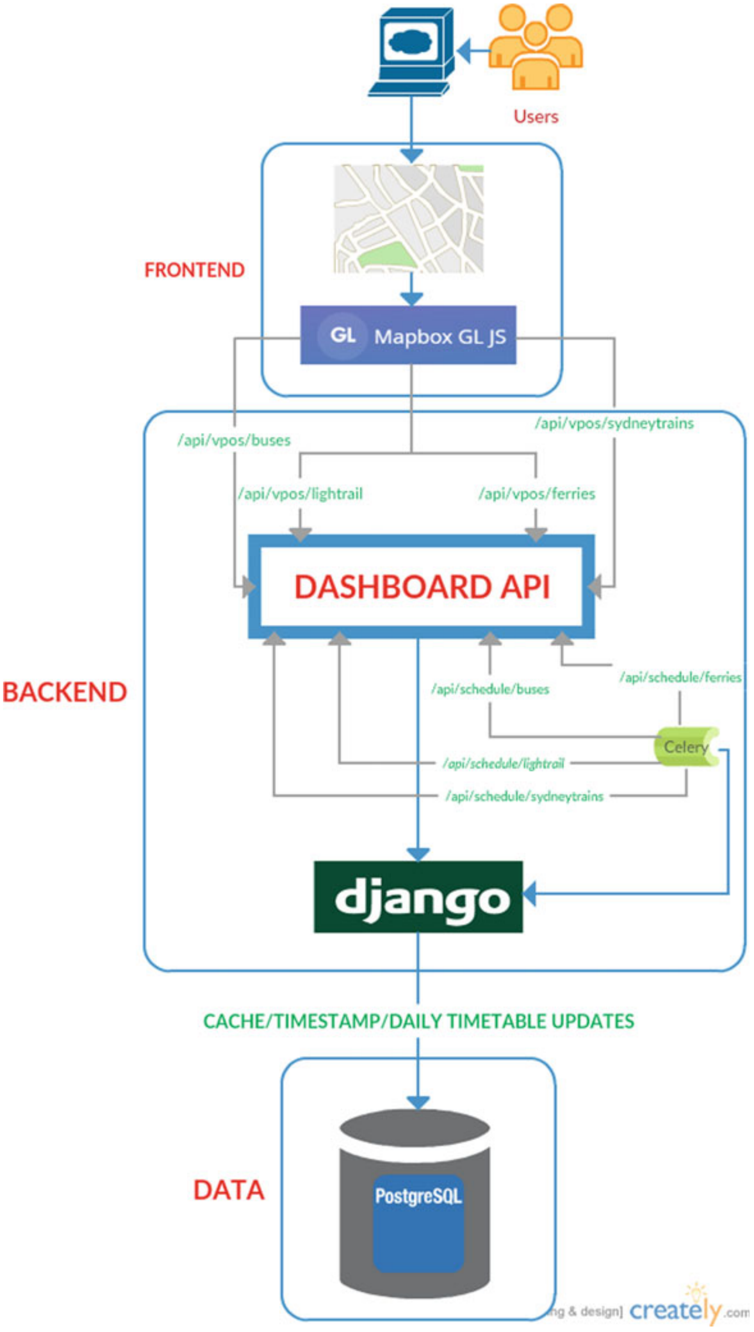


Fig. 8 CityDash Map view Technical Architecture

Table 1 Sydney CityDash data interval times

Widgets	Data interval time
Weather (BOM)	5 min
Air Quality (NSW OEH)	1 h
Sydney Trains Network	10 s
Sydney Ferries Network	10 s
Market (Yahoo)	10 s
ABC News	10 s
Live Traffic Cameras	20 s
Twitter Trends for Sydney	2 min
Sydney Universities	1 min

respective data interval times. Interval times are set according to the data update frequency of the corresponding data source.

In the next section of the chapter we draw upon the insights in undertaking a review of the state of the art in city dashboards and the experiences in creating the Sydney Citydash.

5 Recommendations for City Dashboard

Recommendation 1. Understand the specific purpose of a dashboard and design accordingly. Following from Kitchin et al. (2015a), "*…the dashboard interface … profoundly influences its message and use*" (p. 5)—do not try and create one dashboard for all users, i.e. a dashboard that will meet the needs of decision-makers, planners, technologists and citizen all via one dashboard. Different cohorts have different user requirements. For example, household vacancy rates or average household size in a city would be of interest to a city planner, but not necessarily to an ordinary citizen. Meanwhile, the average citizen will be interested in public transport performance, particularly in real-time as they plan their journey home for the day. A dashboard that tries to satisfy everyone is likely to satisfy no one.

Recommendation 2. When developing a city dashboard, human computer interaction (HCI) guidelines—particularly around usability—should be considered. City dashboards should be tested with end users to ensure they meet their requirements both from a functionality and usability perspective. It is recommended that a more general usability evaluation framework, such as DEFINITE as developed by Rogers et al. (2011) be deployed. Such a framework has been used and customised in the development and testing of Planning Support Systems (Russo et al. 2015), and would be suitable for evaluating the usability of city dashboards. For example, focus group meetings and/or usability testing sessions should occur with the actual end users of the dashboard rather than those who are funding and creating a dashboard for an assumed end user group. Also with a neo-liberal agenda in place in a number of countries, government agencies increasingly have a tendency to outsource the creation of dashboards. It has been observed that common practice is to test such dashboards internally between that government agency and the dashboard developer but not necessarily including the actual end user who in many instances are in another government group or even the wider public. This can cause issues in the wider adoption of the city dashboard.

Recommendation 3. Dashboards should support the visualisation of big data to support locational insights. Batty (2013) and Kitchin et al. (2015a) surmise that the embedding of sensors and computing within nearly every aspect of urban systems and infrastructure is producing vast quantities of data. These data are typically tied to either time or location (or both), and represent a substantial increase in the availability of data, which describe and predict what happens when and where in urban systems (Batty 2013). Dashboards are an information interface to smart cities (Mattern 2014). They have the potential to move smart cities where infrastructure are embedded with sensors, big data are generated, and volumes of data are crowdsourced—towards smart governance that links ICT with public participation and collaboration. For example, a recent paper by Pettit et al. (2016) reports on the processing, visualisation and new insights on the bikeability of cities made possible through urban big data. This crowdsourced data from a smart phone application has resulted in the CityViz City movement indicators for Sydney and Melbourne which are essentially map-based dashboard for informing planners and urban designers where citizen are commuting across the city (see: https://cityfutures.be.unsw.edu.au/cityviz/). As these urban big data visualisations are public facing they have been receiving media attention and creating a dialogue between the community and city planners around the bikeability of Australian cities.

Recommendation 4. Link dashboards to established online data repositories, commonly referred to as open data stores, clearinghouses, portals, or hubs. There is a significant open data movement, which has seen the development of large government data repositories; e.g. the London DataStore in the UK (https://data.london.gov.uk/), and the transport Open Data portal in Sydney (https://opendata.transport.nsw.gov.au/search/type/dataset). Where possible, dashboards should leverage such open access data services to provide point of truth access to real-time city data. City dashboards then become aggregators of up-to-date data, making it more attractive for the end user to revisit and use the dashboard. Real-time data has relevance to city resilience in so much that if there is a shock to the system (e.g. flood), such real-time data as Twitter information can be used as part of the emergency response and planning. See for example the PetaJakarta project which is a crowdsourced approach to real-time mapping of floods in Jakarta using tweets (Perez et al. 2015).

Recommendation 5. Support a two-way exchange of information to empower citizens to engage with elements of the dashboard. This can be achieved by embedding social media data feeds, as is the case with the London and Sydney dashboards. Additional functionality would enable citizens to post comments via mapping pinboard applications such as pinmaps. (https://www.pinmaps.net/mymaps/). For example, the pioneering work in online public participatory GIS (PPGIS) by Kingston et al. (2000) enabled the community to interactive with the shaping Slaithwaite Village project and leave online comments and participate in the planning process. However, it was noted by the researchers that the cost of certain data from the UK Survey Ordinance proved a problem. However, with the advent of open data access across the UK, and in many countries around the world such barriers for community participation in using such online mapping and dashboard tools are greatly reduced.

6 Conclusions and Future Work

In recent times, there has been a step change in the production of urban data through the embedding of computation into the fabric and infrastructure of cities. This creation of 'everyware' (Greenfield 2006) produces a new form of data-rich and data-driven networked urbanism (Shepard 2011; Kitchin and Dodge 2011; Townsend 2013). Here, a variety of devices, cameras, transponders, actuators and sensors, each producing streams of big data that can be processed and responded to in real-time, are used to augment and mediate the operation and governance of urban systems (Kitchin 2015b). These digital environments, which are machine-readable and controllable form a critical part of the present, drive to create a new form of tech-urbanism—that which is widely termed 'smart cities' (Hollands 2008; Townsend 2013; Kitchin et al. 2015b). With this plethora of data, which is being captured as part of the smart cities agenda, we are now able to create visual interfaces or city dashboards due to the democratisation of data available within cities, and chiefly due to the increasing use of open datastores (Gray et al. 2016). This real-time information is now offering exciting possibilities for further community engagement in city planning, including the response to system shocks such as floods, as demonstrated in the PetaJakarta project (Perez et al. 2015).

In the context of the City of Sydney Dashboard, the next steps in development and research include enhanced data feed mapping (additional data feeds along with clear and compelling presentation within widgets), archiving storage and retrieval mechanisms, improvements to the real-time map showing transportation feeds across the city, and the inclusion of thematic maps of service performance. The implementation of two-way interactivity so that citizens can actively engage and contribute comments to the dashboard is considered an important next step. Finally, the user testing and evaluation of the dashboard to improve functionality and usability is considered critical. Google Analytics provides some useful metrics for this but further one-on-one testing with end users is also crucial.

In this chapter we have provided a critique of the state of play in city dashboards. We have introduced the Sydney City Dashboard, known as CityDash. Finally, we have provided a series of recommendations with supporting examples, which we believe are important for the success and future of city dashboards as one of the digital tools for measuring and monitoring the performance of smart cities. Measuring and monitoring done in a way that is engaging to the most important end users—the people who live in the city—is crucial if we are to realise the vision of smart and resilient cities.

References

ARUP. (2010). C40 urban life: Melbourne smart city. http://www.cityofsound.com/files/c40_melbourne_report_final_email.pdf. Accessed November 27, 2016.

Batty, M. (2013). Big data, smart cities and city planning. *Dialogues in Human Geography, 3*(3), 274–79. doi:10.1177/2043820612513390

Batty, M. (2015). A perspective on city dashboards. *Regional Studies, Regional Science, 2*(1), 29–32. doi:10.1080/21681376.2014.987540

Few, S. (2006). *Information dashboard design: The effective visual communication of data*. Sebastopol, CA: O'Reilly Media, Incorporated.

Gray, S., O'Brien, O., & Hügel, S. (2016). Collecting and visualizing real-time urban data through city dashboards. *Built Environment, 42*(3), 498–509.

Greenfield, A. (2006). *Everyware: The dawning age of ubiquitous computing*. Berkeley, CA: New Riders.

Henderson, L. J., & Center, W. (2003). *The Baltimore citistat Program: Performance and accountability*. Arlington, VA: Managing Results Series, IBM Endowment for The Business of Government.

Hollands, R. (2008). Will the real smart city please stand up? Intelligent, progressive, or entrepreneurial? *City, 12*(3), 303–320. doi:10.1080/13604810802479126

ISO. (2014). *ISO 37120:2014 Sustainable development of communities—Indicators for city services and quality of life*. http://www.iso.org/iso/catalogue_detail?csnumber=62436. Accessed November 27, 2016.

Kingston, R., Carver, S., Evans, A., & Turton, I. (2000). Web-based public participation geographical information systems: An aid to local environmental decision-making. *Computers, Environment and Urban Systems, 24*(2), 109–125.

Kitchin, R., & Dodge, M. (2011). *Code/space: Software and everyday life*. Cambridge, MA: MIT Press.

Kitchin, R., Maalsen, S., & McArdle, G. (2015a). The praxis and politics of building urban dashboards. *SSRN Electronic Journal*. doi:10.2139/ssrn.2608988

Kitchin, R., Lauriault, T. P., & McArdle, G. (2015b). Knowing and governing cities through urban indicators, city benchmarking and real-time dashboards. *Regional Studies, Regional Science, 2*(1), 6–28. doi:10.1080/21681376.2014.983149.

London Datastore. (2016). London Datastore. https://data.london.gov.uk/. Accessed December 12, 2016.

Mattern, S. (2014). Interfacing urban intelligence. *Places*. https://placesjournal.org/article/interfacing-urban-intelligence/. Accessed November 27, 2016.

Mattern, S. (2015). Mission control: A history of the urban dashboard. *Places*. https://placesjournal.org/article/mission-control-a-history-of-the-urban-dashboard/. Accessed November 23, 2016.

Perez, P., du Chemin, T. H., Turpin, E., & Clarke, R. (2015, September). Citizen-driven flood mapping in Jakarta: A self-organising socio-technical system. In: *2015 IEEE International Conference on Self-Adaptive and Self-Organizing Systems Workshops (SASOW)* (pp. 174–178). IEEE.

Pettit, C. J., Lieske, S. N., & Leao, S. Z. (2016). Big bicycle data processing: From personal data to urban applications. In *ISPRS XXIII Congress (2016)*, Prague, Czech Republic, July 12–19th, 2016.

Prefeitura do Rio de Janeiro. (2010). Centro de Operações Rio chega para integrar 30 órgãos municipais. http://www.rio.rj.gov.br/web/guest/exibeconteudo?article-id=1419835. Accessed November 28, 2016.

Rivard, K., & Cogswell, D. (2004). Are you drowning in BI reports? Using analytical dashboards to cut through the clutter. *DM Review*. http://internal.advizorsolutions.com/press/Cut%20Through%20The%20Clutter.pdf. Accessed December 16, 2016.

Rogers, Y., Sharp, H., & Preece, J. (2011). *Interaction design: Beyond human-computer* (3rd ed.). Chichester, West Sussex: Wiley.

Russo, P., Costabile, M., Lanzilotti, R., & Pettit, C. (2015). Usability of planning support systems: An evaluation framework. In S. Geertman, J. Ferreira, J. Goodspeed, & R. Stillwell (Eds.), *Planning support systems and smart cities, Lecture notes in geoinformation and cartography* (pp. 337–353). Switzerland: Springer International Publishing.

SF OpenData. (2017). SF OpenData. https://data.sfgov.org. Accessed February 23, 2017.

Shepard, M. (2011). *Sentient city: Ubiquitous computing, architecture, and the future of urban space*. Cambridge, MA: MIT Press.

Singer, N. (2012, March 3). Mission control, built for cities: IBM takes ‘smarter cities’ concept to Rio de Janeiro. *New York Times*, p. BU1. http://www.nytimes.com/2012/03/04/business/ibm-takes-smarter-cities-concept-to-rio-de-janeiro.html. Accessed November 28, 2016.

Townsend, A. (2013). *Smart cities: Big data, civiv hackers, and the quest for a new utopia*. New York, NY: W.W. Norton & Company.

Tufte, E. R. (2001). *The visual display of quantitative information* (2nd ed.). Cheshire, CT: Graphics Press.

United Nations. (2014). *World urbanization prospects: The 2014 revision*. New York: UN Department of Economic and Social Affairs. https://esa.un.org/unpd/wup/publications/files/wup2014-highlights.Pdf. Accessed November 27, 2016.

Images

Centre for Advanced Spatial Analysis. (2017). CityDashboard [Webpage, screen capture]. Retrieved from http://citydashboard.org/london/

City Futures Research Centre. (2017). Sydney City Dashboard [Webpage, screen capture]. Retrieved from http://citydashboard.be.unsw.edu.au/

Maynooth University. (2016). Dublin Dashboard [Webpage, screen capture]. Retrieved from http://dublindashboard.ie/pages/HomeEnvironment

WCCD. (2015). WCCD metrics for Dubai, Melbourne, and Toronto’s 2015 performance [Webpage, screen capture]. Retrieved from http://open.dataforcities.org/

Chapter 20

Consistency Analysis of City Indicator Data

Yetian Wang and Mark S. Fox

Abstract Cities use a variety of metrics to evaluate and compare their performance with the goal being to improve city services. The ISO 37120 standard provides definitions for city indicators that measure a city's quality of life and sustainability. A problem that arises in indicator-based comparisons, is whether the comparison is invalid due to inconsistencies in the data used to derive them. In this chapter we present three types of consistency analysis for automating the detection of inconsistencies in open city data. Namely, definitional consistency analysis that evaluates if data used to derive a city indicator is consistent with the indicator's definition (ISO 37120); transversal consistency analysis that evaluates if city indicators published by two different cities are consistent with each other; and longitudinal consistency analysis that evaluates if an indicator published by a city is consistent over different time intervals.

Keywords City indicator · Consistency · Ontology · Semantic Web · ISO 37120

1 Introduction

Cities use a variety of metrics to evaluate and compare their performance with the goal being to improve city services. With the introduction of ISO 37120, which contains 100 indicators for measuring a city's quality of life and sustainability, it is now possible to consistently measure and compare cities. A problem that arises in indicator-based comparisons, is whether the comparison is invalid due to inconsistencies in the data used to derive them (Fox 2015a). In this paper we present three types of inconsistencies, and an algorithm for detecting them in open city data:

Y. Wang (✉) · M.S. Fox
Department of Mechanical and Industrial Engineering, University of Toronto,
Toronto, ON M5S 3G8, Canada
e-mail: yetian.wang@mail.utoronto.ca

M.S. Fox
e-mail: msf@eil.utoronto.ca

S. Geertman et al. (eds.), *Planning Support Science for Smarter Urban Futures*, Lecture Notes in Geoinformation and Cartography,
DOI 10.1007/978-3-319-57819-4_20

1. **Definitional consistency** evaluates if data used to derive a city indicator is consistent with the indicator's definition (e.g. ISO 37120). For example, if the indicator is a student/teacher ratio, then a city's reported indicator is inconsistent if it includes teachers that do not satisfy the ISO 37120 definition, e.g. administrative staff.
2. **Transversal consistency** evaluates if city indicators published by two different cities are consistent with each other. For example, if the indicator measures homeless population, then indicators are transversally inconsistent if the homeless definition used by each differs. Note that each city's indicator can be definitional consistent but not transversal consistent.
3. **Longitudinal consistency** evaluates if an indicator published by a city is consistent over different time intervals. For example, if the indicator measures a city's PM10 air pollution, then the indicator is longitudinally inconsistent if the geospatial dimensions of the city have changed, which may arise through amalgamation.

In order to automate the process of inconsistency detection, our approach relies on two assumptions: (1) indicator definitions and the data used to derive their values are represented using standard data models, i.e., ontologies, and (2) the data used to derive the indicators are openly published. Fox (2013, 2015c) defines the Global City Indicator Ontologies (GCIO) that can be used to represent city indicator definitions and the data used to derive their values. The ontologies are formally defined using Description Logic and implemented in OWL, a standard for publishing data on the Semantic Web. Given an indicator definition, an indicator's value and supporting data, both represented using the GCIO, the equivalent graph representation is analysed to detect inconsistencies. The algorithm performs subgraph matching seeking out mismatches such as measurement, temporal, geospatial, and population definition differences. The algorithm detects actual inconsistencies, e.g. incorrect population definitions such as administrators vs. teachers, or potential inconsistencies, such as temporal differences of measurements.

In the remainder of this chapter we review a number of existing city indicator standards and ontologies and consistency checking methods. Next we define definitional, transversal and longitudinal inconsistencies. We then demonstrate these inconsistencies on an example of ISO 37120 15.2 homeless population ratio indicator.

2 Background

2.1 ISO 37120 Standard

ISO 37120 "*Sustainable development of communities—Indicators for city services and quality of life*" defines 100 indicators covering 17 themes including Education, Energy, Health, Safety, Finance and Shelter (ISO 37120 2014). Each indicator contains a definition that reduces ambiguity of interpretation by cities, leading to greater consistency in measurement and comparability across cities. An example of an indicator definition is Shelter indicator 15.2 "*Number of homeless per 100,000 population*":

> The number of homeless per 100,000 population shall be calculated as the total number of homeless people (numerator) divided by one 100,000th of the city's total population (denominator). The result shall be expressed as the number of homeless per 100,000 population.
>
> The following definition is used by the United Nations to define homelessness: Absolute homelessness refers to those without any physical shelter, for example, those living outside, in parks, in doorways, in parked vehicles, or parking garages, as well as those in emergency shelters or in transition houses for women fleeing abuse.

The World Council on City Data (WCCD: www.dataforcities.org) was created to collect and visualize the indicator values for cities that have adopted ISO 37120. They provide a certification process for ISO 37120 which cities ostensibly satisfy. However, the data required to verify a city's indicators are generally difficult to access and too large and complex to analyse (Fox and Pettit 2015).

2.2 GCI Ontologies

The Global City Indicator Ontologies (GCIO) have been created to represent ISO 37120 indicator definitions and the supporting data used to derive a city's indicator values (Fig. 1). GCIO is composed of a Foundation ontology and a set of theme specific ontologies. The GCI Foundation ontology (Fox 2013) represents fundamental concepts and patterns that underlie all ISO 37120 indicators, including time, geographic location, statistics, provenance, trust and validity. The GCIO theme specific ontologies span the 17 themes in the ISO standard, including Education (Fox 2015b), Environment (Dahleh and Fox 2016), Innovation (Forde and Fox 2015), Shelter (Wang and Fox 2015), and Finance (Wang and Fox 2016). Each theme ontology represents theme specific common sense knowledge and provides the capability for representing city specific definitions. They are used to represent the definitions of a theme's indicators, and a city's indicator values and the supporting data used to derive them. Following is an example of the ontology pattern for representing indicator 15.2.

It is a ratio indicator composed of two parts. The left arm defines the size of the homeless population. This is defined by the size of the population that satisfies the definition of a homeless person. The right arm defines the size of the population in general.

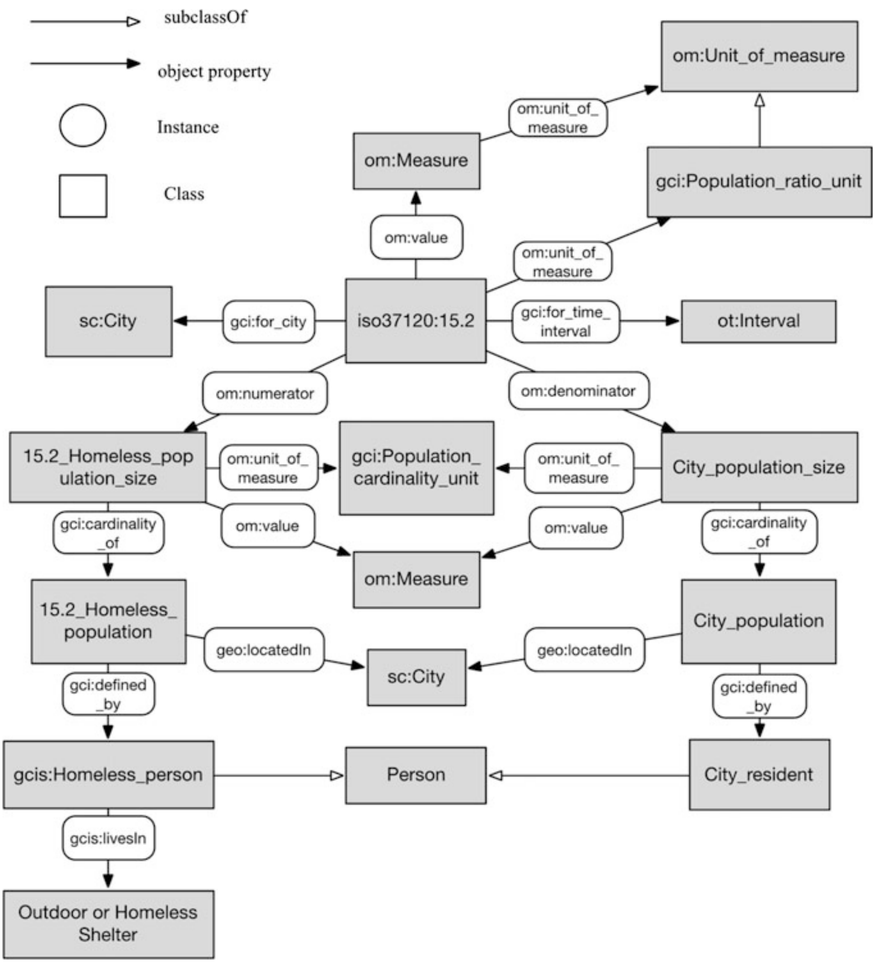


Fig. 1 ISO 37120 15.2 Indicator Definition

2.3 Consistency Evaluation

General ontology consistency checkers verify if an ontology is logically consistent by verifying if there is at least one model that satisfies all axioms in the ontology. Within an ontology, its class definitions (TBox) and individual assertions (ABox) must be free of contradiction in order to be consistent. A class must have at least one instance in order to be consistent (concept satisfiability) (Grau 2006).

Logical consistency checkers such as ConsVISor (Baclawski et al. 2002) and SimpleConsist (Mendel-Gleason et al. 2015) are able to detect contradictions within an ontology. Protégé plug-in reasoners such as Pellet (Sirin et al. 2007), FaCT++ (Tsarkov and Horrocks 2006), and HermiT (Shearer et al. 2008) provide reasoning services for ontologies represented in OWL. Reasoning services including consistency test, satisfiability test, and classification are performed by constructing models of the ontology that satisfy all axioms in the ontology with completion rules. If there exists at least one model of the ontology that satisfies all the axioms, the reasoner will terminate and conclude that the ontology is consistent. Otherwise, the reasoner will fail if a contradiction is detected indicating that the ontology is inconsistent.

General ontology consistency checkers can be used to determine whether the GCIO and their imported ontologies are consistent, and whether definitions created using the GCIO are consistent. Where they fail is in determining indicator specific inconsistencies. For example, is the data used to derive an indicator temporally consistent, i.e., generated during the same time period? Is the data spatially consistent, i.e., generated for the same geographic area? Is the definition of the population being measured across time or between cities consistent, i.e., has the definition of a homeless person changed from one time period to another in longitudinal analysis? In the next section we identify the types of indicator inconsistencies that general consistency checkers are not designed to handle.

3 City Indicator Consistency Analysis

A city's published indicator data can be consistent, inconsistent or potentially inconsistent. A city indicator's data is inconsistent if it does not satisfy the indicator's definition, or is inconsistent with the data it is being transversally or longitudinally compared to. A city's indicator data may be potentially inconsistent if there is a possible interpretation of the indicator data that is inconsistent.

Published indicator data and indicator's definition are represented as graphs with nodes representing instances, classes or literals (e.g. integers, strings), and arcs representing properties. Indicator values and supporting data correspond to (are individuals of) classes in the indicator's definition, or to instances of city data that it is being transversally or longitudinally compared to. Correspondence can be detected using the following method:

- An instance *m* is an instance of definition class *n* or
- If instance *m* corresponds to class *n*, *m* and *n* are linked to *m*' and *n*' respectively via property *a*, then *m*' corresponds to *n*'.

Correspondence inconsistency occurs in the case where there is no correspondence detected for a definition class *n*. This means that according to the indicator's definition there is data missing in the indicator data published by the city.

3.1 Definitional Inconsistency Analysis

In this section we define the types of definitional inconsistencies and potential inconsistencies.

3.1.1 Type Inconsistency

The most basic definitional inconsistency occurs when instances do not satisfy the definitions of classes they are supposed to correspond to.

Inconsistency TC: A city's indicator supporting data is *type inconsistent* with the indicator's definition if and only if an instance *m* in the supporting data is an instance of a class *c* that is neither equivalent nor a subclass of indicator's corresponding definition class *d*, and *m* cannot be classified as an instance of *d*.

In Fig. 2, instance *m* corresponds to class *n*. It is an instance of a class *c*. Both classes are linked to *n'* and *c'* through property *a* respectively. *m* is type consistent with *n* if and only if *c* is equivalent or a subclass of *n* and thus the same for *c'* and *n'*.

3.1.2 Temporal Inconsistency

City indicators measure a city's performance during a specific time interval. The quantities and measures of published indicator data must refer to the same time interval in order to be temporally consistent. Data that are believed to be true at the time they are gathered may be invalid during other time periods (Fox 2013). Supporting data that are generated outside the time interval of the indicator are not relevant and are therefore temporally inconsistent. For example, a 15.2 indicator

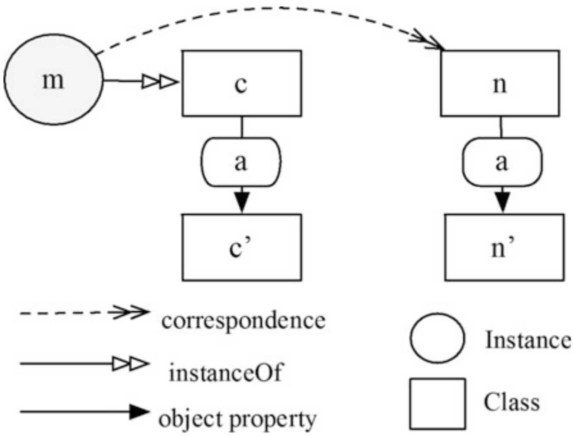


Fig. 2 Correspondence and type inconsistency

value measured for Toronto in the year of 2013 is temporally inconsistent if its numerator (i.e. homeless population size) is based on a survey conducted in a prior year.

Inconsistency TI: An instance *m* is potentially *temporally inconsistent* with another instance *m'* if *m* and *m'* are linked to time intervals *int* and *int'* respectively where the interval *int* is before, after, a subinterval of (overlapping, during, meets), or expressed in different temporal unit with *int*'.

Temporal inconsistency is a type of potential inconsistency since it is not always the case that the indicator is measured based on supporting data of the same time. For example, ISO 37120 city indicator 6.2: *Percentage of Students Completing Primary Education: Survival Rate* is defined as "*the total number of students belonging to a school-cohort who complete the final grade of primary education (numerator) divided by the total number of students belonging to a school-cohort, i.e. those originally enrolled in the first grade of primary education (denominator)*" (Fox 2015b). Its numerator measures a population of students from a year that is after the population measured by the denominator.

3.1.3 Place Inconsistency

Place concepts (i.e., toponym) such as city, province, area, et cetera are one of the foundational concepts involved in the definition of a city indicator. For example, in GCIO the property 'locatedIn' is used for 'Population' class to describe the location where the target population resides in. The population must refer to a place instance that is spatially equivalent with the city referred to by the indicator in order to be consistent.

Inconsistency PI: An instance *m* is inconsistent with *m'* in terms of place if the place city and *city'* linked to m and *m'* respectively are not equal, or *city* is spatially located within the area of *city'*, or *city* is a revision of *city'*.

3.1.4 Measurement Inconsistency

Measurement inconsistency determines whether the units of measure of quantities specified in the supporting data are inconsistent with their corresponding quantities in the indicator definition. The GCI Foundation ontology uses the OM ontology (Rijgersberg et al. 2013) to represent quantities and units of measure (*om: Quantity* class, e.g. length, *om: Unit_of_measure* class, e.g. meters).

Inconsistency MI: an instance *m*, of type *Quantity* or *Measure*, is *measurement inconsistent* with its corresponding *m*' if *m* and *m*' are linked to instances of *om: Unit_of_measure unit* and *unit*' respectively, and *unit* is not equivalent to *unit*'.

3.2 Transversal Inconsistency Analysis

Transversal analysis looks for the reason why two cities differ with respect to an indicator. But before this analysis can be performed it is important to identify whether inconsistencies exist between the two sets of supporting data. Assuming that both cities' supporting data are definitional consistent, transversal inconsistency can still arise between the supporting data of the two cities for the same indicator. Similar to definitional inconsistency, there exists transversal type, temporal, place and measurement inconsistencies.

3.2.1 Transversal Type Inconsistency

Consider the case where city C_1 defines its homeless person using the class H_1, and city C_2 defines its homeless person using the class H_2. Both H_1 and H_2 could be subclasses of the indicator's definition of homeless person, hence be definitional consistent. But if H_1 and H_2 are not equivalent classes, then the cities are using different definitions of homeless person and may not be comparable. For example, a homeless person is defined differently between Toronto and New York City. Toronto defines a homeless person to be a person who lives outdoor, in an emergency homeless shelter, a Violence-against-women shelter or a treatment facility (City of Toronto 2013). A homeless person in New York City is defined to be a homeless person who lives in a single adult shelter or a family shelter (Coalition of Homeless 2016). Both cities satisfy the indicator's definition of homeless defined by ISO 37120 but disagree on the specific types of homeless shelters that characterize their homeless population.

Inconsistency Trans_TC: an instance *m* from C_1 is *type inconsistent* with its corresponding instance *m'* from C_2 if *m* is an instance of a class *c*, and *m'* is an instance of *c'*, and *c* is not equivalent to *c'*.

3.2.2 Transversal Temporal Inconsistency

Transversal temporal inconsistency occurs when the time intervals of the two cities are not equivalent. For example, one city's indicator may be for 2013 while the other's is for 2014. Though transversal analysis across different time intervals may be desired, we still classify it as an inconsistency.

Inconsistency Trans_TI: If an instance *m* from city C_1 and corresponding instance *m'* of city C_2 which are linked to time intervals *int* and *int'* respectively, then *m* and *m'* are *transversally temporally inconsistent* if *int* and *int'* are not equivalent.

3.2.3 Transversal Place Inconsistency

Transversal place inconsistency identifies when the cities being compared are of different administrative types. In Geonames (www.geonames.org), feature codes are used to distinguish different types of cities.[1] For example, feature code *P.PPLC* represents a capital of a political entity, and *P.PPL* represents a farm village. City indicators that measure two cities with different feature codes are potentially inconsistent due to the basic nature of the cities.

Inconsistency Trans_PI: If an instance *m* is linked to city C_1 and its corresponding instance *m'* is linked to city C_2, *m* and *m'* are potentially *transversal place inconsistent* if the C_1 and C_2 have different feature codes.

3.2.4 Transversal Measurement Inconsistency

Indicator's supporting data and city specific knowledge published by two cities may disagree on the units of measure used. E.g. Toronto may use '*Population Cardinality unit*' (pc) as the unit of measure of its homeless population size measure while New York City uses '*kilo-pc*' which measures the population size in 1000 times of the unit 'pc'. Measurement consistency is guaranteed if the indicator data published by the two cities is definitional consistent, and is transversally type consistent.

3.3 Longitudinal Consistency Analysis

Longitudinal consistency analysis evaluates if a city's indicator and its supporting data is consistent over different time intervals. Over time, a city's spatial boundaries, definitions of populations, et cetera may change. Even if these changes are definitional consistent with the ISO 37120 indicator definition, they may be inconsistent with prior definitions. In the following we assume the indicator and its supporting data are definitional consistent for each of the two time intervals 1990 and 2010.

3.3.1 Longitudinal Type Inconsistency

City specific knowledge such as the definition of a homeless person or homeless shelter may change over time. Similar to transversal inconsistency analysis, the class definitions of city specific knowledge are evaluated between the two versions

---

[1] Other classifications of cities, e.g. urban, suburban, rural, may be more relevant, but are not available in geonames.org.

of the indicator and supporting data specified for the two time intervals. For example, suppose Toronto has changed its definition of homeless shelter by replacing treatment facilities with family shelters in 2010, which was not part of the 1990 definition. In this case the 15.2 indicator of Toronto published in 2010 is inconsistent with its previous version published in 1990. Longitudinal type inconsistency can be identified using same method as transversal type inconsistency (*Trans_TC*).

Inconsistency Long_TC: an instance *m* from time T_1 is *type inconsistent* with its corresponding instance *m'* from time T_2 if *m* is an instance of a class *c*, and *m'* is an instance of *c'*, and *c* is not equivalent to *c'*.

3.3.2 Longitudinal Temporal Inconsistency

Longitudinal temporal inconsistency compares the durations of the two time intervals. Consider an indicator that measures pollution. If the first time interval spans the first six months of 1990, and the second time interval spans the last six months of 2010, then the indicator values may not be comparable due to the seasonality of pollution.

Inconsistency Long_TI: An instance *m* from time T_1 and corresponding instance *m'* from time T_2 are temporally inconsistent with the indicator if *m* and *m'* are linked to time intervals with different durations.

3.3.3 Longitudinal Place Inconsistency

Longitudinal place inconsistency determines whether the same city is being measured during the two time intervals. Consider the city of Toronto. In 1998 the city was merged with five surrounding cities. The name stayed the same, but the all aspects of the city changed, including spatial boundaries, population, et cetera.

Inconsistency Long_PI: An instance *m* of time T_1 and its corresponding instance *m'* of time T_2 are longitudinally inconsistent if *m* and *m'* are linked to different versions of the same city.

3.3.4 Longitudinal Measurement Inconsistency

A city should use the same unit of measure for indicator data published during different time periods. E.g. the unit of measure for population size should remain as ‘pc’ for indicator instances published in different years. If published indicator value and supporting data were evaluated to be definitional consistent, and longitudinal type inconsistency (*Long_TC*) was not detected, then the unit of measures are guaranteed to be consistent.

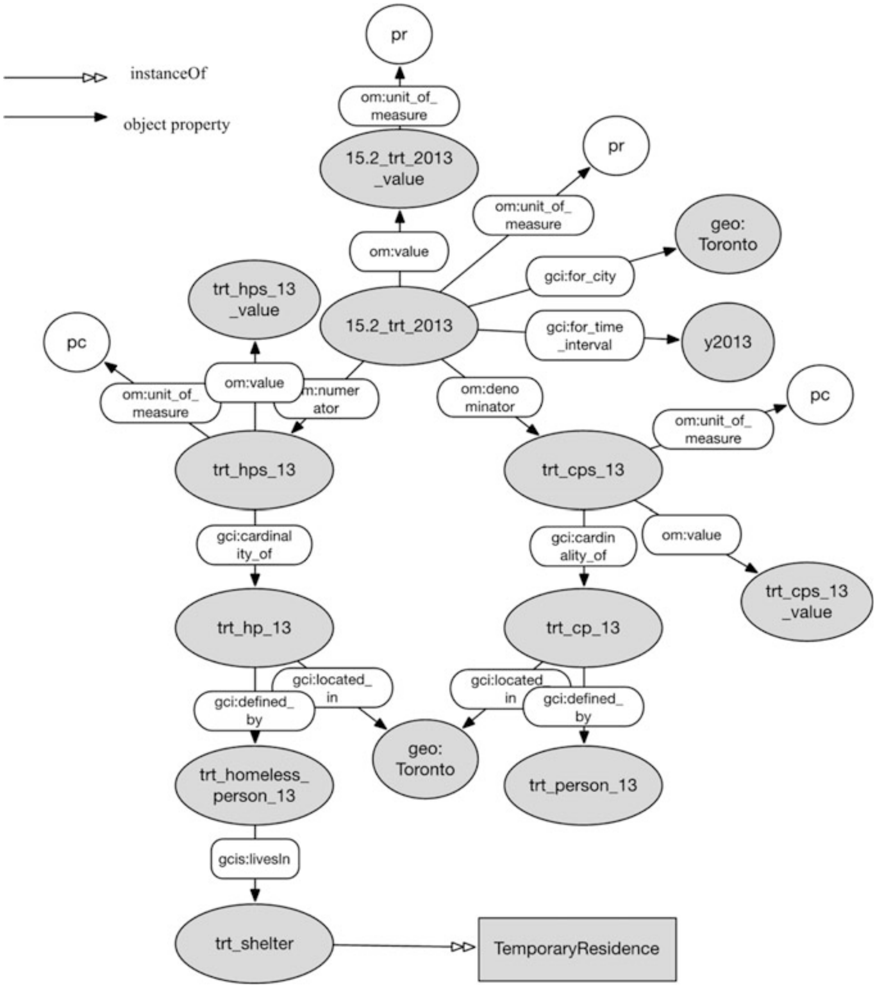


Fig. 3 Example of ISO 37120 15.2 Homeless population ratio Indicator

4 Example and Implementation

We will use the city of Toronto published data for their 2013 Shelter theme indicator 15.2 ‘Homeless population ratio’[2] as our example. Figure 3 depicts the structure of the 15.2 indicator instance and its supporting data following the ISO 37120 definition introduced previously. An indicator value instance was created

---

[2] The city of Toronto ISO 37120 data for 2013 is available in pdf format only. It contains a subset of the data we are using to test the checker. The data was manually translated into the GCIO.

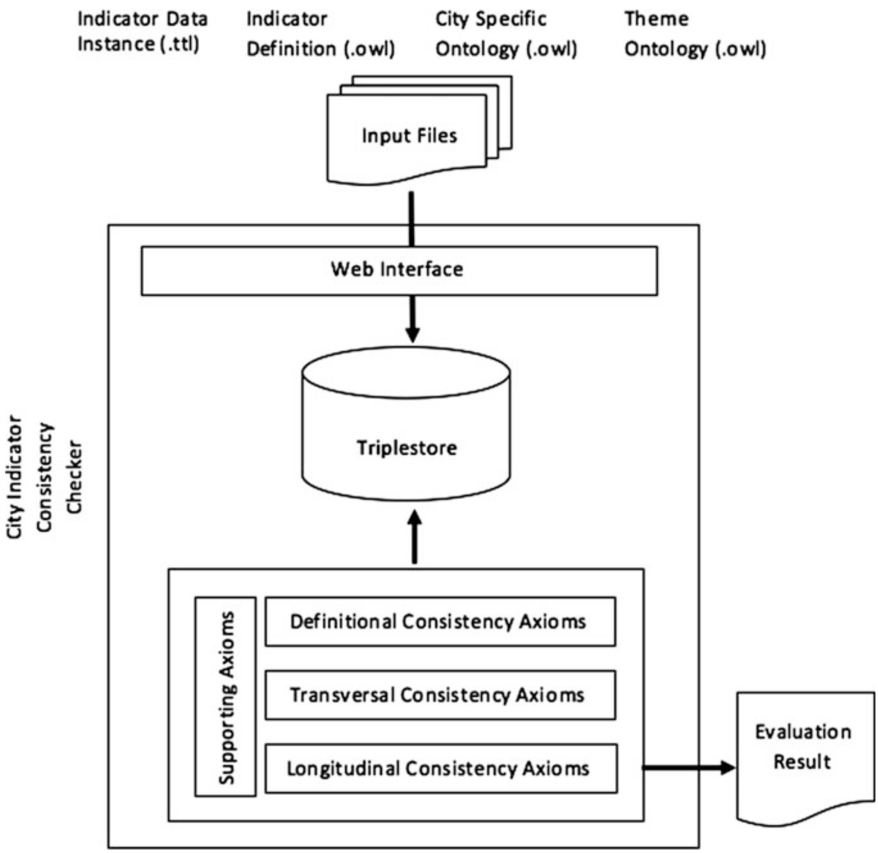


Fig. 4 Architecture of city indicator consistency checker

and linked to the city Toronto and year 2013. Its numerator is the size of Toronto's homeless population in 2013, which is the cardinality of Toronto's homeless population, defined by an instance of a homeless person in Toronto. For the purpose of demonstrating inconsistency detection, suppose a homeless person in Toronto is linked to a temporal residence class via a property 'livesIn'. This does not satisfy the indicator's definition where a homeless person lives in (livesIn) a homeless shelter class. Therefore it is definitional type inconsistent.

The instances in published indicator data and Toronto's city specific ontology was evaluated with respect to the indicator's definition[3] and GCI Shelter ontology[4] (Wang and Fox 2015) using our City Indicator Consistency Checker (CICC)

---

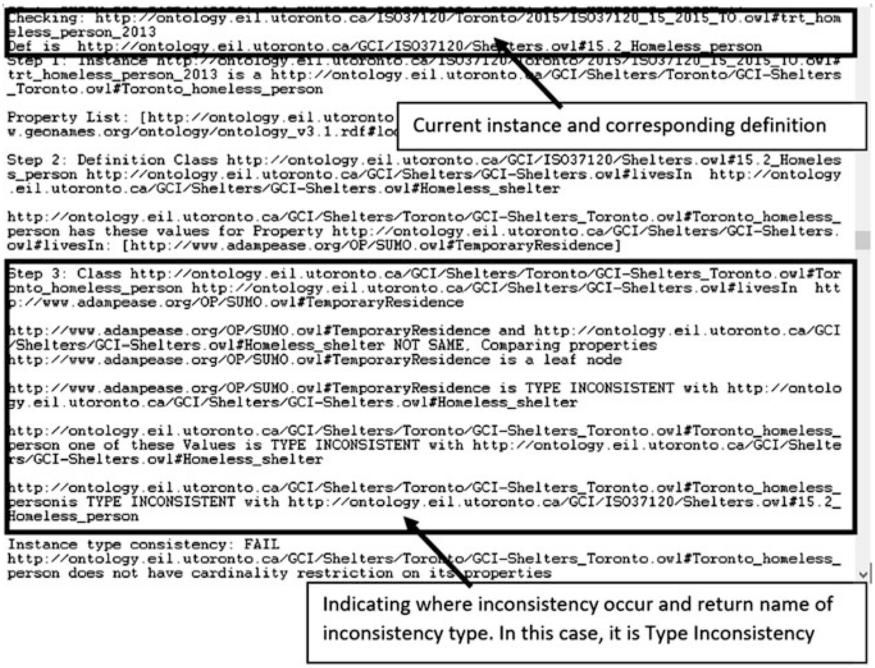
[3] http://ontology.eil.utoronto.ca/GCI/ISO37120/Shelters.owl.

[4] http://ontology.eil.utoronto.ca/GCI/Shelters/GCI-Shelters.owl.

(Wang, forthcoming) implemented using SWI-Prolog. The CICC performs definitional, transversal or longitudinal consistency analysis based on user inputs. Users provide indicator instances that are stored as Turtle (.ttl) files, and city specific knowledge ontologies in OWL (.owl) format through a web interface. All instances, classes and properties in the files are loaded as triples in a triplestore which can then be queried using Prolog. The core of the CICC consists of the definitions defined in this chapter for all three categories of inconsistencies implemented using a set of Prolog axioms which can be found in (Wang, forthcoming). Figure 4 depicts the architecture of the evaluator.

All instances in the submitted indicator data are evaluated and a text format output is returned indicating whether it is, in this case, definitional inconsistent. The returned results are shown in Fig. 5 with a description of inconsistency types. In this case, a Toronto homeless person is type inconsistent (*TC*) with the indicator's definition of homeless person.

The CICC will be available at the Enterprise Integration Laboratory website (eil.utoronto.ca) at University of Toronto in January 2017.



```
Checking: http://ontology.eil.utoronto.ca/ISO37120/Toronto/2015/ISO37120_15_2015_TO.owl#trt_hom
eless_person_2013
Def is  http://ontology.eil.utoronto.ca/GCI/ISO37120/Shelters.owl#15.2_Homeless_person
Step 1: Instance http://ontology.eil.utoronto.ca/ISO37120/Toronto/2015/ISO37120_15_2015_TO.owl#
trt_homeless_person_2013 is a http://ontology.eil.utoronto.ca/GCI/Shelters/Toronto/GCI-Shelters
_Toronto.owl#Toronto_homeless_person

Property List: [http://ontology.eil.utoronto
w.geonames.org/ontology/ontology_v3.1.rdf#lo

Step 2: Definition Class http://ontology.eil.utoronto.ca/GCI/ISO37120/Shelters.owl#15.2_Homeles
s_person http://ontology.eil.utoronto.ca/GCI/Shelters/GCI-Shelters.owl#livesIn  http://ontology
.eil.utoronto.ca/GCI/Shelters/GCI-Shelters.owl#Homeless_shelter

http://ontology.eil.utoronto.ca/GCI/Shelters/Toronto/GCI-Shelters_Toronto.owl#Toronto_homeless_
person has these values for Property http://ontology.eil.utoronto.ca/GCI/Shelters/GCI-Shelters.
owl#livesIn: [http://www.adampease.org/OP/SUMO.owl#TemporaryResidence]

Step 3: Class http://ontology.eil.utoronto.ca/GCI/Shelters/Toronto/GCI-Shelters_Toronto.owl#Tor
onto_homeless_person http://ontology.eil.utoronto.ca/GCI/Shelters/GCI-Shelters.owl#livesIn  htt
p://www.adampease.org/OP/SUMO.owl#TemporaryResidence

http://www.adampease.org/OP/SUMO.owl#TemporaryResidence and http://ontology.eil.utoronto.ca/GCI
/Shelters/GCI-Shelters.owl#Homeless_shelter NOT SAME. Comparing properties
http://www.adampease.org/OP/SUMO.owl#TemporaryResidence is a leaf node

http://www.adampease.org/OP/SUMO.owl#TemporaryResidence is TYPE INCONSISTENT with http://ontolo
gy.eil.utoronto.ca/GCI/Shelters/GCI-Shelters.owl#Homeless_shelter

http://ontology.eil.utoronto.ca/GCI/Shelters/Toronto/GCI-Shelters_Toronto.owl#Toronto_homeless_
person one of these Values is TYPE INCONSISTENT with http://ontology.eil.utoronto.ca/GCI/Shelte
rs/GCI-Shelters.owl#Homeless_shelter

http://ontology.eil.utoronto.ca/GCI/Shelters/Toronto/GCI-Shelters_Toronto.owl#Toronto_homeless_
personis TYPE INCONSISTENT with http://ontology.eil.utoronto.ca/GCI/ISO37120/Shelters.owl#15.2_
Homeless_person
Instance type consistency: FAIL
http://ontology.eil.utoronto.ca/GCI/Shelters/Toronto/GCI-Shelters_Toronto.owl#Toronto_homeless_
person does not have cardinality restriction on its properties
```

Fig. 5 Consistency checker output example

5 Conclusion and Future Work

Comparative analysis of city performance has been enabled by the definition and adoption of city indicators, such as ISO 37120. But without the availability of the data used to derive the indicators, it is unknown whether the comparisons are valid. With the introduction of city ontologies, it is possible to openly publish both indicator definitions and the data used to derive their values. The question is what do we do with this data?

Our ultimate goal is to be able to diagnose the root cause of performance variations between cities, and the same city at different times (Fox 2015c). But before we reach this goal, we have to be assured that the data used to derive a city's indicator is consistent with the indicator's definition, and that the data from two cities are transversally and longitudinally consistent. Without this guarantee of consistency, we would not be making an "*apples to apples*" comparison; hence any diagnosis would be faulty.

The major contribution of this research is the identification of three categories of inconsistency: definitional, transversal and longitudinal, and the various types of inconsistencies within each. We have implemented a city indicator consistency checker based on these types of inconsistencies. It assumes that indicators and their supporting data are openly published on the Semantic Web using the Global City Indicator Ontologies.

We expect the ultimate user of these results will be the providers of Business Intelligence software for cities. A necessary component of any indicator-based dashboard, will be an analysis of the data used to derive an indicator to see if it is consistent with the definition of the indicator, and in a comparative situation, consistent with what it is being compared to.

References

Baclawski, K, Kokar, M. M, Waldinger, R., & Kogut, P. A. (2002). Consistency checking of semantic web ontologies. *The semantic web—ISWC 2002* (pp. 454–459). Heidelberg: Springer.

City of Toronto. (2013). *2013 Street Needs Assessment Results*.

Coalition for the Homeless. (2016). *New York City homeless municipal shelter population, 1983-present.* Advocacy Department.

Dahleh, D., & Fox, M. S. (2016). *An environment ontology for global city indicators (ISO 37120)*. Working paper, Enterprise Integration Laboratory, University of Toronto. http://eil.mie.utoronto.ca/wp-content/uploads/2015/06/An-Environmental-Ontology-for-Global-City-Indicators-12oct2016.pdf

Forde, A., & Fox, M. S. (2015). *An innovation ontology for global city indicators.* Working paper, Enterprise Integration Laboratory, University of Toronto. http://eil.mie.utoronto.ca/wp-content/uploads/2015/06/GCI-Innovation-Ontology-v15.pdf

Fox, M. S. (2013). *A foundation ontology for global city indicators*. Working paper, Enterprise Integration Laboratory, University of Toronto, Revised: May 16, 2015. http://eil.utoronto.ca/wp-content/uploads/smartcities/papers/GCI-Foundation-Ontology.pdf

Fox, M. S. (2015a). *Polisnosis Project: Ontologies For city indicators, mechanical and industrial engineering department*. University Of Toronto. http://eil.utoronto.ca/smartcities/papers/PolisGnosis-11mar2015.pdf

Fox, M. S. (2015b). *An education ontology for global city indicators (ISO 37120).* Mechanical and Industrial Engineering Department, University Of Toronto.http://eil.utoronto.ca/wp-content/uploads/smartcities/papers/GCI-Education.pdf

Fox, M. S. (2015c). The role of ontologies in publishing and analyzing city indicators. *Computers, Environment and Urban Systems, 54,* 266–279.

Fox, M. S., & Huang, J. (2005). Knowledge provenance in enterprise information. *International Journal of Production Research*, 43(20).

Fox, M. S., & Pettit, C. (2015). On the completeness of open city data for measuring city indicators. In *Proceedings of the IEEE Conference on Smart Cities, Guadalajara, Mexico*.

Grau, B. C. (2006). *OWL 1.1 Web ontology language tractable fragments*. The University of Manchester.

ISO37120. (2014). *ISO 37120: Sustainable development of communities—Indicators for city services and quality of life* (1st ed.). International Organization for Standardization, May 15, 2014, ISO37120:2014(E).

Mendel-Gleason, G. E., Brennan, R., & Feeney, K. (2015). Ontology consistency and instance checking for real world linked data. In *Proceedings of the 2nd Workshop on Linked Data Quality, Portoroz.*

Rijgersberg, H., van Assem, M., & Top, J. (2013). Ontology of units of measure and related concepts. *Semantic Web, 4*(1), 3–13.

Shearer, R., Motik, B., & Horrocks, I. (2008). HermiT: A highly-efficient OWL reasoner. In *OWLED* (Vol. 432, p. 91).

Sirin, E., Parsia, B., Grau, B. C., Kalyanpur, A., & Katz, Y. (2007). Pellet: A practical owl-dl reasoner. *Web Semantics: Science, Services and Agents on the World Wide Web, 5*(2), 51–53.

Tsarkov, D., & Horrocks, I. (2006). FaCT++ description logic reasoner: System description. In *Automated reasoning* (pp. 292–297). Heidelberg: Springer.

Wang, Y., & Fox, M. S. (2015). *A shelter ontology for global city indicators (ISO 37120).* Working Paper, Enterprise Integration Laboratory, University of Toronto. http://eil.mie.utoronto.ca/wp-content/uploads/2015/06/GCI-Shelter-Ontology.pdf

Wang, Y. (forthcoming). *City indicator consistency analysis: An approach to inconsistency detection*. M.A.Sc. thesis, Mechanical and Industrial Engineering Department, University of Toronto.

Wang, Z., & Fox, M. S. (2016). *A finance ontology for global city indicators (ISO 37120).* Working Paper, Enterprise Integration Laboratory, University of Toronto. http://eil.mie.utoronto.ca/wp-content/uploads/2015/06/GCI-Finance-20160606.pdf

Chapter 21
From Blue-Printing to Finger-Printing: Building Healthy Communities with Scenario Planning

Ming-Chun Lee

Abstract Scenario-based planning practices are generally conducted in two ways. Both are important and complementary to one another in a sequential way with a regional vision first being laid out as an underlying planning framework followed by a more locally-focused approach tailored to the specifics and uniqueness of a smaller jurisdiction. The two planning practices can be understood from multiple sets of planning theories, including planning as spatial inquiry, planning as communications, and planning as place-making. This chapter illustrates these different perspectives by presenting two scenario planning projects in the US as well as discussing a pilot project in North Carolina. This project employs scenario analysis methods as a way to connect regional *blue-printing* framework to local *finger-printing* processes and intends to translate regional planning principles, previously developed by a regional planning project, to a set of executable implementation items customized to a local neighborhood.

Keywords Scenario planning · Visioning · Regional planning · GIS

1 Introduction

The US Department of Housing and Urban Development (HUD) launched its Sustainable Communities Regional Planning Grants Program in 2009. The program supports collaborative efforts that bring together municipalities in a region to determine how best to target economic development and infrastructure investments to create healthy communities throughout the region. Recognizing that regions are in different stages of plan development, HUD established two funding categories. Category-1 supports the preparation of regional plans where such plans do not currently exist or where they exist but need to be revised; Category-2 supports

---

M.-C. Lee (✉)
School of Architecture, University of North Carolina at Charlotte, Charlotte, NC 28223, USA
e-mail: ming-chun.lee@uncc.edu

S. Geertman et al. (eds.), *Planning Support Science for Smarter Urban Futures*, Lecture Notes in Geoinformation and Cartography,
DOI 10.1007/978-3-319-57819-4_21

efforts to refine existing regional plans or the preparation of implementation actions for these existing plans.

This program places a priority on investing in technologies and methodology to address issues of regional significance, use data and computer software to monitor progress and performance, and engage residents in decision-making (HUD 2009). Although HUD did not specify or recommend the types of computer programs to be considered, many grantees used mapping software applications and scenario planning methods for their projects.

Long before this recent HUD program, during the 1990s a style of regional land use and transportation planning emerged in US metropolitan areas that employed scenario analysis methods originally developed by business and military strategic planners. Land use and transportation scenario planning, as it is generally known, has since then gained popularity as a means to evaluate compact alternatives for future growth (Bartholomew and Ewing 2008). HUD's recent program is only to re-emphasize the importance of integrating technologies, participation, and procedures in planning processes that lead to a sustainable future on the regional level.

As demonstrated by most of these HUD-funded projects, scenario planning is typically conducted at the regional scale. There have been however many successful cases in which scenario planning was applied to small community planning projects at the neighborhood scale. Examples include many HUD Category-2 projects completed in Oregon, Texas, and Utah over the past 10 years.

This chapter argues that both approaches are important and complementary to one another in a sequential way with a regional vision first being laid out as an underlying planning framework followed by a more locally-focused approach tailored to the specifics and uniqueness of a smaller jurisdiction. This chapter also points out the differences in the ways by which the scenario-based methods are applied to these two approaches as well as the outcomes of the two processes. The regional approach relies on mapping exercises in two dimensions and use of region-wide indicators of socio-economic statuses to engage citizens in the creation of a unified vision with emphases on the effectiveness of land use control, resource distribution, and movement of goods and people across the region; while the local approach employs graphics, computer-generated models in three dimensions, and measures of spatial qualities linked to residents' daily life experiences to facilitate discussions among stakeholders and in turn allows the development of implementation strategies with emphases on building typology, street characters, development performance, and place identity.

Using two examples of scenario planning projects in the US, both began with a regional visioning component and later concluded with a more locally-focused implementation component, this chapter characterizes and compares the two different but inter-related approaches. This chapter then discusses a project conducted by the author for Town of Davidson in North Carolina.

This pilot project employed scenario analysis methods as a way to connect a regional blue-printing framework, which takes an aspirational view towards regional consensus and performance outcomes on a more efficient land use pattern, to a locally-focused finger-printing process, which brings together community members to identify local characters, prioritize community needs, and generate solutions to solve common problems and improve physical conditions of the community. It intended to translate regional planning principles, previously developed by a regional planning project, to a set of executable implementation items customized to local neighborhoods in Davidson. This chapter details the steps taken to implement this scenario planning exercise, including visioning, choosing indicators, compiling data, conducting a community workshop, and drafting a future growth plan. A survey, conducted during the workshop, suggests that this exercise helped planners and residents better understand the issues facing their community and further explore various ways of building their future with comparisons across different growth scenarios.

2 Scenario Planning and Its Application in Land Use and Transportation Planning

According to Bartholomew (2007) and Smith (2007), the origin of scenario planning can be traced back to the RAND Corporation (Kahn 1962) in the 1950s, during which scenario planning was used as a way to consider multiple aspects of a problem at the same time. It was considered as a technique to help strategic planners with limited information and resources to address the uncertainty embedded in decision-making (Andrews 1992; Bradfield et al. 2005; Chakraborty et al. 2011). A scenario is an internally consistent view of what the future might turn out to be. It is not a forecast, but one possible future outcome (Ringland 1998; Bartholomew and Ewing 2008). Fundamentally, scenarios are stories about the future (Ogilvy 2002). They cannot predict the future precisely. Rather each should only present a vision of the future that is plausible in light of known information (Ringland 2002).

The land use and transportation scenario planning practice that emerged in the 1990s basically implanted the military and business models into routine planning practices that were required by Federal Highway Act of 1962, and the environmental impact assessment requirements by National Environmental Policy Act (Bartholomew 2007; Bartholomew and Ewing 2008). A typical project compares one or more alternative future development scenarios to a trend scenario. In the trend scenario, both land development and transportation investment patterns of the recent past are assumed to continue to a planning horizon of 20–50 years in the future and the impacts of this trend on the region and its transportation infrastructure are assessed. This is followed by the formulation of one or more alternative scenarios that differ from the trend with respect to land use choices and transportation investments. These alternative scenarios are then assessed for their impacts using the same set of outcome measures that were used to analyze the trend scenario (Bartholomew and Ewing 2008).

This type of planning practice reached a new level of prominence in the past two decades in the US, especially at the regional scale. HUD's latest rounds of grants program all but recommend such an approach (HUD 2009).

2.1 GIS-Enabled Scenario Planning Tools

Aided by the increasing computational capacity in the area of geographic information system (GIS), the scenario planning practice has expanded substantially over the past two decades (Ewing 2007). This expansion was also fueled by the development of a new class of scenario planning tools in the 1990s. For instance, What If?, developed by Klosterman, is able to facilitate scenario planning based on future land use demands from demographic projections (Klosterman 1999). CommunityViz, developed by PlaceWays (Kwartler and Bernard 2001), allows for some routine planning procedures typical to urban and regional planning, including development impact analysis, land use build-out analysis, and visualization of possible future urban forms (Walker and Daniels 2011).

To follow GIS-enabled scenario planning is to recognize it as not appearing from nowhere, but alongside longstanding endeavors to embed computational techniques into established planning professions, generally known as planning support systems (Harris 1989). There have been many integrated land use transportation models developed and critiqued over the past half century (Batty 1994; Wegener 2003). These models are predictive software calibrated on historical data and attempt to forecast what future land use or traffic patterns would occur based on historic trends. They rely profoundly on data and model specifications, rather than community opinions and aspirations. Examples include a range of technical and theoretical approaches, such as MEPLAN, an economic model simulating supply and demand for real estate and travel (Echenique et al. 2012); UrbanSim, an agent-level behavioral simulation system integrating multiple urban systems including real estate development, household and economic location, demographic transitions, and accessibility (Waddell 2002); SLEUTH, a land use model using cellular automata to simulate the spatial pattern of urban land development (Jantz et al. 2004).

Despite their ambitious attempts, only a handful of these models have had significant impact on planning practices. In addition, as such models usually take hours, if not days or weeks, to run, they are not overly suited to real time collaborative planning processes. Hence, there has been a role for a new breed of GIS-enabled planning support systems that are more suitable for day-to-day planning contexts, where collaboration and communications are central to the success of projects. Examples include Envision Tomorrow (ET 2014; University of Utah 2014), INDEX (Allen 2001), CommunityViz, and What If?, mentioned earlier.

As a tool for public engagement, this type of GIS application also has its roots in the field of Public Participatory GIS (PPGIS), which intends to bring mapping practices to grassroots communities in order to promote public discloses, knowledge production, and problem solving for shared challenges. Pioneers in this field include Kheir Al-Kodmany, whose early work utilized web-based technologies and GIS to discover public preferences as a guide in neighborhood design (Al-Kodmany 2000).

3 Regional Planning

To better understand this type of scenario-based planning practices, we need to look into the following three aspects of regional planning.

(1) Uncertainty in regional planning: The number of factors that influence whether changes occur in a region and to what extent they take place is enormous. Moreover, past trends and the knowledge learned from historical events may not necessarily be the direction communities wish to head (Lemp et al. 2008). The larger geographical territories covered by a region present a wide variety of issues. Furthermore, regional planning typically considers a longer timeframe, which may contribute only to an even higher degree of uncertainty. Planning at the regional scale therefore requires new methods and tools. Consequently, scenario planning has grown in use, typically referred to as visioning (Bartholomew 2005). It is through scenario planning that the question of what the future might look like can be narrowed down to a more manageable set of possibilities.

(2) Regional planning as spatial planning: Regional planning is inherently a spatially oriented practice (Cowen and Shirley 1991). As spatial planning, it gives geographical expression to the economic, social, cultural, and environmental policies of society (Council of Europe 1983). It also offers a strategic approach to the organization of space at different levels of scale (Albrechts 2004). Planners need to convert spatial data into the type of information necessary to support decision-making. The nature of the data distinguishes planning from other data business because practically all planning data is closely related to spatial locations (Cowen and Shirley 1991). Scenario planning provides structured processes in which decision-making takes place (Kliskey 1995). Within these structured processes, information becomes a key element for effective decision-making.

(3) Regional planning as communicative planning: In contrast to its rational and technical aspect, regional planning is best seen as not only the activity of spatial analysis performed by professionals, but also as an ongoing process of social interaction and dialogue through which planners, elected officials, and the public together make decisions on how to best deal with their collective concerns of the region (Healey 1992; Klosterman 1997). Regional planning is considered a process of structured negotiation and deliberation that requires greater participation from those who are involved in its processes (Bischof and Dale 1997). It requires a shift in planning style in which the stakeholders

become actively involved in the process sharing interests and knowledge with one another (Innes and Boober 2010).

4 Regional Planning Cases

This section presents two regional planning projects. Both utilized GIS-enabled scenario analysis methods to articulate growth strategies and facilitate public outreach activities. More importantly, both cases started with a regional visioning component followed by a locally-focused implementation plans at the neighborhood scale. Envision Utah is widely considered a model for regional planning through a voluntary partnership of key agencies, its significant public engagement, and use of convincing data aided by geospatial technologies (Scheer 2012). Envision Central Texas, followed the footsteps of Utah Model, successfully adopted a preferred growth scenario into its official regional transportation policy framework, which in turn designates major activity centers with implementation strategies being developed and proposed for some of these centers.

4.1 Envision Utah

Envision Utah arose out of an effort to educate the public and decision makers about the issues and consequences associated with rapid growth in the Greater Wasatch area of Utah. In 1995, this area was home to 1.6 million residents involving 10 counties, 91 cities and towns. The project included the development and modeling of four regional growth scenarios that illustrated the consequences of varying growth patterns and transportation investments (Fig. 1). They ranged from a low-density alternative with auto-oriented development to a high-density transit-oriented alternative with more compact growth and higher levels of infill and redevelopment.

A public-private coalition, *Envision Utah*, was set to oversee the project in 1997. They contracted Calthorpe Associates and Fregonese/Calthorpe Associates to facilitate. A map-based workshop process was introduced, coupled with GIS software to generate scenarios and evaluate the consequences of each scenario. Extensive public outreach formed the foundation of a *Quality Growth Strategy* for the region, which was adopted by the Utah State Legislature in 1999. The Strategy included 47 development goals in 6 major categories. Detailed maps showing the locations of different kinds of urban growth were also created.

Envision Utah's technical analysis was conducted through collaboration among state, regional, and local agencies. Much of its technical work was prepared by a technical committee, which created and maintained their core tools suite QGET (Quality Growth Efficiency Tools). The focus of QGET was to enhance technical

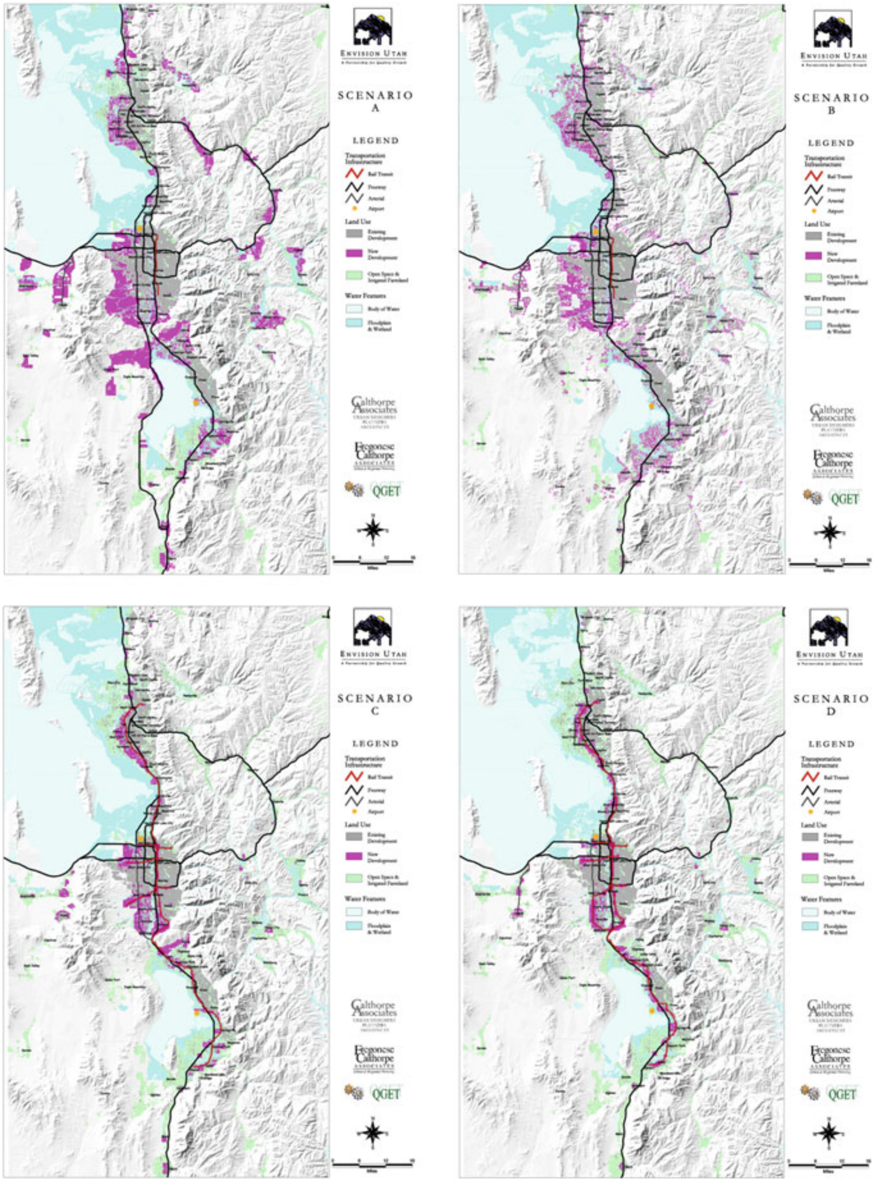


Fig. 1 Four regional growth scenarios—Envision Utah (*source* Envision Utah: Producing a Vision for the Future of the Greater Wasatch Area)

modeling tools, data, and processes. Its key components included: a GIS raster data environment supporting the development of existing land use data as well as forecasting land use data under various scenarios; a simplified air quality model; and an infrastructure cost model (Fig. 2).

Fig. 2 GIS analysis by QGET—Envision Utah (*source* Envision Utah: Producing a Vision for the Future of the Greater Wasatch Area)

4.2 Envision Central Texas

Envision Central Texas (ECT) was formed in 2001 to assist in the public development and implementation of a regional vision addressing the growth of the five-county area. Fregonese/Calthorpe Associates (FCA) provided consulting services, including conducting research, facilitating workshops, developing growth scenarios, and preparing a preferred growth vision incorporating public feedback. Public engagement was done through a mailed-out survey, and more through workshops. In 2004, *Preferred Growth Vision* was developed to incorporate the priorities and needs expressed by the residents of Central Texas.

Envision Tomorrow (ET) was developed by FCA to collect data and create four alternative growth scenarios. It functioned as a software extension to the ArcGIS program. A series of region-wide public workshops were conducted. During these workshops, attendees formed small groups in which they were given a base map of the region and "*chips*" representing new development of several different types suitable to the region (Fig. 3). Participants were asked to place the chips in a way that they would like the region to grow, given a fixed total amount of development that will occur. After the workshops, FCA grouped maps by major land use patterns represented by individual maps.

5 Characteristics of Scenario-Based Regional Planning

This type of scenario-based regional planning practices and the tools supporting visioning exercises, as demonstrated in the two cases presented here, are designed to take advantage of geospatial technologies to support a planning process that is characterized by these three key elements:

(1) Metropolitan contexts facing a wide variety of issues contributing to uncertainty about their futures. The Utah case was facing the effects of explosive growth that occurred in the late 1990s and concerned with quality of life issues, sprawl, congestions, and the decline of central cities.

(2) A focus on spatial development patterns typically in the form of land uses requiring extensive use of spatial data, geographical analysis, and visualization. The Central Texas case was focused on balancing infrastructure investments with sustainable growth patterns confined within activity centers across the region.

(3) The involvement of multiple stakeholders through public participation (Bartholomew 2007; Goodspeed 2013). Both cases relied on careful public-private political setups and various methods and platforms to engage the public, cultivate trusts, and build consensuses.

From the technological standpoint, there are also three key enabling features that together support this type of planning practices.

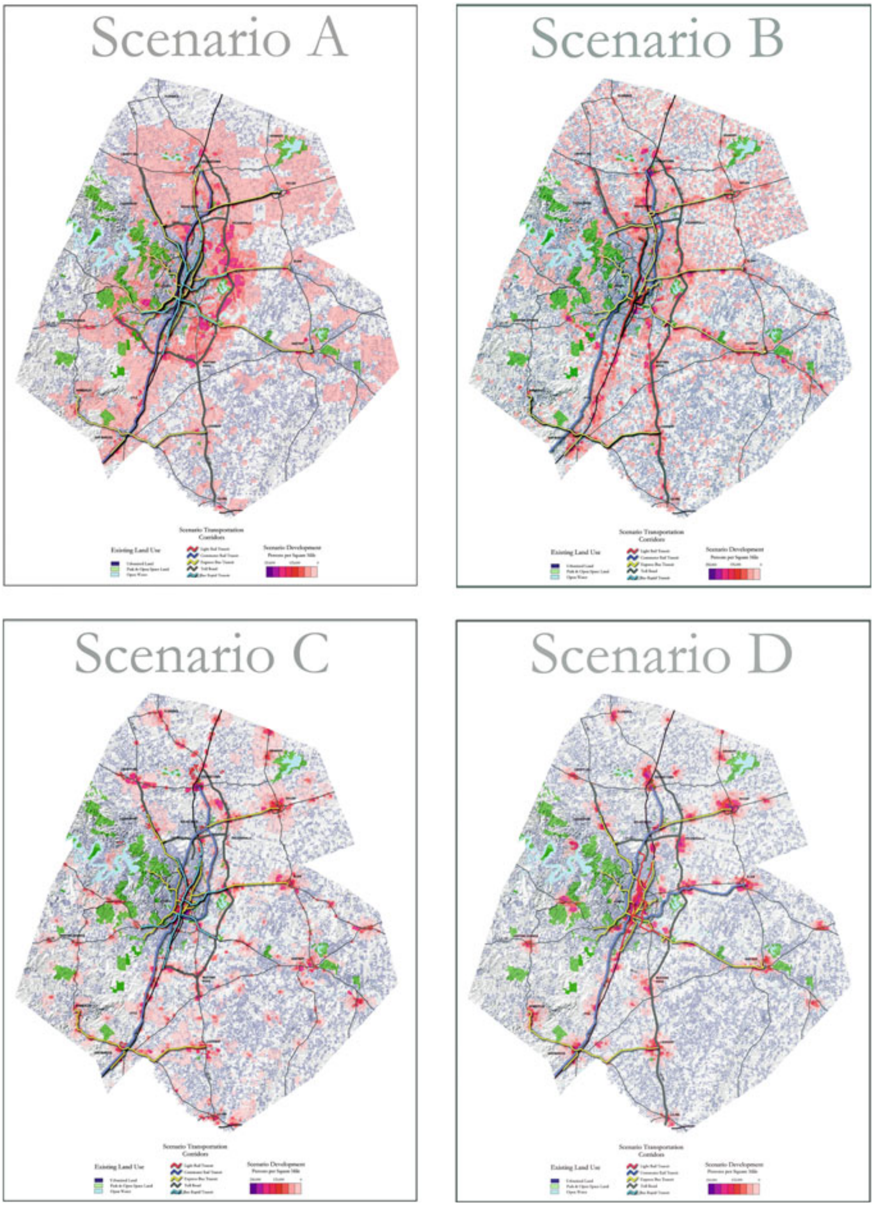


Fig. 3 Four regional development scenarios—Envision Central Texas (*source* Envision Central Texas Briefing Packet)

(1) Scenario creation and evaluation informed by geographic contexts. The technical approach and the tools that enable it can be used to answer questions of where, how much, and/or the more complex what-if inquiries by applying analytical spatial modeling techniques in a quantitative way. The QGET system and ET used in the two projects demonstrate the advantage of this approach to manage a diverse set of spatial data and to build the information infrastructure needed for conducting planning at the regional scale.
(2) Simulation and visualization using mapping technologies. The maps and the graphs generated in the two projects for the presentations of various development scenarios and their associated performances serve well as visual aids to help participants understand problem contexts, and together explore and negotiate solutions. In this regard, scenario planning becomes a tool for prospective exploration rather than for control.
(3) Stakeholder participation and collaboration. Based on the conception of planning as a participatory process requiring an inclusive approach to information sharing and deliberation, the intensive public participation activities in these two projects democratize the process and empower stakeholders by facilitating communications and collaboration informed by organized information and neutral evidence revealed by technical analysis.

Overall, this type of planning practice takes on a unique approach that seeks to integrate the social and technical dimensions of planning. This socio-technical perspective is essential to examine this particular genre of planning. It emphasizes the importance of investigating technology and social contexts together in order to both develop methodology and improve problem-driven technology.

6 Locally-Focused Scenario Planning

Community planning offers a different view from its regional counterpart towards how a healthy neighborhood can be built and maintained. Mollenkopf (2001) argues that where we live makes a big difference in the quality of our lives. Not only does the physicality of a community dictate our view of the place, but also that the communal aspect of where we live contributes to the wellbeing of our lives. It is through social connections and interests shared by inhabitants within a defined and proximate spatial limit, that the idea of a place is enhanced (Chaskin 2003). Community planning seeks to identify a distinct place's unique finger-print and focuses on a wide range of issues relevant to the health of the place.

Most scenario planning projects conducted between late 1990s and mid-2000s were done on the regional level, including Envision Utah, Metro (Portland) 2040, Chicago 2020 Plan, and Envision Central Texas (Bartholomew and Ewing 2008). Starting in early 2010s, fueled mostly by HUD's Category-2 planning grants, a new type of scenario planning practices emerged. They were conducted for relatively smaller geographical areas on the local level ranging from a small town to a neighborhood. The intention of these small-area planning efforts also differed from those on the regional level. Unlike the blue-printing nature of the approach inherited in regional visioning efforts, this type of approach is focused on identifying strategies to move from visioning to implementation. It seeks to take actions leading to changes in a local neighborhood while embracing the region-wide goals and complying with the regional guidance.

7 Small-Area Planning Cases

7.1 After Envision Utah

After the completion of Envision Utah, a new round of region-wide scenario planning process was initiated in 2002 by a coalition of three public agencies. It was done with the specific intention of using the vision generated by this new study as the basis for the region's next set of official transportation plans. The resulting report *Wasatch Choices 2040* is a set of growth principles meant to guide land use and transportation planning for the 4-county Wasatch Front area.

In order to ensure success in realizing the vision illustrated in the latest plan, the leaders from the coalition believed that their region was in need of good working models of successful transit-oriented development projects (TOD) to build confidence among developers and residents to continue to grow. Several demonstration projects were initiated in 2011 with a Category-2 planning grant. Over the next three years, the money funded the creation of an affordable housing plan and the study of 6 TOD sites.

One of the sites is Magna's historic Main Street. Two mapping workshops to gather public input for this catalytic site were conducted during 2012. Four scenarios with varying land uses and densities were created using the new generation of ET scenario planning tool. It is now called *Envision Tomorrow Plus* (ET+, Fig. 4). These scenarios were presented to the residents to collect feedback. An online survey was conducted. A final composite vision scenario using the feedback was then developed. Key vision elements include: maintaining the historic character of Main Street; building on existing assets; cleaning up and creating an attractive community; and re-branding Magna's image and identity (Fig. 5).

7.2 Sustainable Places Project

A similar development also occurred to the case in Central Texas. Implementation of ECT vision has been seen in other forms of progress since adoption, primarily through its integration in new official regional policy. The Capital Area Metropolitan Planning Organization (CAMPO) released its *2035 Regional Growth Concept* in 2007. The plan incorporates parts of the ECT vision while reflecting existing adopted local plans and values.

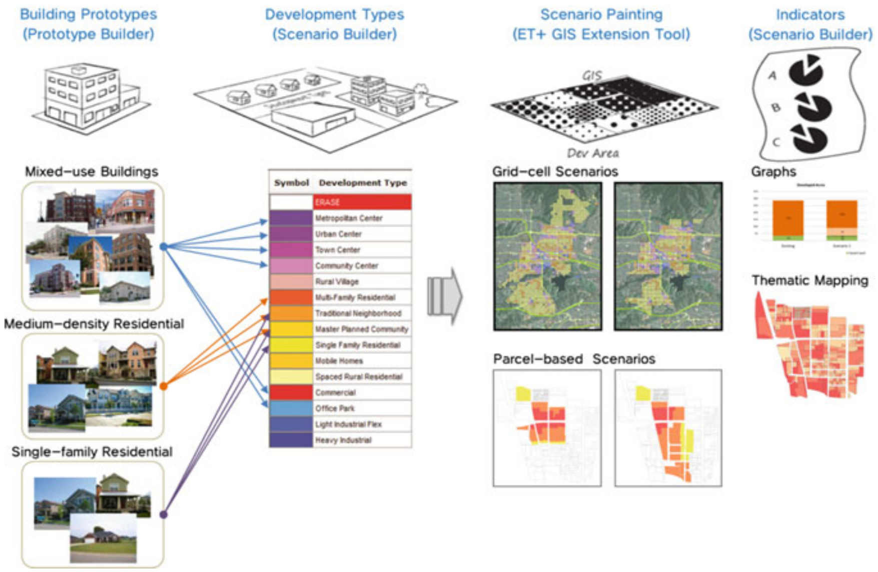


Fig. 4 Envision Tomorrow Plus (ET+) platform (*source* Envision Tomorrow Plus (ET+) Software User Manual: Beginner Level)

Fig. 5 Renderings of possible street configurations—Magna Main Street (*source* Magna Main Street Case Study)

To move the ETC vision further ahead, the *Capital Area Texas Sustainability Consortium* (CATS) was formed in 2010. CATS, with a Category-2 planning grant, led the effort in assisting five local cities to create their activity center demonstration project. Specific attentions were paid to the following development items: (1) Examination of different urban design principles for each scenario, including streetscape and open spaces; (2) Mapping and renderings that complement text and charts of the planning reports, including post-processing artwork for visuals of scenarios; and (3) Catalytic site identification and detailed design.

City of Elgin, one of the five demonstration sites, includes the historic downtown and an 85-acre property two miles to the west. ET+ was used in a series of workshops to create different development scenarios (Fig. 6). A public fiscal impact model was used to provide an understanding of city's costs and revenues associated with various scenarios. One of the goals of developing the downtown area was to focus on physical design qualities that can create a vibrant mix of public and private uses, promote a better balance of jobs and housing, and create a more balanced transportation network (Fig. 7).

8 Characteristics of Locally-Focused Scenario Planning

Locally-focused scenario planning practices, as community planning, can be understood by looking into the notion of place and the associated ideas of place-making and place identity.

(1) Place-making: We refer to places with a strong sense of place as quality places. Good place-making that results in quality places requires a combination of proper physical form characteristics and a healthy mix of uses and functions. Design as a discipline requires proper graphic tools for exploration and communication. As demonstrated in the two small-area scenario planning projects in Utah and Central Texas, images, graphics, and renderings of streetscape play a crucial rule in this process.

(2) Place identity: Place can define unique characteristics, both tangible and intangible, of a location. Intangible components may be evoked by photographs, stories, songs, or other forms of human activities, expressions, customs, and habits. The workshop settings in both cases with the techniques utilized in the public participation processes, such as photo surveys and visioning exercises, all helped to create an environment for seeking a common identity among participants.

(3) Togetherness: Place-making requires engaging and empowering people to participate in the process. Community planning requires the involvement and participation of local residents in identifying the strategies they wish to improve the quality of life. An inclusive and meaningful citizen-oriented process increases the likelihood of implementing the recommendations contained in the neighborhood plan. Public participation is typically more heated and intense at the local level because the issues are closer to home than those addressed at the regional plan level. As seen in the two local cases, participants contributed to discussions with broad knowledge of local conditions and good understanding of issues facing their community.

Fig. 6 Three development scenarios—Elgin demonstration site (*source* Elgin: The Sustainable Places Project: Final Report)

CONCEPT A:
Keep it as it is.

- 70' curb-to-curb
- Diagonal pull-in parking

CONCEPT B:
Add trees and "bulb-outs".

- Reduce walking distance at crosswalks
- Possible reverse angle parking

CONCEPT C:
Add a tree-lined median.

- Pedestrian refuge at crosswalk
- Calm traffic
- A green "ribbon"

CONCEPT D:
Widen the sidewalks.

- Replace diagonal with parallel parking on one side
- Add trees
- Reduce street width

Main Street Improvement Concepts

Fig. 7 Renderings of various street design concepts—Elgin Main Street (*source* Elgin: The Sustainable Places Project: Final Report)

9 North Carolina Experiment

City Building Lab (CBL) at the University of North Carolina at Charlotte launched its Scenario Planning Assistance Team in 2015. The team partnered with Town of Davidson to conduct a community planning project. This project utilized GIS and scenario planning methods to develop community growth alternatives.

Centralina Council of Governments with Catawba Regional Council of Governments, together representing 14 counties across North and South Carolinas, were awarded a Category-1 planning grant in 2011. *CONNECT Our Future* (COF) project was initiated to create a regional growth vision through community engagement. Four development scenarios were created. A preferred growth scenario, *Regional Growth Concept for 2050*, was later drafted based on public input in 2014 (Fig. 8). The preferred Growth Concept identifies 10 priorities for future planning and investments. Various planning guidelines and toolkits have also been developed for local jurisdictions in the region to adopt.

This community planning project, built upon the regional vision created by COF, intended to explore possible ways to guide future implementation of this vision. According to the Growth Concept, Davidson is designated as one of mixed-use walkable centers with anticipation of transit-oriented higher density development. Located north of downtown Davidson, the North Gateway area, a 134 acres green field, was chosen to be the project site.

9.1 *The Tools and Processes*

The project used ET+ to create and test land use scenarios. ET+ includes two components: an Excel spreadsheet and an extension to ArcGIS. The scenario planning process consisted of following four steps:

(1) Create prototype buildings: Develop a range of prototype buildings at the parcel level that are financially feasible based on local conditions. This step included a series of on-site field surveys and in-person interviews with local planners and developers to identity the set of prototype buildings that were mostly suitable for the site.

(2) Create development types: Based on the regional growth concept, create a series of development types that are suitable for a mixed-use walkable center by combining a mix of prototype buildings with streets, open spaces, public amenities and other urban attributes.

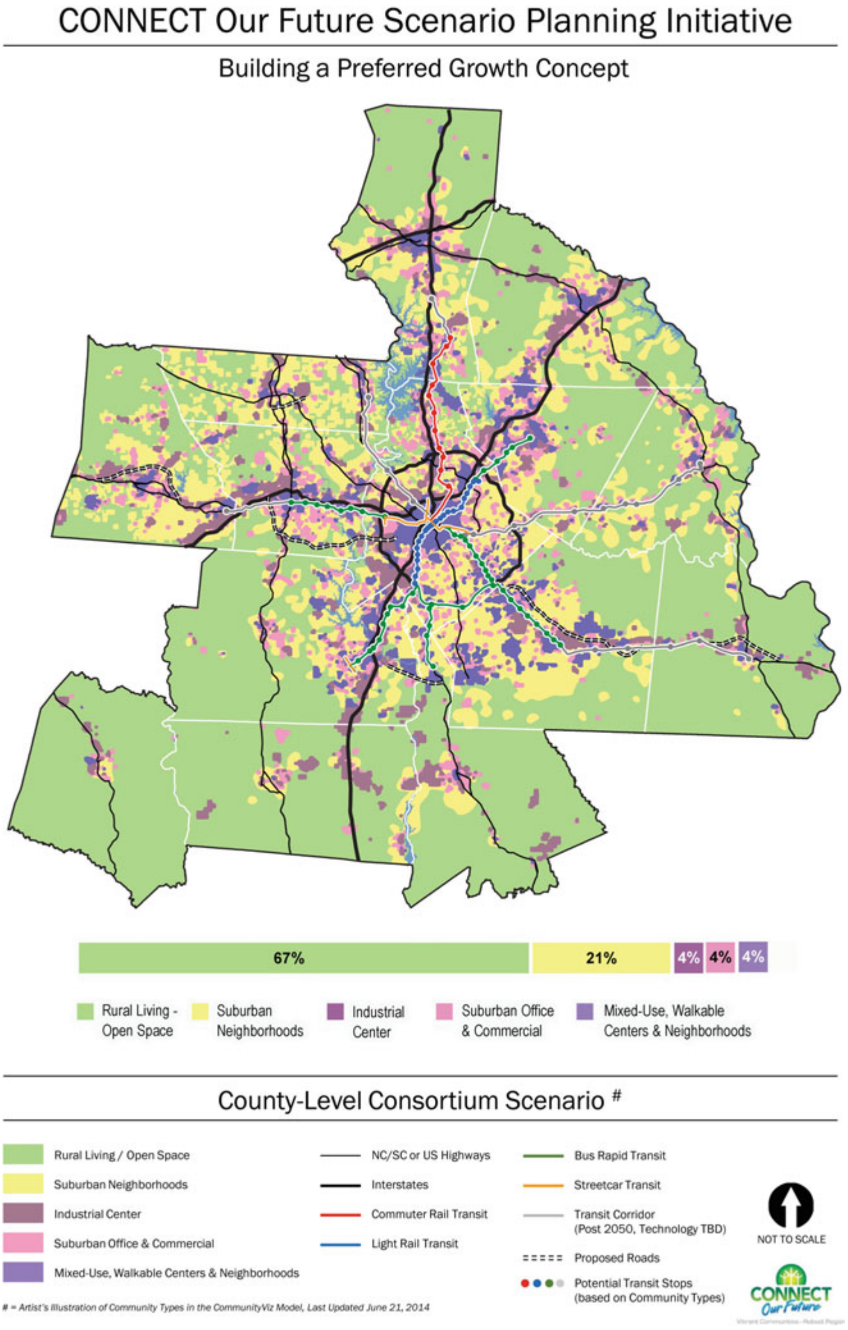
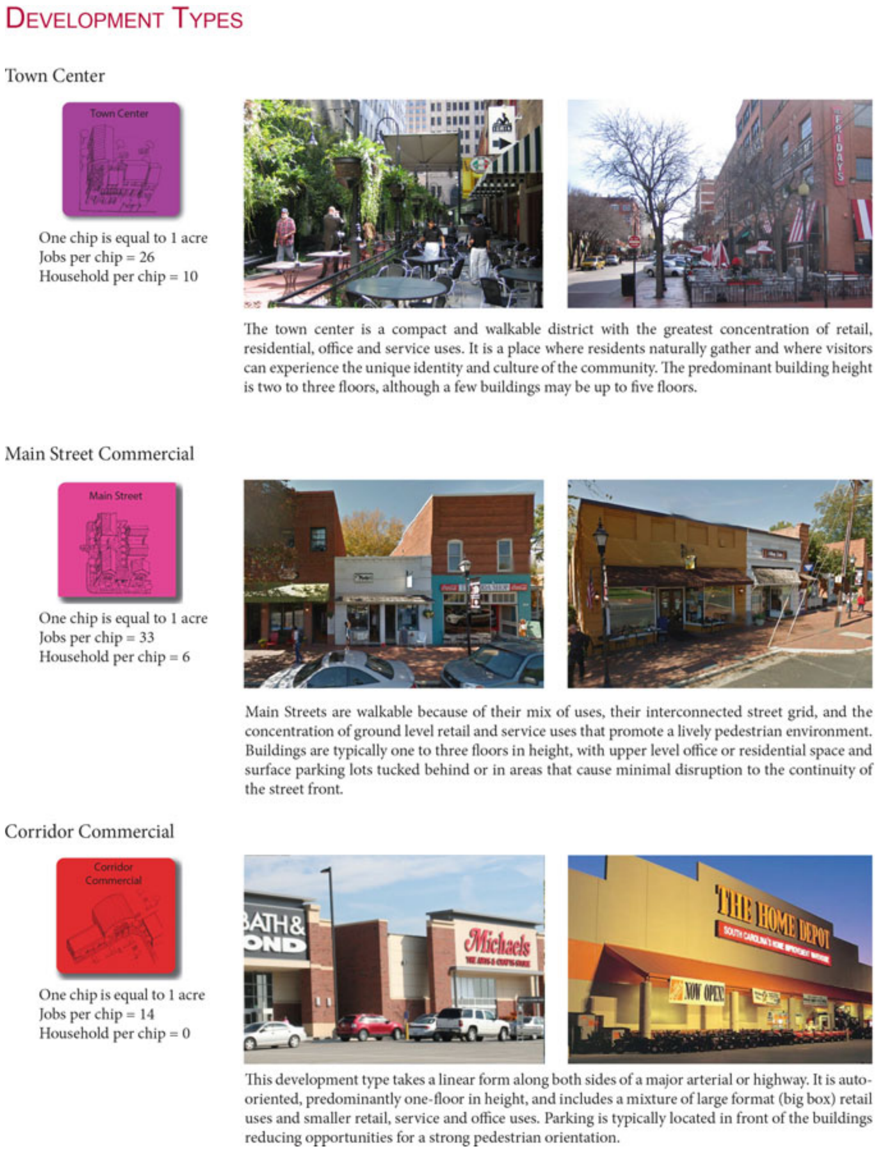


Fig. 8 Regional Growth Concept for 2050—Connect Our Future (*source* The CONNECT Preferred Regional Growth Concept Map)

(3) Build scenarios: Conduct a workshop with a mapping exercise to allow participants to create scenarios. ET+ was used alongside the mapping exercise to digitize these workshop scenarios on the fly.
(4) Evaluate scenarios: Evaluate the scenarios using ET+ template maps, charts, and graphics.

A total of 27 prototype buildings were identified with 9 different development types being developed and included in ET+ model for this project (Fig. 9).



DEVELOPMENT TYPES

Town Center

One chip is equal to 1 acre
Jobs per chip = 26
Household per chip = 10

The town center is a compact and walkable district with the greatest concentration of retail, residential, office and service uses. It is a place where residents naturally gather and where visitors can experience the unique identity and culture of the community. The predominant building height is two to three floors, although a few buildings may be up to five floors.

Main Street Commercial

One chip is equal to 1 acre
Jobs per chip = 33
Household per chip = 6

Main Streets are walkable because of their mix of uses, their interconnected street grid, and the concentration of ground level retail and service uses that promote a lively pedestrian environment. Buildings are typically one to three floors in height, with upper level office or residential space and surface parking lots tucked behind or in areas that cause minimal disruption to the continuity of the street front.

Corridor Commercial

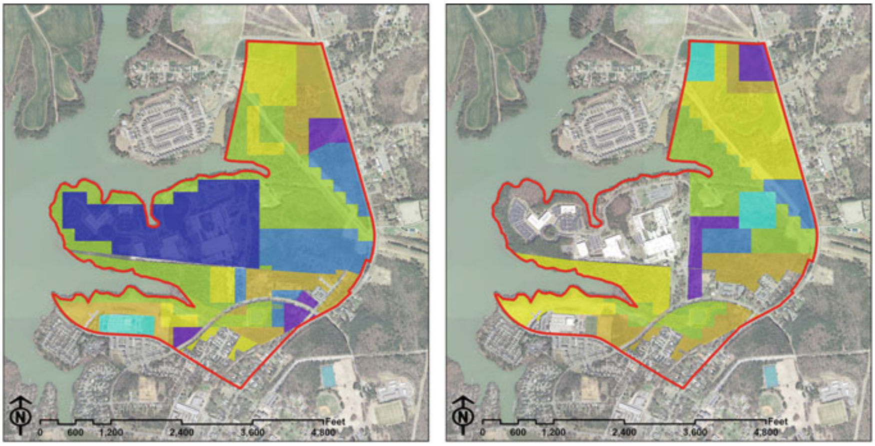
One chip is equal to 1 acre
Jobs per chip = 14
Household per chip = 0

This development type takes a linear form along both sides of a major arterial or highway. It is auto-oriented, predominantly one-floor in height, and includes a mixture of large format (big box) retail uses and smaller retail, service and office uses. Parking is typically located in front of the buildings reducing opportunities for a strong pedestrian orientation.

Fig. 9 Development types—Davidson

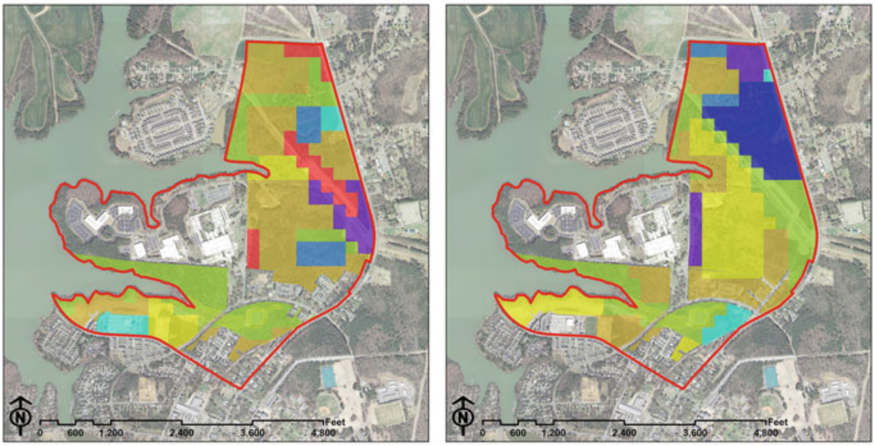
9.2 Workshop

A workshop was held at Town Hall in April 2015 with 27 participants. The Regional Growth Concept along with its 10 priorities was first presented to the audience. The designation of Davidson as a growth center was also explained. All this information was considered the basis for discussions and the scenario-building exercise that followed during the workshop. Four alternative growth scenarios were created (Fig. 10). Three complete scenarios were further digitized and analyzed in ET+. In addition to these workshop scenarios, a baseline scenario was later generated. This baseline scenario was mainly based on current planning ordinances and was used as references for policy comparison.



Baseline Scenario

Workshop Scenario A



Workshop Scenario B

Workshop Scenario C

Fig. 10 Four growth scenarios—Town of Davidson

9.3 Visualizing the Future in 3-D

3-D representation is an effective way to help stakeholders understand proposed development choices and visualize what their neighborhoods may look like in the future under these scenarios. ESRI CityEngine, a procedural modeling program, was used to create 3-D models to visualize these scenarios. GIS scenario maps were imported from ET+ into CityEngine, which then generated 3-D scenes of these scenarios using procedural rules available in the program (Fig. 11).

9.4 Open House

Finally, an open house event was held at Town Hall to present the four scenarios based upon the results from the workshop. Maps of four scenarios along with their performance measures by indicators were displayed (Fig. 12).

9.5 Outcomes

This project was mainly conducted as a pilot study to examine the region-to-local coordination necessary for successful implementation of a regional vision. Despite its experimental nature, this pilot project thoroughly followed steps for a typical scenario planning process to calibrate all analytic components based on local

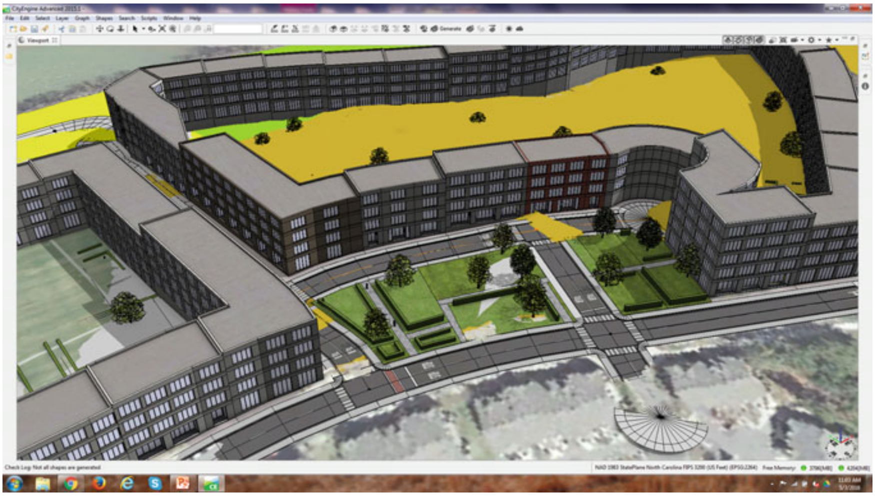
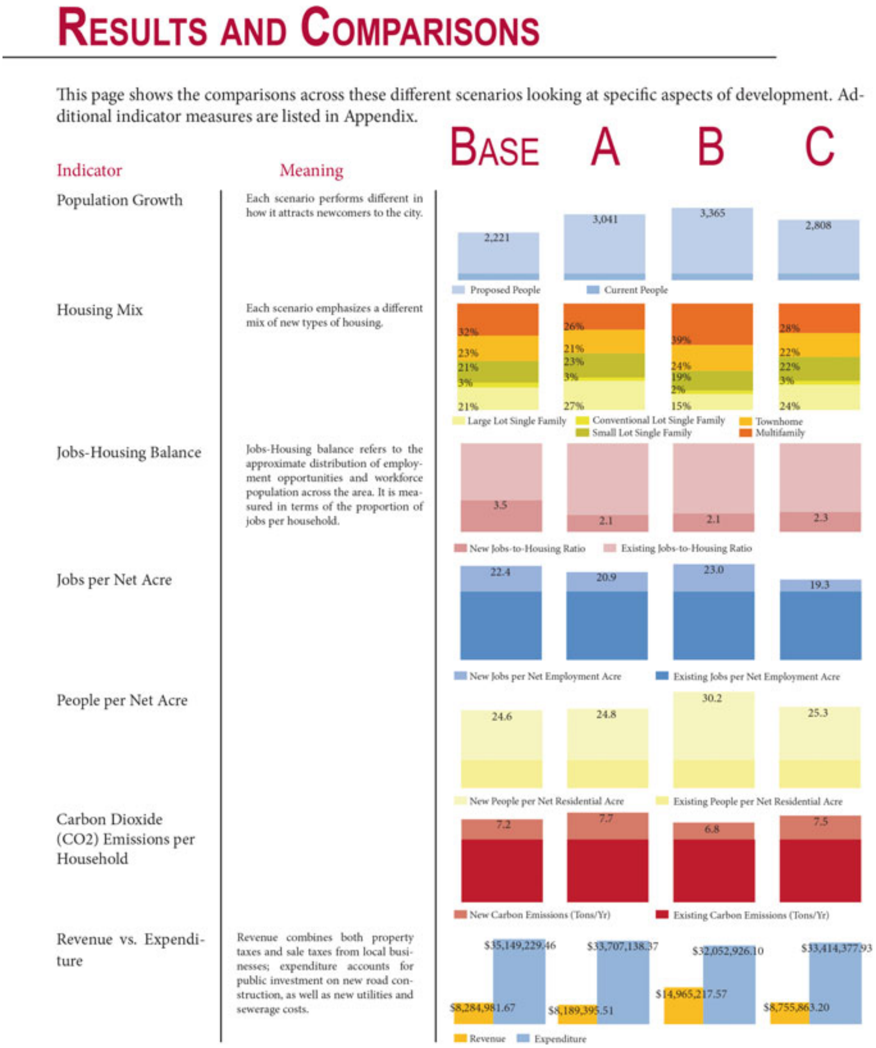


Fig. 11 3-D rendering of possible build-out condition—Davidson



RESULTS AND COMPARISONS

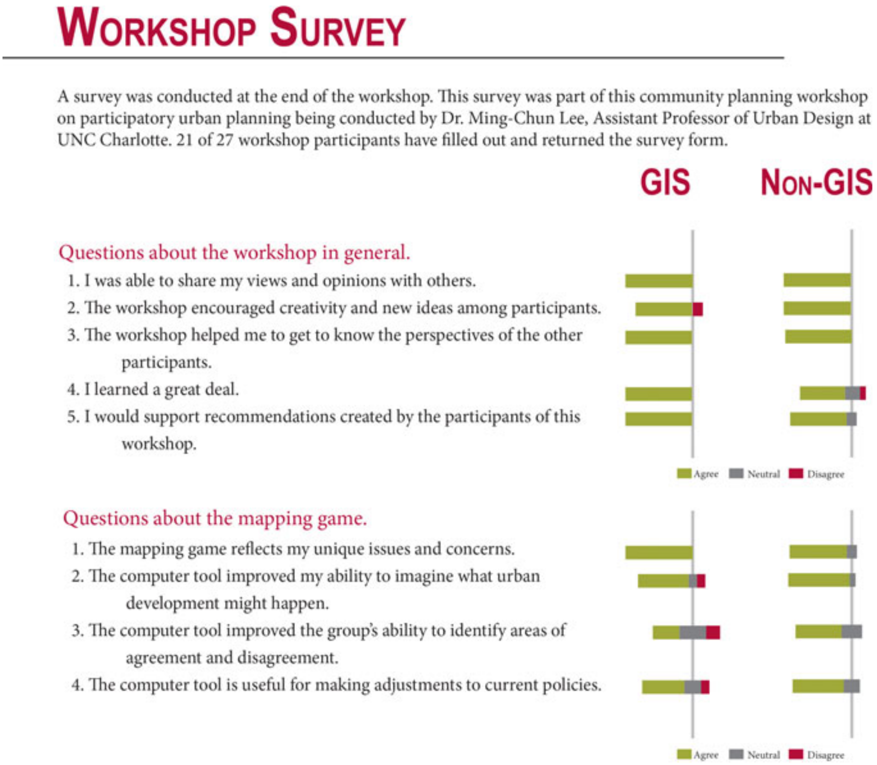
This page shows the comparisons across these different scenarios looking at specific aspects of development. Additional indicator measures are listed in Appendix.

Indicator	Meaning
Population Growth	Each scenario performs different in how it attracts newcomers to the city.
Housing Mix	Each scenario emphasizes a different mix of new types of housing.
Jobs-Housing Balance	Jobs-Housing balance refers to the approximate distribution of employment opportunities and workforce population across the area. It is measured in terms of the proportion of jobs per household.
Jobs per Net Acre	
People per Net Acre	
Carbon Dioxide (CO2) Emissions per Household	
Revenue vs. Expenditure	Revenue combines both property taxes and sale taxes from local businesses; expenditure accounts for public investment on new road construction, as well as new utilities and sewerage costs.

Fig. 12 Scenario comparisons—Davidson

development conditions and market trends to ensure that the GIS model reflects closely what is on the ground in Davidson. In addition, with enthusiasm, rich awareness of local issues, and constructive dialogues during the workshop, participants together created four different community growth scenarios. All their thoughts in these scenarios can be carried further to facilitate future conversations among residents and other stakeholders.

A survey was conducted at the end of the workshop. 21 of 27 workshop participants completed the survey form. The results revealed participants' positive experience with this type of planning exercise involving the use of GIS and scenario



WORKSHOP SURVEY

A survey was conducted at the end of the workshop. This survey was part of this community planning workshop on participatory urban planning being conducted by Dr. Ming-Chun Lee, Assistant Professor of Urban Design at UNC Charlotte. 21 of 27 workshop participants have filled out and returned the survey form.

Questions about the workshop in general.

1. I was able to share my views and opinions with others.
2. The workshop encouraged creativity and new ideas among participants.
3. The workshop helped me to get to know the perspectives of the other participants.
4. I learned a great deal.
5. I would support recommendations created by the participants of this workshop.

Questions about the mapping game.

1. The mapping game reflects my unique issues and concerns.
2. The computer tool improved my ability to imagine what urban development might happen.
3. The computer tool improved the group's ability to identify areas of agreement and disagreement.
4. The computer tool is useful for making adjustments to current policies.

Fig. 13 Workshop survey—Davidson

methods (Fig. 13). In general, participants found use of scenarios with performance indicators useful for them to understand potential tradeoffs between alternatives. The introduction of regional growth concept also allowed them to see broader context and understand the linkage between local actions and regional coordination.

10 Discussion

10.1 Socio-Technical Perspective

This pilot project offered some indications showing that GIS-enabled analytic tools, such as ET+, can be useful in managing the complexity of local and regional planning activities by reducing it into a controllable set of measures. Though an in-depth evaluation on the exact effectiveness of scenario planning is outside the scope for this study, a closing discussion taken from the socio-technical perspective about some of the key lessons learned in this case as well as from the two projects discussed earlier will conclude this chapter.

As discussed earlier, GIS-enabled scenario planning seeks to boost the technical efficiency of spatial analysis in regional planning as well as to build transparent channels for communications and open platforms for the participation necessary in the planning process. This socio-technical perspective is important to understand the significance of this particular type of planning, which seeks to integrate social practices of planning with information and communications technologies. It is again through this particular viewpoint that four key observations about the interplays between the two aspects are drawn as follows:

(1) Technology enables scientific inquiry, increases understanding of social, economic, and natural systems: the capability of ET+ to conduct analyses quantitatively and illustrate the results during the Davidson workshop as well as in the Central Texas case increased participants' ability to engage in discussions about key issues facing the community and various factors involved in the process.
(2) Technology allows collaborative design, enables quick exploration and performance evaluation on design alternatives: ET+, used in Davidson and Central Texas, provided workshop participants with a sketching interface to paint different combinations of development prototypes, which were further tested and refined based on performance indicators and consensus amongst users in a collaborative way.
(3) Technology helps identify community values and promotes social learning: various public engagement techniques used in the Davidson case as well as the two projects in Utah and Central Texas, including surveys, polling activities in workshops, use of indicators, mapping and sketching exercises, all afforded the participating residents the opportunities to express concerns, raise issues, and together identify key values that may be essential to the future of their communities.
(4) Technology helps shape political coalitions and builds organizational capacity: in the early phase of the Davidson project, a collective effort was made by various units within Town Hall and by key stakeholders to identify suitable development prototypes and potential indicators for performance evaluation. This step allowed all parties to exchange ideas, share concerns, understand the scope of the project, and more importantly learn the necessary procedures, data requirements, and presentation techniques necessary to conduct scenario exercises. Likewise, similar processes occurred in both Utah and Central Texas cases.

10.2 Planning Across Scales

The necessity of establishing sustainable practices in our life is important in both present and future contexts. Such practices require a focus on the holistic incorporation of economic, environmental, and social factors. As demonstrated by the two cases and the pilot project presented in the chapter, these sustainability issues can be battled on two fronts, which represent the two opposite but mutually supportive directions in planning. First, a region-wide planning framework for a broad territory needs to be established to coordinate related planning efforts targeting different issues by different agencies. This regional planning effort is meant to create a blue-print that guides local agencies to deploy resources in an organized way. A community-based planning approach with clear implementation strategies on the local level then has to follow. Community planning is meant to reveal each locale's unique finger-print and in turn develop a set of actions tailored specifically to its uniqueness. The two approaches have to be taken in a sequential way with a regional framework established first and then a set of implementation strategies developed accordingly. To ensure a smooth transition between scales, the various tools that enable planners and residents to easily switch lenses between seeing the big picture and detecting the fine details on the ground, are both certainly needed.

10.3 Some Thoughts on Future Applications

As much is learned from these three cases, this final section presents some thoughts about critical issues of future applications of scenario planning practices that may be relevant for other projects. Four themes emerge from this work. Firstly, equip the public and decision makers with convincing data and objective analyses. Durable and inclusive consensus requires ongoing public relations and understanding built upon reliable, complex, and convincing data. Secondly, create engagement that is relevant to community values. Interactive public events that begin with an accurate representation of community values can harness the wisdoms of crowds and recognize the multitude of perspectives that people may add to the process. Thirdly, initiate and sustain the right public-private coalition. The success of scenario planning is dependent on the delicate political sensibility of project leadership. Getting the buy-in of key political players before starting the process is a formula for minimizing resistance in the long run. And fourthly, make alternative plans easy to understand with visualization techniques. Visualizations offer a method of sharing ideas and concerns. As tools, they function as illustrations to allow participants to see tradeoffs between alternatives.

This project provides a methodology for smarter urban futures, using scenario analysis methods that successfully connect regional *blue-printing* framework to local *finger-printing* processes, to create an integrated planning approach that simultaneously fulfills regional and local planning needs.

Acknowledgements The author is grateful for funding to support this research from School of Architecture at the University of North Carolina at Charlotte under Faculty Research Grants 2014–2015. The author thanks the anonymous reviewers for their thorough review and highly appreciates the comments and suggestions.

References

Albrechts, L. (2004). Strategic (spatial) planning reexamined. *Environment and Planning B: Planning and Design, 31,* 743–758.

Al-Kodmany, K. (2000). Using web-based technologies and geographic information systems in community planning. *Journal of Urban Technology, 7*(1), 1–30.

Allen, E. (2001). INDEX: Software for community indicators. In R. K. Brail & R. E. Klosterman (Eds.), *Planning support systems: Integrating geographic information systems, models, and visualization tools* (pp. 229–261). Redlands, CA: ESRI Press.

Andrews, C. J. (1992). Sorting out a consensus: Analysis in support of multiparty decisions. *Environment and Planning B: Planning and Design, 19*(2), 189–204.

Bartholomew, K. (2005). *Integrating land use issues into transportation planning: Scenario planning summary report.* Washington, DC: Federal Highway Administration, U.S. Department of Transportation. http://www.trb.org/news/blurb_detail.asp?id=5689

Bartholomew, K. (2007). Land use-transportation scenario planning: Promise and reality. *Transportation, 34*(4), 397–412.

Bartholomew, K., & Ewing, R. (2008). Land use-transportation scenarios and future vehicle travel and land consumption: A meta-analysis. *Journal of the American Planning Association, 75*(1), 13–27.

Batty, M. (1994). A chronicle of scientific planning: The Anglo-American modeling experience. *Journal of the American Planning Association., 60,* 7–16.

Bischof, R. J., & Dale, A. P. (1997). *Regional resource use planning and GIS: Practice trailing theory*. Presented at AURSIA 97, Christchurch, New Zealand, November 19–21, 1997. http://chrrupp.sl.csiro.au/Resources/pdf/rrup-gis.pdf

Bradfield, R., Wright, G., Burt, G., Cairns, G., & van der Heijden, K. (2005). The origins and evolution of scenario techniques in long range business planning. *Futures, 37*(8), 795–812.

Chakraborty, A., Kaza, N., Knaap, G.-J., & Deal, B. (2011). Robust plans and contingent plans. *Journal of the American Planning Association, 77*(3), 251–266.

Chaskin, R. J. (2003). Fostering neighborhood democracy: Legitimacy and Accountability within loosely coupled systems. *Nonprofit and Voluntary Sector Quarterly, 32*(2), 161–189.

Council of Europe. (1983). *European regional/spatial planning Charter*. http://www.coe.int/t/dgap/localdemocracy/cemat/VersionCharte/Charte_bil.pdf

Cowen, D. J., & Shirley, W. L. (1991). Integrated planning information systems. In D. J. Maguire, M. F. Goodchild, & D. W. Rhind (Eds.), *Geographical information systems, Volume 2: Applications*. Longman, UK: Wiley.

Echenique, M. H., Hargreaves, A. J., Mitchell, G., & Namdeo, A. (2012). Growing cities sustainably. *Journal of The American Planning Association, 78*(2), 121–137.

ET—Envision Tomorrow. (2014). *Tools*. http://www.envisiontomorrow.org/tools/

Ewing, R. (2007). Research you can use: Regional scenario plans and meta-analysis. *Planning, 73*(3), 38.

Goodspeed, R. (2013). *Planning support systems for spatial planning through social learning*. Doctoral dissertation submitted to the Department of Urban Studies and Planning, MIT.

Harris, B. (1989). Beyond geographical information systems: Computers and the planning professional. *Journal of the American Planning Association, 55,* 85–92.

Healey, P. (1992). Planning through debate: The communicative turn in planning theory. *Town Planning Review, 63*(2), 143–162.

HUD—The US Department of Housing and Urban Development. (2009). *Overview: Sustainable communities regional planning grants*. http://portal.hud.gov/hudportal/HUD?src=/program_offices/sustainable_housing_communities/sustainable_communities_regional_planning_grants

Innes, J. E., & Boober, D. E. (2010). *Planning with complexity: An introduction to collaborative rationality for public policy*. New York, NY: Routledge.

Jantz, C. A., Goetz, S. J., & Shelley, M. K. (2004). Using the SLEUTH urban growth model to simulate the impacts of future policy scenarios on urban land use in the Baltimore-Washington metropolitan area. *Environment and Planning B, 31*(2), 251–272.

Kahn, H. (1962). *Thinking about the unthinkable*. Ann Arbor, Michigan: University of Michigan Press.

Kliskey, A. D. (1995). The role and function of a GIS as a planning tool in natural resource management. *Computers, Environment and Urban Systems, 19*(1), 15–22.

Klosterman, R. E. (1997). Planning support systems: A new perspective on computer-aided planning. *Journal of Planning Education and Research, 17,* 45–54.

Klosterman, R. E. (1999). The what if? Collaborative planning support system. *Environment and Planning B: Planning & Design, 26*(3), 393–408.

Kwartler, M., & Bernard, R. N. (2001). Communityviz: An integrated planning support system. In R. K. Brail & R. E. Klosterman (Eds.), *Planning support systems: Integrating geographic information systems, models, and visualization tools*. Redlands, California: ESRI Press.

Lemp, J. D., Zhou, B., Kockelman, K. M., & Parmenter, B. M. (2008). Visioning versus modeling: Analyzing the land use-transportation futures of urban regions. *Journal of Urban Planning and Development, 134*(3), 97–109.

Mollenkopf, J., et al. (2001). *Place matters: Metropolitics for the twenty-first century*. University of Kansas Press.

Ogilvy, J. (2002). *Creating better futures: Scenario planning as a tool for a better tomorrow*. New York: Oxford.

Ringland, G. (1998). *Scenario planning: Managing for the future*. New York: John Wiley.

Ringland, G. (2002). *Scenarios in public policy*. New York: John Wiley.

Scheer, B. C. (2012). *The Utah model: Lessons for regional planning*. Brookings Mountain West Report. http://digitalscholarship.unlv.edu/cgi/viewcontent.cgi?article=1020&context=brookings_pubs

Smith, E. (2007). Using a scenario approach: From business to regional futures. In L. D. Hopkins & M. A. Zapata (Eds.), *Engaging the future: Using forecasts, scenarios, plans, and projects* (pp. 79–101). Cambridge, MA: Lincoln Institute of Land Policy.

University of Utah. (2014). *Envision Tomorrow Plus*. http://www.arch.utah.edu/cgi-bin/wordpress-etplus/

Waddell, P. (2002). Urbansim—Modeling urban development for land use, transportation, and environmental planning. *Journal of The American Planning Association, 68*(3), 297–314.

Walker, D., & Daniels, T. L. (2011). *The planners guide to Communityviz: The essential tool for a new generation of planning*. Chicago: Planners Press, American Planning Association.

Wegener, M. (2003). Overview of land-use transportation models. In *Proceedings of the 8th International Conference on Computers in Urban Planning and Urban Management*, Sendai, Japan, CUPUM, May 27–29, 2003.

Chapter 22
Evolution of a Synthetic Population and Its Daily Mobility Patterns Under Spatial Strategies for Urban Growth

Simone Z. Leao, Nam Huynh, Alison Taylor, Chris Pettit and Pascal Perez

Abstract This chapter proposes and tests an innovative method to integrate a spatial scenario-based approach with a synthetic population evolution model and a mobility assignment model. Results are applied to assess future housing demand by dwelling type, and to identify future hubs for daily trips associated to an urban growth scenario in a case study. Main contributions of this research include the generation of urban population data at fine spatial and temporal scales and the inclusion of spatial planning into a synthetic population evolution model. Although current limitations associated to model assumptions and data availability are identified, the model is built in a platform flexible to adapt to new parameters and datasets. Big data is envisioned as a potential source of future improvements, through better and more frequent characterisation of population behaviour and interdependencies between demographics, land use and transportation.

Keywords Synthetic population · Mobility · Urban growth · Modelling · Simulation · GIS

S.Z. Leao (✉) · A. Taylor · C. Pettit
City Futures Research Centre, University of New South Wales, Sydney 2052, Australia
e-mail: s.zarpelonleao@unsw.edu.au

A. Taylor
e-mail: alison.taylor@unsw.edu.au

C. Pettit
e-mail: c.pettit@unsw.edu.au

N. Huynh · P. Perez
Smart Infrastructure Facility, University of Wollongong, Wollongong 2522, Australia
e-mail: nhuynh@uow.edu.au

P. Perez
e-mail: pascal@uow.edu.au

S. Geertman et al. (eds.), *Planning Support Science for Smarter Urban Futures*, Lecture Notes in Geoinformation and Cartography,
DOI 10.1007/978-3-319-57819-4_22

1 Introduction

Planning residential development, providing infrastructure and managing the delivery of services in increasingly complex and rapidly changing urban environments demands comprehensive supporting information. In order to model the impact of new modes of delivery, to identify sustainable and cost-effective alternatives and to evaluate policy effects, ever more disaggregated data is required. An integral component of this planning information is data on the resident population, which forms the building block to model housing needs, transport infrastructure requirements and provision of services such as schools or health care.

This chapter reports on a study that addressed this need. Public sector decision makers required detailed demographic data for the future population of a small area undergoing considerable redevelopment activity. The area is advantageously located in the south eastern sector of Sydney, Australia. It was recently the recipient of a major piece of public transport infrastructure in the form of light rail valued at Aus$2.6 billion. In key strategic planning documents (DPE 2014), the area has been designated as part of a larger Global Economic Corridor and also as a future urban renewal corridor, with local renewal opportunities yet to be identified. Hence, understanding potential development patterns and their likely contribution to future infrastructure demand was of considerable interest.

In addition to demographic detail on the future population, a comparison of the outcomes of varying scenarios of urban development was desired. Previous approaches have stressed the need for salience, credibility and legitimacy of the scenarios (Murray-Rust et al. 2013). Results of this modelling would then contribute to decisions regarding the preferred spatial pattern of new residential development as reflected by the proximity to public transport, the types of dwellings likely in such zones and the probable future population accommodated therein. Finally, data on the future populations and their transport behaviours was required to inform future infrastructure planning, for example, the need for public transport services or school places.

One of the more promising approaches to meeting such data needs involves producing a synthetic population (Moeckel et al. 2003; Harland et al. 2012). Synthetic populations can be modelled for small areas, with detailed characteristics and time horizons; a combination of attributes that were previously unavailable. The synthetic population is comprised of individual actors with characteristics relevant to the research question. The population is modelled by applying synthesised micro-level data derived from aggregated data usually available for larger areas. In this way the synthetic population reflects the structure and attributes of the real population from which it is derived, but yields more spatially disaggregated detail. Such populations are used to understand and predict the aggregate behaviour of large numbers of individuals (Geard et al. 2013).

Modelling reflects the individual impact of demographic processes such as additions to the population from births, losses from deaths, and both gains and losses from migration. Such actions are modelled with built-in rules based on previous trends. These decisions have typically been informed by the use of census data and less often by developing empirically-justified adaptive decision rules based on survey or interaction data (Filatova et al. 2013). The cumulative result of all these actions is a new population, complete with the demographic and distribution characteristics required to inform key planning decisions.

Causes and dynamics of residential mobility remain a sensitive component of disaggregated demographic models. While work-related circumstances have a direct influence on relocation, Clark and Huang (2003) and Wong (2002) also identified changes in family situation and attractiveness of alternative properties or market as factors. In another study, Kim et al. (2005) found that transport-related factors, residential density and quality of schools significantly influence households' intention to move. Up until recently, economic choice modelling has provided the only conceptually consistent and analytically tractable framework to design models of residential choice and mobility (O'Sullivan 2009). However, many critics of this economically rational choice approach denounce its reductionism, arguing that residential choices encompass factors like social bonding or sense of place that can hardly fit into a single currency framework

Agent based modelling has subsequently been used on these synthetic populations to leverage the benefits of both approaches and specifically, to yield further insights regarding the possible behaviour of the actors (Filatova et al. 2013). The agent based approach involves modelling individuals' or agents' decision-making from the bottom up, thus allowing the compilation of realistic individual-level populations, completed with the outcomes of their cumulative choices, at a variety of spatial scales and temporal periods. These choices may include housing selection, travel behaviour or other characteristics of particular interest (Harland et al. 2012).

Previous approaches to agent based modelling in urban environments have addressed residential choice by modelling the decisions of residential consumers as actors within the constraints of the residential land market (Hosseinali et al. 2012). This study builds on those previous approaches by testing the differential impacts of a number of possible scenarios of urban development within the defined study area. These impacts are reflected in the varying size, distribution, characteristics and behaviour of the modelled populations.

While other studies have incorporated the creation of what if? scenario formulating and evaluation, for example Klosterman (1999) and Pettit (2005), this study specifically models the impacts on the distribution of the population, variations in travel behaviour and the resulting demand for school places. Agent based modelling has previously been used, frequently in conjunction with microsimulation, to predict travel behaviour (Huynh et al. 2015). Iacono et al. (2008) noted that the value of these approaches was their ability to reflect dynamic urban processes and the complexity of individuals' decision making, while overcoming the bias and poor quality outputs of closed-system approaches.

A vital component of any such modelling exercise is the presentation, analysis and communication of the results to the decision makers. Visualisation has much to offer in communicating large amounts of data, illustrating patterns and assisting interpretation (Pettit et al. 2012). Too often, results from synthetic population and agent based modelling are presented in static maps thus undervaluing the extent of data yielded from these sophisticated approaches. Having detailed population characteristics, distribution and behavioural data, in this case travel behaviour, over an extended time horizon creates many opportunities to explore the findings and inform key decisions.

The remainder of this chapter describes the modelling of a synthetic population in a small area of Sydney that is undergoing substantial change. In particular, new residential development will attract a new and potentially different population, and so patterns of migration were a particular focus of the modelling. Testing the differential impacts of a number of scenarios of residential expansion was also part of this study. Additionally, agent based modelling was used to predict future travel behaviour with specific refinements including the incorporation of various survey data.

Significant amounts of useful data were generated from this modelling; data sets that provide important insights for planning future infrastructure and services in this rapidly growing area of Sydney. A series of visualisations of this data were developed to aid interpretation. These innovative visualisations contributed to greatly improved understanding of the results. Specifically, data was visualised to facilitate decisions about which patterns of residential expansion are preferred and what the impact will be on infrastructure demand, in particular for transport and schools. The study reported in this chapter has made a major contribution to informing planning decisions in this rapidly changing urban environment.

2 Method

Figure 1 outlines the modelling framework developed in this study to construct and evolve a synthetic population with associated mobility described by a travel diary. An overview of each model component is presented after the figure. This research progresses upon previous work developed by the authors; therefore, due to limited space, references are made to published work providing more details.

2.1 Initialising the Synthetic Population

The synthetic population was initialised using aggregated and publicly available demographic data from the Australian Bureau of Statistics (ABS) census 2011. Attributes of each synthetic individual include a unique identification, age, gender, relationship in the household, household type and SA1 in which the household resides. An innovative algorithm linking individuals in the population by their relationship permitted the formation of synthetic households. This feature was critical in evolving an agent based simulation of population and in capturing the interdependencies of travel demand of synthetic individuals.

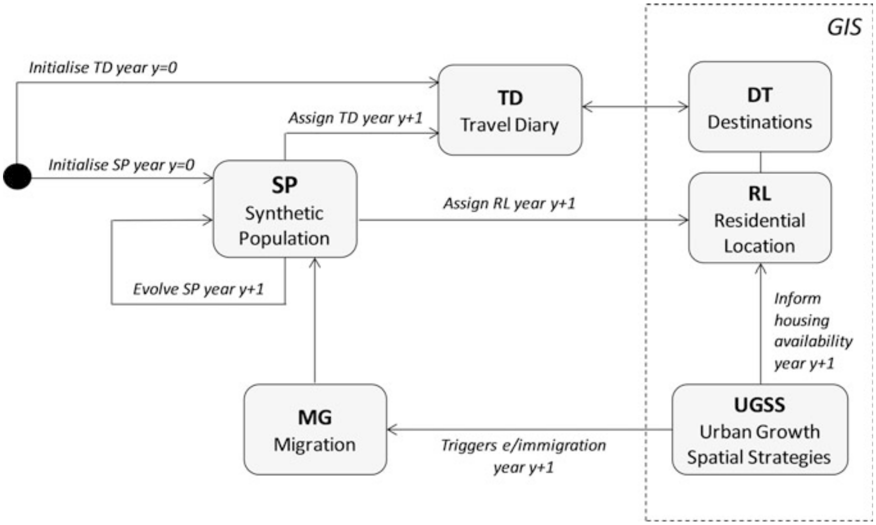


Fig. 1 Modelling framework

The ‘modified sample-free population synthesiser’ used here starts with the construction of a pool of individuals and a pool of households based on the census tables. The model then allocates synthetic individuals in the individual pool into each synthetic household in the household pool following a two-stage process: (i) first it satisfies the requirement of compositional individuals (based on their household relationship) in each household; (ii) second it simultaneously satisfies the demographic distributions, as set out in census tables for “*Family Composition by Sex of Person in Family*”, and “*Household Composition by Number of Persons Usually Resident*”. The recursive assignment process runs until a solution is found. Huynh et al. (2016) describes this process in detail.

2.2 Assigning a Travel Diary to Individuals in the Synthetic Population

Each individual in the synthetic population is assigned a travel diary, which comprises a sequence of trips the person makes in a representative day. Information for each trip includes travel mode, trip purpose, departure time, duration, origin and destination. Due to confidentiality, complete travel details are not available in any single source of published data. The assignment of a travel diary to synthetic individuals therefore relies on a number of data sources (e.g. the UNSW Travel Survey, a key destination in the study area), which are included in two steps. First, it assigns the travel diary, without information on trip origin and trip destination, of individuals in the same household in the Household Travel Survey data for

2006–2011 to individuals in the matching household in the synthetic population. Details of the semi-deterministic algorithm for this step can be found in Huynh et al. (2013). The assignment of trip origin and destination for the synthetic population in the study area relies on the ABS Journey To Work data for 2011 and a comprehensive list of points of interest by types of activity in the area. Details of the algorithm for location assignment to trips that was used in this step can be found in Huynh et al. (2014).

2.3 Evolving the Synthetic Population

The algorithm that evolves the synthetic population operates at regular annual time points and is responsible for two main tasks. The first is the simulation of age dependent life events of each synthetic individual. Details of the part of the algorithm for this task can be found in Huynh et al. (2015). The latter task handles annual migration into and out of the study area following a predefined age profile of individual immigrants and emigrants and constrained by the availability of dwellings in the study area. Dwelling availability in any one year comes from dwellings vacated by existing households in the population (e.g. including emigrating households and those with deceased residents) and the predefined number of those newly constructed dwellings in that year.

2.4 Selecting Emigrating Households from the Current Population

This step aims to reproduce the migration out of the study area as characterised by census data, based on the average number of emigrants (ignoring the intra-zone migrating between zones within the study area) over the 5 years 2006–2011 in comparison to the total population of the study area in 2011.

Emigrating households are selected so that the total resulting emigrating individuals match with (i) the total number of emigrants for that year and also (ii) the emigrant age distribution. The selection relies on a simple algorithm that scores each household in the current population based on the age of each of its residents, the number of existing emigrants in that age group (D_i) and the number of desired emigrants in the age group (T_i), as described by Eq. 1. Weight β_i is optional and can be used to set preferences for a specific type of individuals (e.g. those in a specific age group, or of a specific gender, or in a household type, et cetera) to be selected.

$$hhScore = \prod_{i=1}^{nResidents} \frac{\max(0, T_i - D_i) * \beta_i}{T_i} \qquad (1)$$

The algorithm then selects the household with the highest score, removes it and its residents from the current population, and updates the number of emigrants in each age group. The process is repeated until the number of emigrants exceeds or equals to the pre-determined value.

2.5 Selecting Immigrating Households from the Initial Population

This step aims to reproduce the migration into the study area as characterised by census data, determined from the average number of immigrants from the study area (ignoring the intra-zone migrating) over 5 years 2006–2011 in comparison to the total population of the study area in 2011.

Immigrating households are iteratively selected from the initial population using the same scoring algorithm described in the selection of emigrating households, so that the age distribution of the resulting immigrants matches. Each immigrating household is (randomly) assigned to a vacant dwelling in the study area. The iteration stops when the number of immigrants exceeds or equals the desired value or when there are no more vacant dwellings.

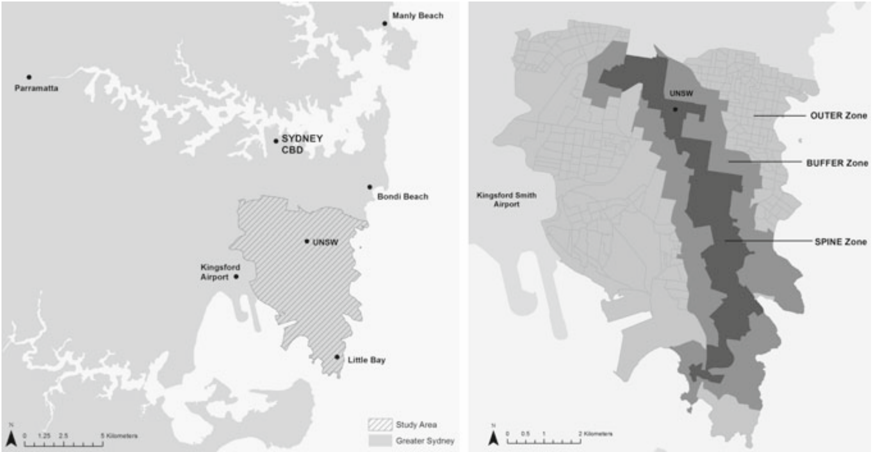
2.6 Selecting Extra Immigrating Households from the Initial Population to Fill in Any Remaining Vacant Dwellings

Each of the households created from the life-event simulation is assigned a dwelling. As a result, the number of extra immigrating households in this step equals the number of vacant dwellings remaining after these allocations. In contrast to earlier selections (in Sect. 2.5), these households are chosen randomly from the initial population. The random procedure can be replaced by a more specific algorithm if information on the characteristics of households or individuals that will occupy these dwellings becomes available.

3 Applications

3.1 Urban Growth Scenarios in South-East Sydney

The South-East Sydney region in the State of New South Wales, Australia is used as a case study to illustrate potential applications of the model outputs (Fig. 2a). The resident population in this area was 180,810 in 2011 (ABS 2011) and it is



(a) Study area within Greater Sydney (b) Urban growth target zones

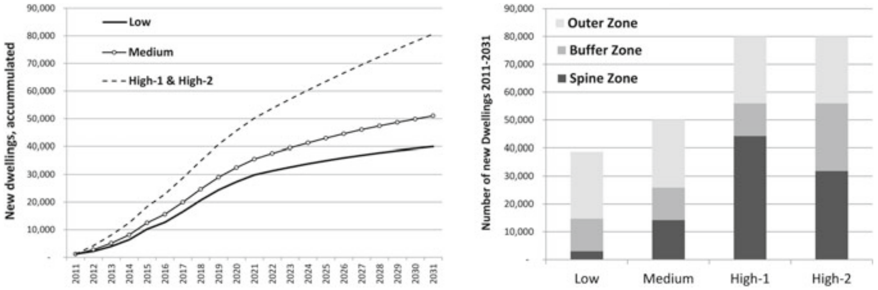
Fig. 2 South-East Sydney region

projected to double by 2031 according to NSW population and dwellings projection data (DPE 2016). Urban growth in the region is stimulated by its advantageous location to employment and amenities and the quality of its services, combined with planning strategies for public transport improvements, urban renewal, and densification. Figure 2b locates zones likely to guide future urban growth in the study area based on the NSW Plan for Growing Sydney (DPE 2014).

Four scenarios of urban growth used in this study are specified by the amount and location of future dwellings. At the base of all scenarios is the NSW urban feasibility model (UFM). The UFM estimates potential housing development sites over time based on planning regulation, development cost, sales prices, and known development proposals (DPE 2011). It indicates the likely number of new dwellings by year and by Census Mesh Block in the study area from 2011 to 2031. These estimates align with low series projections of dwelling growth. Three further scenarios add dwellings to the UFM base case to total either 50,000 or 80,000 dwellings. These scenarios align with the medium and high projections of dwelling growth. New dwellings are located as follows: the Spine (first priority zone for densification, along the major road connection in the study area and partially used for new light rail); Buffer (second priority zone for growth, within 500 m from the edge of the Spine); and Outer (non-priority zone, rest of the area). Table 1 describes the scenarios and quantifies their inputs. For each scenario, Fig. 3a plots the cumulative number of new dwellings between 2011 and 2031, and Fig. 3b presents the share of new dwellings by urban growth zone.

Table 1 Scenarios, descriptions and allocations of new dwellings 2011–2031

	Existing dwellings 2011	Additional dwelling from 2011 to 2031			
		Scenarios of urban growth			
		Low	Medium	High-1	High-2
Description	Initial context	Base case: 38,771 new dwellings (UFM estimates)	UFM estimates plus 11,229 additional dwellings (evenly distributed through the Spine and across time)	UFM estimates plus 41,229 additional dwellings (evenly distributed through the Spine and across time)	UFM estimates plus 41,229 additional dwellings (split 70% in the Spine and 30% in the buffer zones)
Level of growth	N/A	Low	Medium	High	High
Number of dwellings	89,677	+38,771	+50,000	+80,000	+80,000
Spine Zone	18,392	+3003	+14,232	+44,232	+31,863
Buffer Zone	17,972	+11,712	+11,712	+11,712	+24,081
Outer Zone	53,313	+24,056	+24,056	+24,056	+24,056

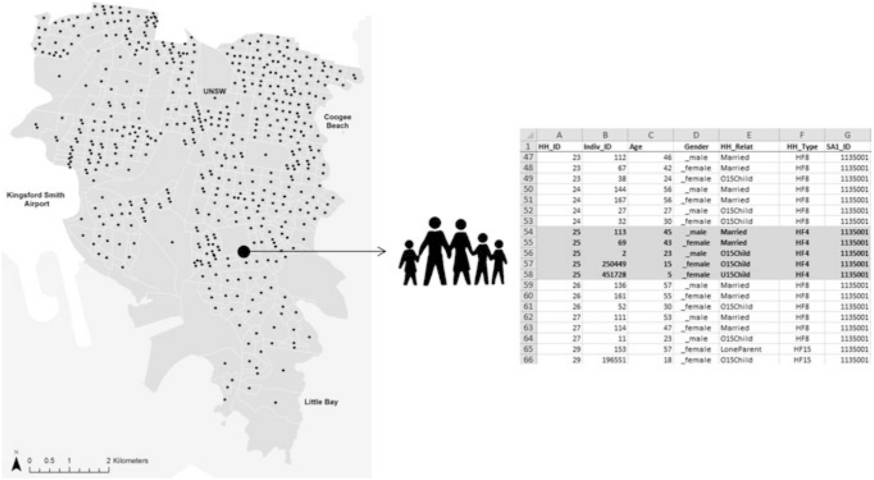


(a) New dwellings' growth (b) Cumulative new dwellings by zone

Fig. 3 Comparison of dwellings' growth and spatial distribution for the four scenarios between 2011 and 2031

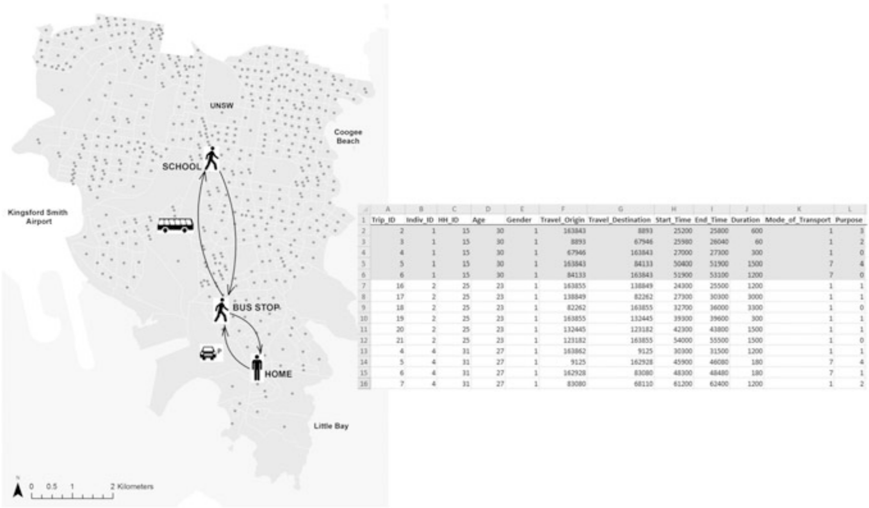
3.2 Demographic Evolution of a Synthetic Population Under Scenarios of Urban Growth and Their Mobility Patterns

Based on the modelling framework described in Sect. 2, synthetic populations and correspondent travel diaries were produced for the study area for the period 2011–2031, considering demographic evolution and mobility patterns with growth priority areas as attractors. For the synthetic population, the model output for each scenario indicates the population at individual level with characteristics of age and gender, and also by relationship in households, with characteristics of household type and location by SA1 (Fig. 4). For the travel diary, the model output for each scenario lists the trips made by individuals in the synthetic population, indicating their purpose, mode of transport, origin, destination, start time, end time, and duration (Fig. 5).



	A	B	C	D	E	F	G
1	HH_ID	Indiv_ID	Age	Gender	HH_Relat	HH_Type	SA1_ID
47	23	112	46	_male	Married	HF8	1135001
48	23	67	42	_female	Married	HF8	1135001
49	23	38	24	_female	O15Child	HF8	1135001
50	24	144	56	_male	Married	HF8	1135001
51	24	167	56	_female	Married	HF8	1135001
52	24	27	27	_male	O15Child	HF8	1135001
53	24	32	30	_female	O15Child	HF8	1135001
54	**25**	**113**	**45**	**_male**	**Married**	**HF4**	**1135001**
55	**25**	**69**	**43**	**_female**	**Married**	**HF4**	**1135001**
56	**25**	**2**	**23**	**_male**	**O15Child**	**HF4**	**1135001**
57	**25**	**250449**	**15**	**_female**	**O15Child**	**HF4**	**1135001**
58	**25**	**451728**	**5**	**_female**	**U15Child**	**HF4**	**1135001**
59	26	136	57	_male	Married	HF8	1135001
60	26	161	55	_female	Married	HF8	1135001
61	26	52	30	_female	O15Child	HF8	1135001
62	27	111	53	_male	Married	HF8	1135001
63	27	114	47	_female	Married	HF8	1135001
64	27	11	23	_male	O15Child	HF8	1135001
65	29	153	57	_female	LoneParent	HF15	1135001
66	29	196551	18	_female	O15Child	HF15	1135001

Fig. 4 Synthetic population table and map, Scenario High-2 2031



	A	B	C	D	E	F	G	H	I	J	K	L
1	Trip_ID	Indiv_ID	HH_ID	Age	Gender	Travel_Origin	Travel_Destination	Start_Time	End_Time	Duration	Mode_of_Transport	Purpose
2	2	1	15	30	1	163843	8893	25200	25800	600	1	3
3	3	1	15	30	1	8893	67946	25980	26040	60	1	2
4	4	1	15	30	1	67946	163843	27000	27300	300	1	0
5	5	1	15	30	1	163843	84133	50400	51900	1500	7	4
6	6	1	15	30	1	84133	163843	51900	53100	1200	7	0
7	16	2	25	23	1	163855	138849	24300	25500	1200	1	1
8	17	2	25	23	1	138849	82262	27300	30300	3000	1	1
9	18	2	25	23	1	82262	163855	32700	36000	3300	1	0
10	19	2	25	23	1	163855	132445	39300	39600	300	1	1
11	20	2	25	23	1	132445	123182	42300	43800	1500	1	1
12	21	2	25	23	1	123182	163855	54000	55500	1500	1	0
13	4	4	31	27	1	163862	9125	30300	31500	1200	1	1
14	5	4	31	27	1	9125	162928	45900	46080	180	7	4
15	6	4	31	27	1	162928	83080	48300	48480	180	7	1
16	7	4	31	27	1	83080	68110	61200	62400	1200	1	2

Fig. 5 Travel diary table and map, Scenario High-2 2031

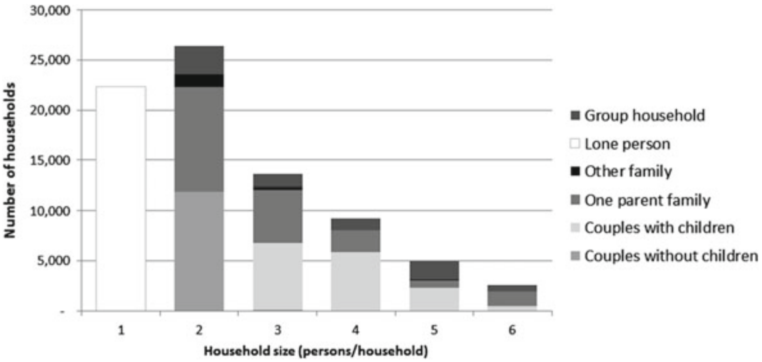
3.3 Exemplar Applications of the Model Outputs

The relevance of the modelled data for urban planning purposes is presented here through two applications: (i) assessment of the future dwelling typology demand based on household type and composition from the synthetic populations; and (ii) identification of destination hotspots within the region by time of day based on travel diaries of local residents. Due to report space limitation, only Scenario High-2 is used for the two applications in comparison to the 2011 base year. This scenario was selected based on its spatially spread distribution of high population growth.

3.3.1 Future Demand by Dwelling Typology

Models to estimate future housing demand by typology can be very useful for planning. These estimates can be used, for example, to assess if current planning controls are sufficient to meet the required demand. Moreover, research (Santin et al. 2009) suggests that there is a strong influence of household and dwelling size on energy consumption, and thus these estimates can be used to infer future electricity demand. Figure 6 illustrates the additional households by type and size generated between 2011 and 2031.

The synthetic households were used to estimate dwelling requirements by minimum number of bedrooms based on the Canadian National Occupancy Standard (2012), which includes the following criteria: (1) no more than 2 persons per bedroom; (2) Children less than 5 years of age may share a bedroom regardless gender; (3) Children 5 years of age or older of opposite gender should have separate bedrooms; (4) Children less than 18 years of age and of the same gender may share a bedroom; and (5) Single household members 18 years or older should have a separate bedroom, as should parents or couples.

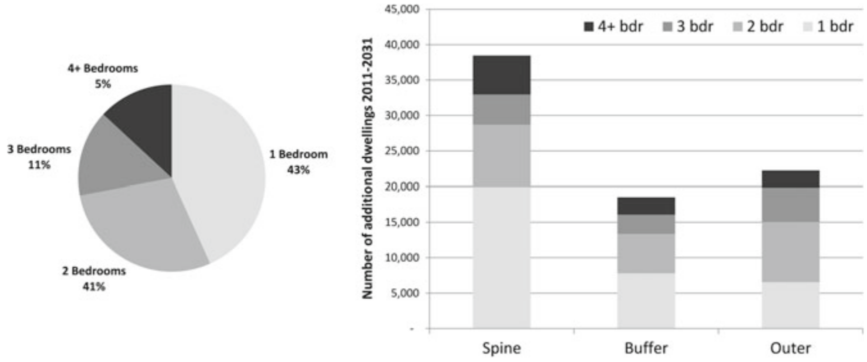


**Couples without children families with more than 2 members include relatives*

Fig. 6 Additional households from 2011 to 2031 by size and type according to Scenario High-2

Based on the number and type of households in 2031 for Scenario High-2, new dwellings required would be as follows: 34,300 1-bedroom; 22,800 2-bedrooms; 11,800 3-bedrooms; and 10,400 4-bedrooms or larger (Fig. 7a). These new dwellings are mostly located in the Spine zone (50%), with 23% in the Buffer zone, and 27% in the outer zones (Fig. 7b). The densities across the area double (+49% in the outer zone, +121% in the Buffer zone and +140% in the Spine zone) (Fig. 8).

In the current model, any synthetic household, regardless of its size and type, can find a dwelling appropriate to its requirements in the statistical area where they have been assigned. Further work could use spatial drivers for urbanisation with finer scale (future dwelling by typologies), and in this case, availability or scarcity of certain typologies would create opportunities or barriers for different household types and sizes. Both approaches are complementary; the former assesses the housing demand created by demographic change; and the latter, the impact of housing supply on demographic change.



(a) Whole study area by dwelling size (b) By Zone and dwelling size

Fig. 7 Demand for new dwellings from 2011 to 2031-Scenario High-2

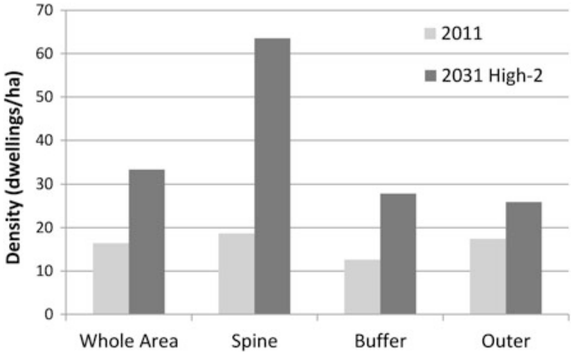


Fig. 8 Change in density from 2011 to 2031/Scenario High-2 for the whole study area and by Zone

3.3.2 Local Hotspots by Time of the Day

Understanding not only where people live, but also their movement around the city over the day is important data for planning, but generally very difficult to obtain. Models that estimate population mobility in fine spatial and temporal resolution can be used, for example, to plan improved or additional transport systems, to evaluate changes in accessibility levels by different modes of transport and purposes, or to assess the future demand for services at certain locations relative to supply.

The travel diary assigned to the synthetic population assists in this analysis. As the population grows, more people will need to access employment, shopping, education, recreation, et cetera. Figure 9 locates the destination hot spots in the study area in 2031 for Scenarios High-2. Destination hotspots include a university, jail, shopping centre, and port precinct.

Eight precincts were identified as main destination areas, encompassing around 80% of the trips in 2011 and 2031/Scenario High-2. There are some variations on the magnitude of the increase among the hot spots, from 65% in precinct 7 to 102% in precinct 3 (Fig. 10).

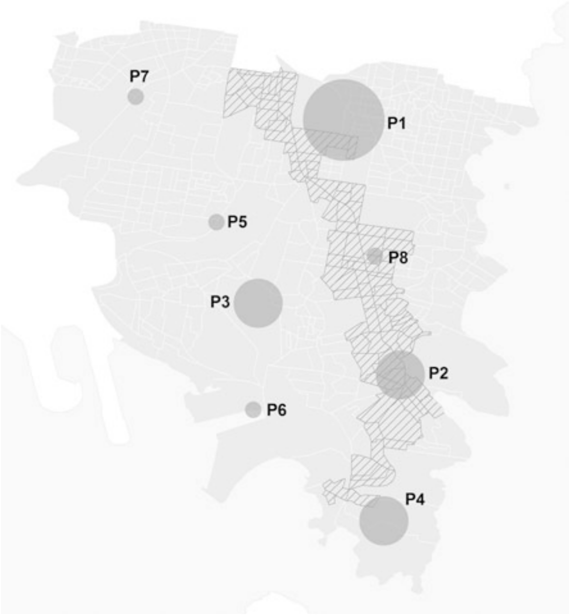


Fig. 9 Destination hot spots in the Study Area in 2031/Scenario High-2

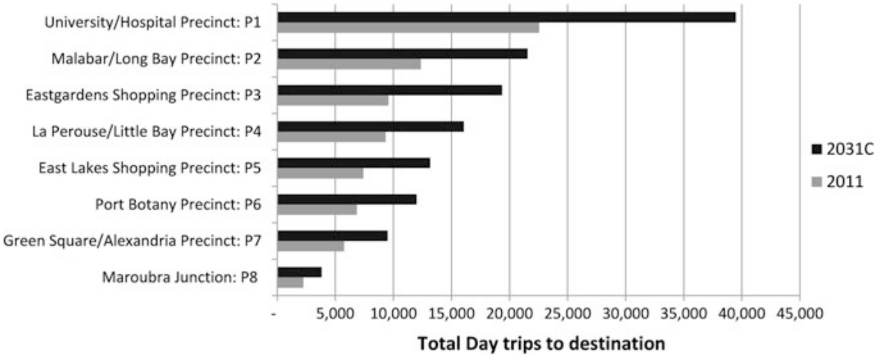


Fig. 10 Increase in trips in 2011–2031 to precincts/Scenario High-2

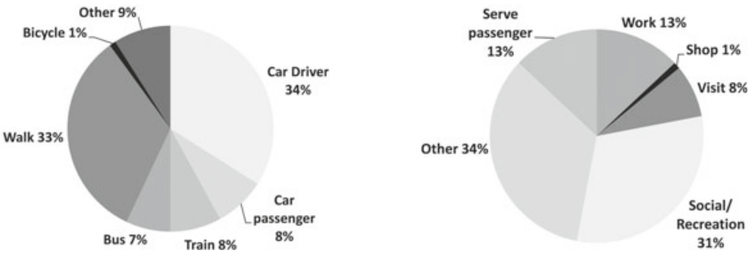
Precinct 4 in the south part of the study area is a region expected to receive significant population growth, and a consequent 79% increase in the number of destination trips was estimated by the travel diary model Fig. 11 compares day distribution of trips to precinct 4 for 2011 and 2031/Scenario High-2, and also characterises trips to P4 in 2031/Scenario High-2 in terms of mode of transport and trip purpose.

The model currently does not produce new destinations; it indicates the growth of trips to existing destinations to meet service demands from a growing population. Further development can include new destinations, planned or hypothetical, as part of the urban growth spatial strategies.

3.4 Visualisation and Interactivity

Synt-Viz (Fig. 12) was developed as part of this research to present and disseminate the model results using available free online mapping platforms. Synthetic population and travel diary data were mapped in the Carto online mapping platform, with the intent to benefit from dynamic graphics to generate map visualisations at different scales, and some map selection tools. These were then embedded in ESRI Story Map environment in order to make use of supporting text and images, and also to combine multiple maps through navigation into one single visualisation address. Synt-Viz can be accessed at: http://arcg.is/2gtMSj4.

(a) Trips to P4 by hour of the day



(b) Mode of transport

(c) Trip Purpose*

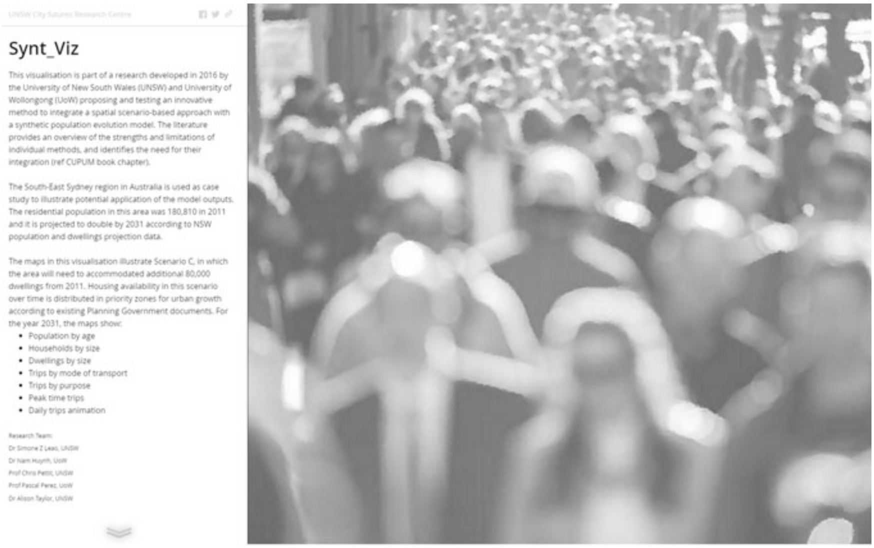
**Serve passenger characterise a trip in which the driver is servinfg a passenger, such as a parent dropping off a child at school*

Fig. 11 Characterisation of trip to Precinct P4 in 2031/Scenario High-2

4 Discussion and Conclusions

This chapter reported on research undertaken for modelling and visualising future urban growth scenarios for South East Sydney. This ambitious work endeavoured to establish fine scale future populations at individual and household levels, and to allocate them in specific dwellings at Census SA1 zones.

The first relevant contribution of this work was to link population evolution to spatial planning at individual and household levels. Planning decisions that drive urbanisation and densification affect spatial distribution of population over the future and their demographics. Modelling this process can provide significant



Synt_Viz

This visualisation is part of a research developed in 2016 by the University of New South Wales (UNSW) and University of Wollongong (UoW) proposing and testing an innovative method to integrate a spatial scenario-based approach with a synthetic population evolution model. The literature provides an overview of the strengths and limitations of individual methods, and identifies the need for their integration (ref CUPUM book chapter).

The South-East Sydney region in Australia is used as case study to illustrate potential application of the model outputs. The residential population in this area was 180,810 in 2011 and it is projected to double by 2031 according to NSW population and dwellings projection data.

The maps in this visualisation illustrate Scenario C, in which the area will need to accommodated additional 80,000 dwellings from 2011. Housing availability in this scenario over time is distributed in priority zones for urban growth according to existing Planning Government documents. For the year 2031, the maps show:

- Population by age
- Households by size
- Dwellings by size
- Trips by mode of transport
- Trips by purpose
- Peak time trips
- Daily trips animation

Research Team:
Dr Simone Z Leao, UNSW
Dr Nam Huynh, UoW
Prof Chris Pettit, UNSW
Prof Pascal Perez, UoW
Dr Alison Taylor, UNSW

(a) Opening page

(b) Housing demand by dwelling size Tab (c) Daily trips animation Tab

Fig. 12 Synt-Viz Interface

insights into the complex relations between forms of planning-guided growth (which affect locations, densities, housing typologies, property markets, et cetera) and resulting demographics (total population, age group share, household types and sizes, income, et cetera). The current model is still simplified in the urban and demographic parameters included and their modelled relationships, but it is the basis for further work that can incorporate more complex and realistic interdependencies. For example, the model currently does not include household income or housing typology and cost as inputs. The model is a fertile platform to assess the impacts of hypothesis and assumptions of behavioural change that could affect demographics of an area. A good example is the recent evidence on the behavioural shift in Australian large cities of families with children that are remaining in inner city apartments, instead of moving towards the lower density suburbs in the outskirts.

A second relevant contribution of this work was to link evolved population under planning-guided urban growth scenarios to mobility patterns at individual level with fine spatial and temporal scales. The '30 min city' concept recently announced by the Federal Government (Commonwealth of Australia 2016) as a goal for all large Australian cities, is a good context to explore the modelled mobility over the future. It proposes that the majority of city residents should be able to satisfy their needs for employment, shopping, recreation, education, and other purposes, taking no longer than 30 min travel time, preferably though public or active modes of transport.

The main limitation of the synthetic population model is in its simplification of the population residential allocation; it maintains existing households in their original SA1 or sends new households to random locations within the study area. This is mostly due to the fact that the model progresses upon a previous version designed for transportation research purposes, in which the model assumptions were acceptable. Future work is recommended to introduce a residential choice component in the model based on dwelling typology and cost, also taking into consideration household size, composition and income. This would result in a more realistic allocation of the population, and could be the basis to model processes of displacement and gentrification, not possible in the current model format. Families that could not find a dwelling to satisfy their demand considering the size of the dwelling and/or the purchasing/rental cost at their current zone would move to a different zone in the study area, or would ultimately leave the system (displacement). A population generator external to the model could create new households which would be allocated within the area if their demand criteria are satisfied by existing supply (gentrification).

The main limitation of the travel diary model is the fact that it is conservative in terms of past and present travel behaviour as represented by the household travel survey, Journey to Work data, and UNSW travel survey at the initial year of the simulation. The model maintains the travel patterns and the destinations' locations over the 20-year time horizon of the simulation. The increase in trips is mainly a consequence of the increase in the population. Since there is no limitation on destinations' capacity, although conservative, the model results are useful for assessing future demand for services in areas with significant population growth. For example, more families with children in an area may imply a significant increase in the number of school children. Trips to local schools would indicate a demand for school places above existing supply. This would provide information for planning about required expansion of existing school, or if this is not possible, the need for a new school in a region.

Whilst every effort was made to obtain fine scale data for all the required variables, the model is still mostly based on Census and survey data with spatial and temporal aggregation, which reflect general past trends. The model, however, was built in a format with flexibility to incorporate new datasets that may be made available in the future that better describe some of the model parameters and processes. The introduction of the UNSW Travel Survey in the study, for example, proved to be a significant improvement of the modelled trips, since it provided details of origins, time of the day, frequency in the week, and mode of transport used in trips to the major educational and health precinct in the study area. Some of the model improvements proposed above will require additional data with high spatial and temporal resolution data. It is anticipated that new big data from smart city systems will make a great contribution.

Demographics, land use and transportation are the foundations of urban processes and many modelling approaches along scientific history tried to capture their interdependencies and dynamics with different levels of detail and varied techniques. This research contributes to this field by proposing a flexible platform to generate relevant data for urban planning purposes and a platform to develop scenarios at fine spatial and temporal scales.

Acknowledgements The authors wish to acknowledge the support from the Data Analytics Centre, NSW Government Department of Finance, Services and Innovation for funding this research.

References

ABS, Australian Bureau of Statistics. (2011). Data and Analysis. http://www.abs.gov.au/websitedbs/censushome.nsf/4a256353001af3ed4b2562bb00121564/data

Canadian National Occupancy Standard. (2012). At Meteor, Metadata Online Repository, Australian Institute of Health and Welfare, Australian Government. http://meteor.aihw.gov.au/content/index.phtml/itemId/386254

Clark, W., & Huang, Y. (2003). The life course and residential mobility in British housing markets. *Environment and Planning A, 35,* 323–339.

Commonwealth of Australia, Department of the Prime Minister and Cabinet. (2016). *Smart cities plan*. Canberra: ACT.

DPE/NSW, Department of Planning and Environment of New South Wales, Australia. (2011). Urban Feasibility model (UFM), http://www.planning.org.au/documents/item/3357. Accessed November 20, 2016.

DPE/NSW, Department of Planning and Environment of New South Wales, Australia. (2014). A plan for growing Sydney, Sydney, Australia. http://www.planning.nsw.gov.au/~/media/Files/DPE/Plans-and-policies/a-plan-for-growing-sydney-2014-12.ashx. Accessed November 14, 2016.

DPE/NSW, Department of Planning and Environment of New South Wales, Australia. (2016). 2016 NSW population and households' projection. http://www.planning.org.au/Research-and-Demography/Demography/Population-projections. Accessed November 20, 2016.

Filatova, T., Verburg, P., Parker, D., & Stannard, C. (2013). Spatial agent-based models for socio-ecological systems: Challenges and prospects. *Environmental Modelling and Software, 45,* 1–7.

Geard, N., McCaw, J., Dorin, A., Korb, K., & McVernon, J. (2013). Synthetic population dynamics: A model of household demography. *Journal of Artificial Societies and Social Simulation, 16*(1), 8.

Harland, K., Heppenstall, A., Smith, D., & Birkin, M. (2012). Creating realistic Synthetic populations at varying spatial scales: A comparative critique of population synthesis techniques. *Journal of Artificial Societies and Social Simulation, 15*(1), 1–15.

Hosseinali, F., Alesheikh, A., & Nourian, F. (2012). Simulation of land-use development, using a risk-regarding agent-based model. *Advances in Artificial Intelligence, 2012*(964148), 11.

Huynh, N., Barthelemy, J., & Perez, P. (2016). A heuristic combinatorial optimisation approach to synthesising a population for agent based modelling purposes. *Journal Artificial Societies and Social Simulation, 19*(4), 11.

Huynh, N., Cao, V., Wickramasuriya, R., Berryman, M., & Perez, P. (2014). An agent based model for the simulation of road traffic and transport demand in a Sydney metropolitan area. In *Proceedings of the 8th International Workshop on Agents in Traffic and Transportation* (pp. 1–7). Paris, France, 5–9 May 2014.

Huynh, N., Perez, P., Berryman, M., & Barthelemy, J. (2015). Simulating transport and land use interdependencies for strategic urban planning—An agent based modelling approach. *Systems, 3,* 178–210.

Huynh, N., Shukla, N., Munoz, A., Cao, V., & Perez, P. (2013). A semi-deterministic approach for modelling of urban travel demand. In *Proceedings of the International Symposium for Next Generation Infrastructure 2013 (ISNGI2013)* (pp. 1–8). University of Wollongong, Wollongong, Australia, 1–4 October 2013.

Iacono, M., Levinson, D., & El-Geneidy, A. (2008). Models of transportation and land use change: A guide to the territory. *Journal of Planning Literature, 22*(4), 323–340.

Kim, J. H., Pagliara, F., & Preston, J. (2005). The intention to move and residential location choice behaviour. *Urban Studies, 42,* 1621–1636.

Klosterman, R. (1999). The what if? Collaborative planning support system. *Environment and Planning B: Planning and Design, 26*(3), 393–408.

Moeckel, R., Spiekermann, K., & Wegener, M. (2003). Creating a synthetic population. In *8th International Conference on Computers in Urban Planning and Urban Management, CUPUM*. Sendai, Japan, May 2003.

Murray-Rust, D., Rieser, V., Robinson, D., & Milicic, V. (2013). Agent-based modelling of land use dynamics and residential quality of life for future scenarios. *Environmental Modelling and Software, 46,* 75–89.

O'Sullivan, A. (2009). *Urban economics* (7th ed., p. 466). McGraw-Hill International Edition.

Pettit, C. (2005). Use of a collaborative GIS-based planning-support system to assist in formulating a sustainable-development scenario for Hervey Bay, Australia. *Environment and Planning B: Planning and Design, 32*(4), 523–545.

Pettit, C., Widjaja, I., Russo, P., Sinnott, R., Stimson, R., & Tomko, M. (2012). Visualisation support for exploring urban space and place. In *Proceedings of XXII Congress of the International Society for Photogrammetry and Remote Sensing*. Melbourne, Australia, 25 August–01 September 2012.

Santin, O., Itard, L., & Visscher, H. (2009). The effect of occupancy and building characteristics on energy use for space and water heating in Dutch residential stock. *Energy and Buildings, 41,* 1223–1232.

Wong, G. K. M. (2002). A conceptual model of the household's housing decision-making process: The economic perspective. *Review of Urban & Regional Development Studies, 14,* 217–234.

Chapter 23
Vending the City: Mapping the Policy, Positioning and Policing of Vending in New York City

Rida Qadri

Abstract Policies on street vending are often made without any in-depth understanding of how vending navigates the space of the city or interacts with the larger urban fabric. This project attempts to overcome this knowledge gap through empirical analysis of administrative data, GIS mapping and data visualization to uncover the unique interactions street vending has with each neighborhood's socio-spatial environment, resulting in the creation of diverse vending cultures. By recognizing this vibrancy and untangling the determinants of the spatial landscape of vending rule enforcement, this work can be used to advocate for a fairer and more effective regulatory schema of informal commerce.

Keywords Regulating informality · Street vending · Spatial analysis · 311 data

1 Introduction

A stroll down St. Nicholas Avenue between 181st and 179th street in New York City will have you brushing past empanadas sold out of shopping carts, iced fruit-lollies stacked in an Elvis themed scooter and fresh seafood laid out in the boot of a van. The standardized silver Halal carts and hot dog stands, so common a sight in Midtown and lower Manhattan, will be nowhere to be seen. Yet, policies regarding vending in New York betray a lack of sensitivity to its geography even when vending by its mobility is inherently a spatial practice. Vendors hardly use the same sidewalk space for the entire day, yet licenses do not distinguish between duration of usage. While each neighborhood has its own relationship with vending, policies treat the City as a blanket space, with similar restrictions applying everywhere. There also seems to be little reflection on how the ability of the state to enforce vending laws differs from street to street.

R. Qadri (✉)
Department of Urban Studies and Planning, Massachusetts Institute of Technology,
02139 Cambridge, MA, USA
e-mail: rqadri@mit.edu

S. Geertman et al. (eds.), *Planning Support Science for Smarter Urban Futures*, Lecture Notes in Geoinformation and Cartography,
DOI 10.1007/978-3-319-57819-4_23

Gaps in policy are testament to the difficulty of acquiring granular information about urban informal processes at the city-wide scale. Characterized by unorthodox organizational patterns, informal systems have not lent themselves well to being studied through traditional methods of data collection or newer Geographic Information Technology[1]. For instance, most of the informal sector is completely or partially outside governmental regulation, and thus there are often little to no official city/administrative records of geographical location, land use, customers, residents, or physical conditions (Feige 1990). At times even city administrations are unaware of the geographical, physical and population characteristics of its informal sector. Even when governments have such data, they can potentially make access difficult to any information they deem sensitive (or which might reveal any malpractice). Street vending, in addition to these challenges, is also extremely mobileand thus even more difficult to quantify.

Thus investigating the micro-interactions and life-experiences of those engaged in the informal sector, almost exclusively falls to studies employing qualitative methods. On the other hand, works attempting a more quantitative analysis limit themselves to assessing policy impacts (Dündar 2001; Saavedra and Chong 1999) or providing numbers on the economic scale and spread of these sectors (Amis 2001; Miraftab 1997). A third category of work employs mapping to understand spatial patterns of informality (Abbott 2002, 2003; Burgess et al. 2012).

We cannot however, make better policy till such granular, spatially attuned information is available. This chapter attempts to fill such a knowledge gap by empirically evaluating the interaction of informal vending with the space of the city. Using administrative datasets, innovative mapping and qualitative study, we understand the spatially contingent, variegated forces which shape vending and its regulatory outcomes in New York.

To undertake this task a few measurements are necessary. First, there needs to be a large scale, spatial study done on the current policy outcomes of vending, specifically where it is ticketed and where it is allowed. This would allow us to see if any ordering of areas by enforcement is evident. Only when these patterns are discovered, can explanatory variables be tested. For instance, theories on street vending (Devlin 2011) have ascribed stringent regulations to the power held by Business Improvement Districts (BID), and criticized these organizations for promoting exclusionary urbanism. If the city is indeed reacting to BID demands when it initiates a crackdown on street vending, enforcement numbers should be consistently high in BID areas. However, if that is not the case, other variables need to be introduced to the equation. Scholars like Loukaitou-Sideris and Ehrenfeucht (2009) have suggested that a factor in government action against vending is in fact the demand of middle-class/elite residents and business owners to get rid of vendors in their areas. A logical start would be to examine the attitude of citizens towards

---

[1] Geographic Information Technology refers to a group of tools related to spatial analysis such as aerial photography, satellite imaging and processing systems, Geographic Information Systems (GIS) and Global Positioning Systems (GPS).

vending, since this could be what the city is responding to in its policing drives. Even richer insights can be distilled if the socio-economic profile of areas with high and low enforcement is compared. This would inform us if the opinions of certain citizens have more weight than others, in the larger web of forces at play. Conceptually creating this methodology would be useless if these seemingly amorphous concepts could not be quantified. This study attempts to do just that.

2 Importance of a Spatially Oriented Vending Policy

Reviewing policy for vending[2] in New York, the pitfalls of a non-spatial approach are clear. There are a set number of licenses (853 general merchandise vending licenses, 3000 food cart licenses and a 1000 seasonal food vending permits) (Gerson 2005; Kettles 2014) with each license giving the vendor access to most sidewalk spaces in New York. However, static licensing makes little sense for street vending. Vendors hardly use a sidewalk space for the entire day, nor should they-given the constant fluctuations in their consumer market. This market varies not just by season and time of day, but also by area. Thus, vendors should only be charged for the space they use, when they use it. What is the use of a vendor having a license for months if he/she does not use them? Sidewalks are a precious resource and should be treated accordingly.

Due to this policy, very few licenses open up every year due to non-renewal, and there are thousands on the wait list. The asymmetry in supply and demand has led to a large black market of people illegally renting out their licenses to vendors. Other than food and general vendors, there are also two special categories of vendors: veterans and first amendment vendors (selling including artifacts such as paintings, illustrations, photographs, and books).[3] Veterans can obtain special licenses without a wait list and first amendment vendors do not need a license to vend on non-restricted streets (Gerson 2005) However, there are further sub categories within veteran licenses, and limits to where first amendment vendors can vend.

Other than licensing requirements, there are complicated rules governing where and when vendors can vend even with a license. Vendors cannot stand for instance: within 10 ft of fire hydrants, bus stops, and crosswalks; within 20 ft from building

---

[2] For more information see work by Ray Bromley, Ryan Devlin, Turetsky et al.

[3] There has been some controversy as to what counts as first amendment vending: e.g. Is it 1st amendment vending when a vendor is selling photographs taken and reproduced by someone else? Is distribution permitted, like book distribution? Some artists sell canvases, but also sell the frames. The frames are not 1st amendment permissible. Is performance art the same as art? While a discussion of legal definitions of vending is not within the scope of this project, for more discussion of the topic please see work cited by Genevieve Blake, Testimony of Irum Taqi and Minutes of Community Board 8.

entrances; or on a sidewalk less than 12 ft in width[4] (Community Board 6, NYC). Beyond these restrictions, streets in certain parts of Mid- and Downtown-Manhattan are closed off to vendors at particular times, with the restrictions varying block to block. For example, between East 46th street and East 55th Street on Park Avenue vendors cannot vend Monday–Friday 9 am to 6 pm, but can vend anytime Saturday and Sunday. However, between 55th and 59th Street on Park Avenue, vendors can't vend between 10 am and 7 pm, Monday–Friday. The most stringent of these regulations are in the midtown areas, earning the amalgamation of neighborhoods the title of "*midtown gridlock*" (Community Board 6, NYC).

This preferential treatment of Midtown and Downtown Manhattan also needs to be revisited. While having specific block-by-block policies is a good move, exceptions for Midtown and Downtown were originally granted without any heed to their impact on surrounding neighborhoods, or a reflection on the merits of the arguments (Devlin 2011; Garodnick 2000). Due to an artificial restriction of vending space in Midtown and Downtown Manhattan through time-based restrictions mentioned earlier, vendors spillover to neighborhoods that have less resources for regulation or different views on vending.

Apart from these limited number of street-based restrictions (created more than 15 years ago), the policies in New York treat the City as a homogenous whole. However, each locality has a unique vending culture, vending needs and opinions. What works for Midtown does not necessarily work for Washington Heights, and will not work for SOHO. Vendors are mobile, they should ideally have a low-cost entry and can be used to provide better services to neighborhoods if they are allowed to move freely without fear of undue harassment and enforcement.

The question that this chapter grapples with though is whether we can use planning support systems in the form of GIS, data and datasets to enrich our understanding about vending and its regulations in New York City?

3 Investigating Responses to Vending

This study starts its analysis by mapping government response to vending through the use of New York City's Environmental Control Board's dataset of ticketed city-wide administrative code violations. From 2010–2015, various State agencies in New York handed out 3,422,455 Environmental Control Board summons for administrative code violations related to 'quality of life' in New York City. There were around 30 types of violations and 97,773 of the summons written for a

---

[4] The average sidewalk width in Manhattan is 15 ft, but sidewalks of less than 12 ft are common in Downtown Manhattan around the Financial District. City of New York, "Lower Manhattan Pedestrianization Study", 1997. (http://www.streetsblog.org/wpcontent/uploads/2014/07/1997_DCP_LowerManhattanPedStudy.pdf)

Table 1 Breakdown of environmental control board data by Borough

	New York	Manhattan	Brooklyn	Queens	Staten Island	Bronx
Total Summonses	3,422,455	897,431	935,034	767,669	123,010	698,255
Summonses written for vending	98,614	75,510	8370	7520	147	6721
% of vending infractions as a total (%)	2.88	8.41	0.90	0.98	0.12	0.96

vending infraction (see Table 1). With 76% of these vendor summons originating in Manhattan, I decided to focus my analysis on the borough of Manhattan.

This dataset though, was not geocoded for the latitude and longitude of the addresses. Using New York City's Address locator in ArcGIS, I was able to geocode 72,460 data points accurately out of 75,015 recorded tickets. 2555 data points were not geo-codeable due to data entry issues (missing street, avenue or house addresses names, addresses which did not exist).

Mapping out these enforcements (Fig. 3) reveals how significantly the magnitude of enforcement varies across Manhattan neighborhoods. Hotspots are visible around Downtown, SOHO and Midtown, but lessen in intensity as we go further north. However, we cannot stop at this variation but need to extend our analysis to its explanation.

One consideration in this disparity that must be instantly considered might be that enforcement follows the presence of street vendors. While we do not have any numbers of street vendor presence for all of Manhattan, in 3 neighborhoods I collected vendor density data by geocoding vendor locations three times a day, over four seasons. The neighborhoods I visited were: (1) Washington Heights; (2) the Garment District; and (3) SoHo. Interestingly, in all three vendor locations, the presence and enforcement were completely inverted. Washington Heights had the highest per-day vendor presence, followed by SOHO and then the Garment District (Figs. 1 and 2). On the other hand, when it came to enforcement, the Garment District and SoHo both outstripped Washington Heights by around 400% as shown by Fig. 2.

Another possible explanation for variation in enforcement, theorized by numerous scholars, is citizen complaints. The logic goes that citizens dislike the nuisance caused by vendors, and complain to the City who takes action. In lieu of a large scale survey of people's perceptions of vending in Manhattan, I decided to use 311 complaint data on illegal vending to measure citizen opinions on vending. This dataset has pre-set categories which people have complained about, for example on residential issues such as heat, hot water, or public disorder concerns such as noise, illegal street parking or physical road disrepair including potholes. Within the 311 dataset there is a category for 'vending', with a location of the reported incident.

Fig. 1 Number of vendors present in each neighborhood on an average day

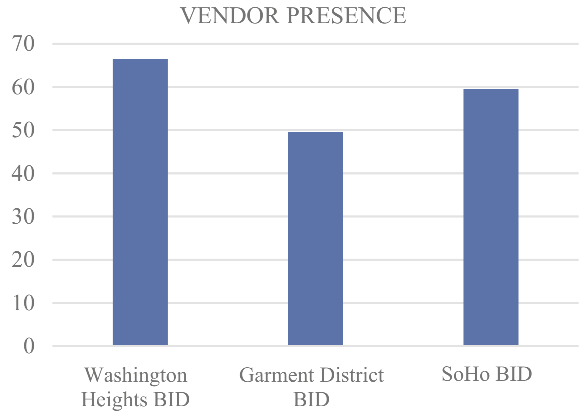


Fig. 2 Number of tickets in each Manhattan neighborhood

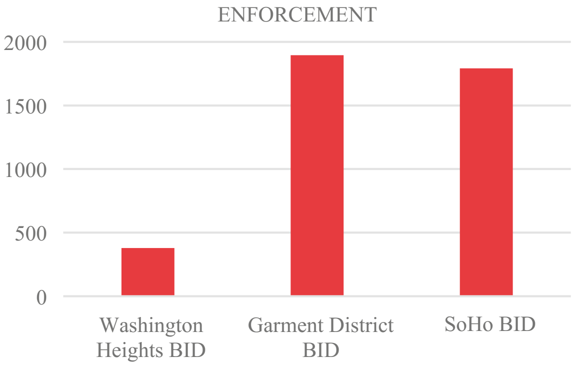


Table 2 Breakdown of 311 calls

	New York	Manhattan
Total 311 complaints	10,809,108	2,035,072
Vending complaints	24,846	13,106

There were 24,846 complaints against vending in New York, 13,106 of them in Manhattan (see Table 2). The idea of using 311 complaints emerged from works that have used administrative complaint data to measure citizen engagement with government (Lerman and Weaver 2014) as well as to get a sense of the spatial distribution of quality of life issues from public disorder to physical disrepair (O'Brien et al. 2015; Sampson and Raudenbush 1999). The benefit of 311 data is that it gives researchers the flexibility to create their own aggregations, whether geographical or theoretical.

Figure 3 shows a comparison of the spatial distribution of 311 calls and enforcement of vending. It is clear that patterns of calls do not follow patterns of ticketing since 311 calls are mostly concentrated near the southwest corner of

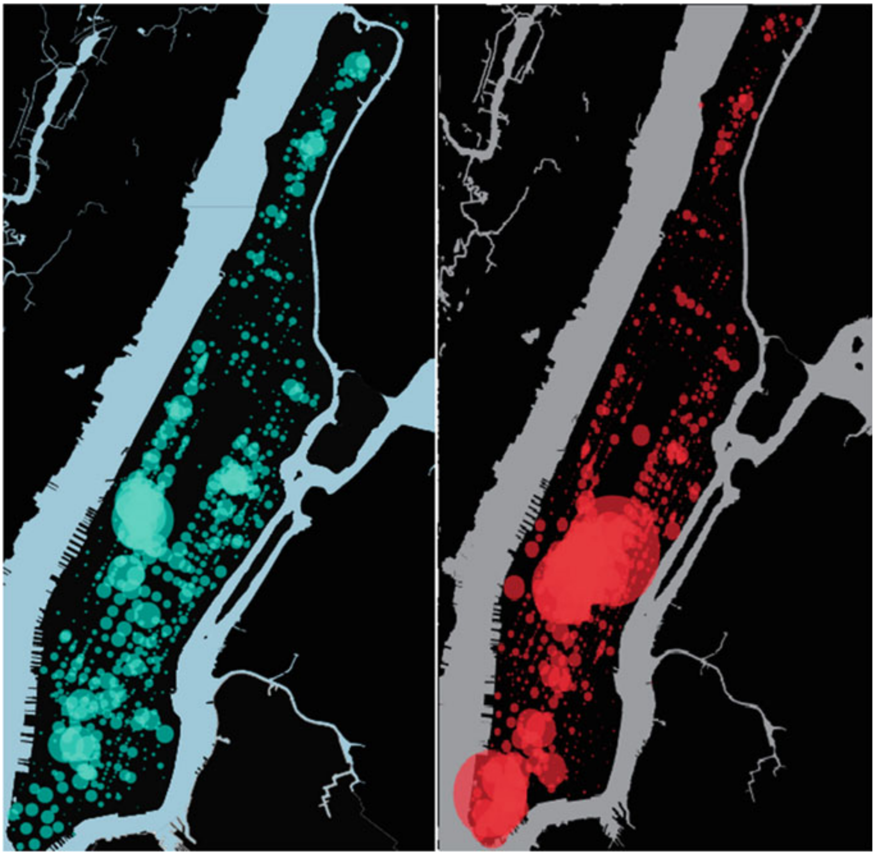


Fig. 3 311 calls per street segment in Manhattan 2010–2015 (*left*) Enforcement per street segment in Manhattan 2010–2015 (*right*)

Central Park and Broadway. 311 calls are also more diffuse than enforcement, with a more equal spread of 311 calls in different blocks, whereas the map of enforcement displays fewer hotspots, and greater disparity in magnitude in between high and low enforcement areas.

4 Model for Analyzing Enforcement Decisions

Having uncovered the complexity of the regimes of enforcement with regard to informality, we can focus on why spatially-contingent regulatory landscapes are created.

4.1 Constructing the Model

I ran a model to test variables which impact on enforcement of vending regulations, calculated by the number of tickets written on the street normalized for a length of street. These were then multiplied by 300 ft to gain a slightly larger unit of measurement and comparison. If enforcement happened on a street intersection, or if there were multiple streets that were in a similar distance range within 20 ft of the enforcement point, the data point was divided amongst those streets, in proportion to their relative distance with one data point going to a maximum of 4 street segments. When enforcement was not on a street segment but in between streets, it was distributed to the street it was nearest to.

The next variable I considered was citizen response as measured by 311 calls. The methodology used to distribute 311 call data points amongst street segments was the same as enforcement data points. I had to think of other ways to capture Manhattan-wide sentiments on vending, which would at the same time not be pre-aggregated to any particular scale.

Unfortunately, 311 calls did not come with any detail about the identity of the caller or the description of the complaint beyond the fact that it was referring to a vendor. Thus I could not know who was making the complaint; a resident or a pedestrian, an employee or a business owner. However, the temporal and spatial patterning of the complaints further aids in creating a measure of the spatial inequity present in the private and public policing of urban informality.

Since I could not test if richer residents were complaining more or pushing for higher enforcement, I decided to test for the sensitivity of enforcement to the socio-economic demographics of a neighborhood; in other words, do areas with richer residents and a higher standard of living experience more enforcement attention than those that are less well off? To capture this information, I initially attempted to use the American Community Survey (ACS) 5 year estimates at the block group level for median housing income. However, this information was only available on the block group level, and assigning street segments values based on their larger block group would have been prone to errors. Thus, I decided to use the NYC Department of Finance's assessed value of tax lots and buildings as a proxy for the economic demographics of the neighborhood. The inference was that the more expensive the building and land, then the wealthier residents were most likely to lodge a complaint. While the ACS estimates bound me to block group levels, the assessed value dataset was available at the individual lot level and thus allowed me to test different levels of geographical aggregations. This is measured by assessed land value/sq. ft. I assume this to have had a positive effect as well since 'richer' neighborhoods probably have more power to get their desired enforcement outcomes. It might also be the case that richer neighborhoods have more anti-vending sentiment and thus desire more enforcement.

Table 3 Street segment based ordinary least squares model

	Total	Commercial	Residential
	E/100 m	E/100 m	E/100 m
Adjusted R^2	16.97	17.78	12.18
F	0.000	0.000	0.000
311/100 m	0.159***	0.154***	0.284***
	(0.000)	(0.000)	(0.000)
BID	0.027***	0.026	0.008
	(0.001)	(0.067)	(0.373)
Land value	0.382***	0.383***	0.121***
	(0.000)	(0.000)	(0.000)
N	18,548	6551	12,780

Standardized beta coefficients; p-values in parentheses
*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$

I also created a variable for commercial and residential density for each street using data from New York City's PLUTO data set.[5] The three data points used were estimates of gross built area of each building, commercial built area and residential built area. The former provides the square footage of the built area of each building. The latter two provided estimates of how much built area in each building was area allocated for either land use, through the exterior dimensions of the portion of structure devoted to commercial or residential use. I then created a proportion of total built area being utilized for either land use. Commercial streets are said to attract more street vendors (and thus attract more enforcement) since vendors prefer areas with heavier foot traffic. Thus, we should expect commercial density to have a positive relationship with enforcement. Another aspect of this relationship is retail density. Shop owners in New York have long decried the impact of vending on their profits. Recently, the grocery chain Gristede's owner contended that fruit stands have been costing the company $7000 per week in produce sales (DeStefano 2015).

The BID variable is a dummy variable that tests whether the street segment falls into a BID or not. For the purposes of this model, all street segments that were within 50 ft of a BID boundary were determined to have fallen within a BID (to allow for overlay errors in projection). The street segments were also separated within 150 ft and within 300 ft of a BID (one or two streets out) for further analysis, but these were not used in the model. I expect this to be a highly significant positive variable. BIDs have generally been blamed for attempting to regulate and privatize public space whereby they are able to exclude any activity which does not conform to their idea of "*clean and safe*". The impact of BIDs on vending enforcement is considered strong enough for vendors to congregate in areas between or just outside BIDs largely because "*the levels of enforcement and*

---

[5] New York City publishes the PLUTO dataset each year which contains land use data at the tax lot level.

harassment are often lighter there than in BID territory" (Devlin 2011). However, this claim has never yet been tested empirically.

The street segment model (Table 3) has 3 types: a model including all streets, and two models that examine commercial and residential streets separately.

4.2 Analysis

Land value and 311 calls having a positive and significant relationship with enforcement across all street types, as expected. However, the first thing to note is that the most important variable across the models is not the presence of a BID, but assessed land value. Further, 311 calls have a higher impact (measured by the beta co-efficient) in residential streets than in commercial streets. The effect of BIDs is not significant in residential areas and BIDs have low significance in commercial areas. Assessed land value has more impact in commercial streets than in residential streets.

It is also worth noting that even though both 311 calls and assessed land value variables were significant, they hint at two different behaviors. 311 calls are meant to be a tool to democratize governance where by anyone can contact and get attention from the City, with this being a significant variable, this should be cause of celebration. However, the assessed land value variable, which measures how 'wealthy' an area is, pulls our analysis in the opposite direction. This might indicate that it is in fact richer neighborhoods which are making more 311 calls and thus, being listened to. A 311 call is made when a need for government intervention is perceived. Neighborhoods that do not view vending as a concern would not be participating in the 311-complaint milieu. So the strong positive relationship of 311 calls needs to be seen within the context of the local demographics of those calling in a complaint.

Fig. 4 Ticketing by assessed land value of street segments

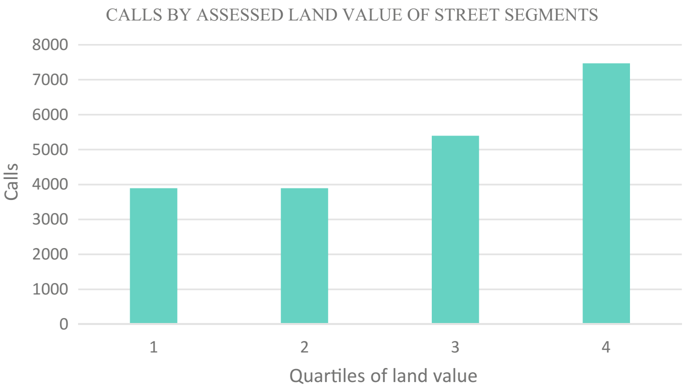


Fig. 5 Calls by assessed land value of street segments

We can explore this relationship further (Figs. 4 and 5). Breaking down calls and ticketing by assessed value of street segment shows the disparity in 311 calls, with 62% of vendor complaints resulting from the top two quartiles of land value. This analysis demonstrates that the wealth of individuals, and economic demographics of the neighborhood clearly impact on what is considered to be "*acceptable use of streets, parks, and building stoops*" (Schaller and Modal 2005). Wealth also leads to differing "*levels of access to the public decision-making process*" (Schaller and Modal 2005, 394) since almost 83% of enforcement comes from the top two quartiles of assessed land value.

5 Conclusion

The results of this study can be used to explore questions which while beyond the scope of this chapter, would be of great social and political importance to cities: should socio-economic status determine your role in public decision making; whose voice should weigh more in sidewalk policy; how should a city leverage data to develop policies which align with public interest as well as market realities?

There are of course limitations on using the datasets chosen for this research. For instance, the enforcement numbers are only for violations summoned by the Environmental Control Board (ECB), which deals with most quality of life infractions in New York. This dataset does not account for tickets written for the criminal court. While a majority of tickets are written through the ECB for vending, we cannot discount the possibility that the criminal court might have been associated with spatially clustered violations in certain neighborhoods.

For the 311 data, one concern was whether it was truly measuring differences in opinion on street vending, or were the spatial patterns a reflection of biases in call volumes by class or locations. However, studies have found 311 to be a popular tool amongst urban residents across socio-economic demographics, so use of this dataset is not likely to be biased due to the propensity of making a call of one class (Johnson 2010; Minkoff 2016).

The data used in this research does not capture everything. We still do not have an accurate count of vendors in the city, which would be a welcome addition to accurate analysis of vending in New York. Even without an official count, studies could be done through capturing cell phone date to ascertain vendor location on a larger scale. The data from the ECB did not take into account the effects of any informal policing done on the streets, for instance, where warnings were issued, the presence of hostile behavior from street users and street design attributes that are unfriendly to vendors.

These limitations aside though, this study indicated the potential of granular, geo-located data to improve our understanding and policymaking around subjects such as urban informality. As ideas of urbanism change, with more 'walkable', 'vibrant' cities coming into vogue, vendors are becoming an acceptable part of the cityscape. Portland has already successfully integrated street vendors into its urban landscape, and even cities such as Los Angeles with it notoriously harsh bans on vending in the past are now considering policy changes. While this study only focuses on Manhattan, the methodology it explores of using administrative datasets, GPS and qualitative study can be applied to other contexts as well.

There is also an increasing and growing recognition that informality's purveyors and consumers require revised planning policy responses, that recognize their diversity and internal organizing mechanism. Thus, there are calls for the planning discipline to expand to accommodate (Yiftachel 2009; Porter 2011) these experiences, and to help re-conceptualize the divide between the formal and informal. A new methodology for studying informality needs to take into account both its particularistic and general aspects. It needs to create a map of the networks, interactions and movement of informality while at the same time giving weight to the dynamic nature of these patterns. It needs to show not only the movement patterns of street vendors but also their preferred locale.

References

Abbott, J. (2002). An analysis of informal settlement upgrading and critique of existing methodological approaches. *Habitat International, 26*(3), 303–315.

Abbott, J. (2003). The use of GIS in informal settlement upgrading: its role and impact on the community and on local government. *Habitat International, 27*(4), 575–593.

Amis, P. (2001). Long-run trends in Nairobi's informal housing market. *International Development Planning Review* (3).

Burgess, R., Hansen, M., Olken, B. A., Potapov, P., & Sieber, S. (2012). The political economy of deforestation in the tropics. *The Quarterly Journal of Economics, 127*(4), 1707–1754.

Community Board 6, NYC. Mobile food vendor regulations, http://cbsix.org/resources/mobile-food-vendor-regulations/. Accessed April 21, 2016.

DeStefano, P. (2015, November 16). Fruit cart man's crushin' it: Grocery stores blame NYC fruit carts for economic hardship. *Spoiled NYC*. http://spoilednyc.com/2015/11/16/grocery-stores-blame-fruit-carts-profit-loss-nyc/. Accessed April 21, 2016.

Devlin, R. T. (2011). 'An area that governs itself': Informality, uncertainty and the management of street vending in New York City. *Planning Theory, 10*(1), 53–65.

Dündar, Ö. (2001). Models of urban transformation. *Cities, 18*(6), 391–401.

Feige, E. L. (1990). Defining and estimating underground and informal economies: The new institutional economics approach. *World Development, 18*(7), 989–1002.

Garodnick, D. R. (2000). What's the BID deal? Can the grand central business improvement district serve a special limited purpose? *University of Pennsylvania Law Review, 148*(5), 1733–1770.

Gerson, D. (2005, July 12). City opens street vending to illegal immigrants. *New York Sun*. http://www.nysun.com/new-york/city-opens-street-vending-to-illegal-immigrants/16845/. Accessed April 21, 2016.

Johnson, S. (2010, November 1). What a hundred million calls to 311 reveal about New York. *Wired*. http://www.wired.com/2010/11/ff_311_new_york/. Accessed April 21, 2016.

Kettles, G. (2014). Crystals, mud, and space: Street vending informality. In V. Mukhija & A. Loukatiour Sideris (Eds.), *The informal American city: Beyond taco trucks and day labor* (pp. 227–242). Cambridge, MA: MIT Press.

Lerman, A. E., & Weaver, V. (2014). Staying out of sight? Concentrated policing and local political action. *The ANNALS of the American Academy of Political and Social Science, 651* (1), 202–219.

Loukaitou-Sideris, A., & Ehrenfeucht, R. (2009). *Sidewalks: Conflict and negotiation over public space*. MIT Press.

Manhattan Community Board 8. (2012). *Vendor task force minutes*. http://cb8m.com/sites/default/files/0912%20Vendor%20Task%20Force%20Minutes.pdf

Minkoff, S. L. (2016). NYC 311 A tract-level analysis of citizen-government contacting in New York City. *Urban Affairs Review, 52*(2), 211–246.

Miraftab, F. (1997). Revisiting informal sector home ownership: The relevance of household composition for housing options of the poor. *International Journal of Urban and Regional Research, 21*(2), 303–322.

O'Brien, D. T., Sampson, R. J., & Winship, C. (2015). Ecometrics in the age of big data measuring and assessing "Broken Windows" using large-scale administrative records. *Sociological Methodology*, 0081175015576601.

Porter, L. (2011). Informality, the commons and the paradoxes for planning: Concepts and debates for informality and planning. *Planning Theory & Practice, 12*(1), 115–153.

Saavedra, J., & Chong, A. (1999). Structural reform, institutions and earnings: Evidence from the formal and informal sectors in urban Peru. *The Journal of Development Studies, 35*(4), 95–116.

Sampson, R. J., & Raudenbush, S. W. (1999). Systematic social observation of public spaces: A new look at disorder in urban Neighborhoods 1. *American Journal of Sociology, 105*(3), 603–651.

Schaller, S., & Modan, G. (2005). Contesting public space and citizenship implications for neighborhood business improvement districts. *Journal of Planning Education and Research, 24*(4), 394–407.

Testimony of Irum Taqi on behalf of The New York civil liberties union before The New York City council committee on consumer affairs regarding INT. 621. In relation to the regulation of vendors. http://www.nyclu.org/content/regulation-of-street-vendors

Yiftachel, O. (2009). Theoretical notes on "gray cities": The coming of urban apartheid. *Planning Theory, 8*(1), 88–100.

Chapter 24
Landsat Surface Temperature Data Analysis for Urban Heat Resilience: Case Study of Adelaide

Ehsan Sharifi, Alpana Sivam, Sadasivam Karuppannan and John Boland

Abstract Smarter urban futures require resilient built environment in the context of climate change. This chapter demonstrates the application of satellite-based surface cover and temperature data to support planning for urban heat resilience. Landsat 7 ETM+ and Landsat 8 data is used to analyse the correlation of urban surface covers to the urban heat island effect in Adelaide. Methods for data source selection, surface cover classification, surface temperature calculation and analysis are detailed in this chapter. Results indicate that tree canopy and surface water covers had the least surface temperature variations in mesoscale. The average minimum surface temperature of tree canopy cover was 2.79 °C lower than asphalt and 4.74 °C lower than paved areas. Freely available satellite urban surface temperature data can assist urban planning authorities in planning heat resilient urban spaces for smarter urban futures in the context of climate change.

Keywords Urban cover · Land use · Urban heat island · Remote sensing · Urban greenery

---

E. Sharifi (✉) · J. Boland
School of Information Technology and Mathematical Sciences,
University of South Australia, Adelaide, Australia
e-mail: ehsan.sharifi@unisa.edu.au

J. Boland
e-mail: john.boland@unisa.edu.au

A. Sivam · S. Karuppannan
School of Art, Architecture and Design, University of South Australia, Adelaide, Australia
e-mail: alpana.sivam@unisa.edu.au

S. Karuppannan
e-mail: sadasivam.karuppannan@unisa.edu.au

S. Geertman et al. (eds.), *Planning Support Science for Smarter Urban Futures*, Lecture Notes in Geoinformation and Cartography,
DOI 10.1007/978-3-319-57819-4_24

1 Introduction

Cities are anticipated to accommodate up to 70% of the global population by 2050 (DESA 2014). Unlike the current urbanisation rate of 50%, almost all the expected global population growth will be accommodated in cities. Such rapid urbanisation means higher densities will be needed in existing cities and many new urban areas to accommodate up to 2 billion new urban dwellers. A considerable amount of natural landscape is transformed into buildings and hard surfaces, creating environmental threats to existing and future cities. Huge demands for natural resources in cities results in a contribution of up to 80% to the greenhouse gas (GHG) emissions (UNECE 2011; UN-Habitat 2014; OECD 2010).

Climate change projections indicate that—due to excessive GHG emissions—the surface temperature of Australia is likely to increase 3.8 °C by 2090 (CSIRO 2007). Such an increase in temperature will have a severe impact on natural ecosystems and human life in cities, including public health and quality of public space (Guest et al. 1999; Stone 2012). In the meantime, the built environment suffers from the effect of an additional form of heat, known as the urban heat island (UHI) effect. This human-made heat is trapped in the built environment's thermal mass and can result in higher densities being significantly hotter, compared to their peri-urban counterparts. The urban-rural temperature difference frequently reaches 4 °C and can peak at more than 10 °C (Gartland 2008; Oke 1988; Wong et al. 2011). Such additional heat stress can seriously impact citizens' health and the quality of public life in cities.

This chapter demonstrates the application of Landsat 7 ETM+ and Landsat 8 surface cover and thermal band data and discusses the use of urban thermal mapping in supporting urban planning and decision making to achieve resilience to heat in the built environment.

2 Background

The literature on the UHI effect indicates that the artificial increase of temperature in cities is happening because of changes in radiative energy and the water budget in the built environment (Erell et al. 2011; Santamouris and Kolokosta 2015; Coutts et al. 2007). This artificial temperature increase affects urban microclimates at different layers of the atmosphere, including the surface layer (buildings and land surfaces), the canopy layer (below the canopy of trees or at human scale) and the boundary layer (up to 1500 metres above the ground surface) (Oke 1987). These three layers of urban microclimates are tangled in complex climatic systems, while local air circulation in the built environment can moderate the UHI effect by mixing the air in each layer with other adjacent layers.

Urban surface cover materials alter the magnitude of heat stress in the built environment. Impermeable and hard surfaces in cities tend to store more heat in their thermal mass during the day compared to natural landscapes. They emit stored heat during the night and cause the built environment to be relatively hotter than the rural counterparts—known as the urban heat island effect. Oke (2006) argues that the UHI effect has four major contributing factors:

- Urban geometry, which alters heat exchange balance in the built environment by affecting shadow and wind patterns. It affects the exposure of materials to sunlight and the consequent heat storage in thermal mass. This complex heat radiation exchange between building mass and adjacent atmosphere can also change the intensity and patterns of airflow in urban canyons.
- Urban cover and surface materials, which affect the heat absorption and reflection time-rate in the built environment. Thermodynamic specification, colour, texture and density of materials and their exposure to sunlight can alter the heat flux in outdoor spaces in complex procedures.
- Urban landscape affects water and heat exchange rate in the built environment. Photosynthesis and evaporation processes in urban greenery contribute to decreasing the ambient temperature. Urban greenery typology, distribution and intensity also affect lower atmospheric air turbulence.
- Urban metabolism and anthropogenic (human-made) waste heat in cities are mainly related to mass energy consumption for indoor air-conditioning and motorised transportation.

Existing literature on the UHI effect is mainly focused on monitoring and documentation of the UHI effect at macro (regional) scales. Research on the key contributors to the surface layer UHI (sUHI) effect at the precinct scale can provide useful links between UHI investigations at the city scale.

The temperature in some Australian cities such as Sydney, Melbourne and Adelaide is already up to 4 °C warmer than the surrounding areas. This chapter investigates the case study of the City of Adelaide's UHI effect, which is an example of a city facing an increasing UHI effect due to its post-19th century style of urban development. Due to the city's temperate climate and the UHI effect, public spaces in Adelaide are increasingly warmer in summer than humans' thermal comfort, pushing citizens into air-conditioned buildings and creating an ever-increasing rise in outdoor temperatures.

3 Materials and Methods

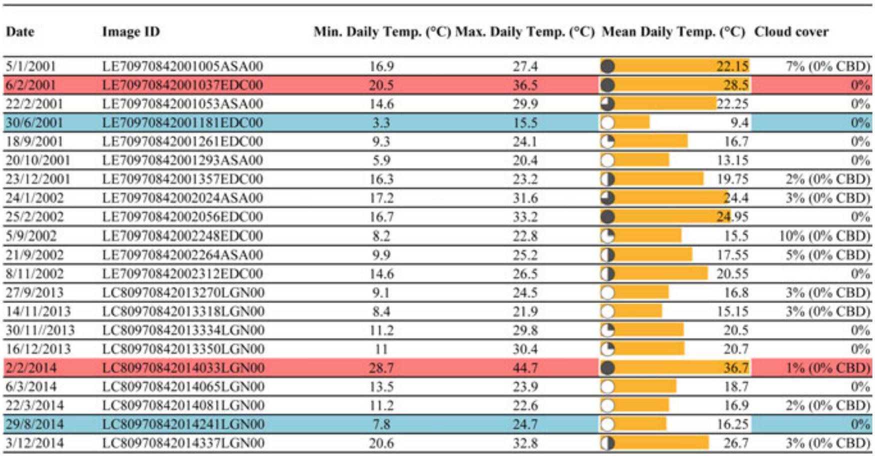
Satellite remote sensing data is used to analyse the mesoscale effect of the urban surface cover classes on the surface heat island effect in Adelaide. Selected Landsat 7 and Landsat 8 images were obtained from USGS Global Visualization Viewer (http://glovis.usgs.gov) to facilitate analysis of urban surface temperature. Four satellite images between 2001–2002 and 2013–2014 covering the coldest and the hottest available remote sensing data in Adelaide are used for surface cover and temperature analysis.

3.1 Selection Criteria for Satellite Images

Satellite images were obtained in two different time spans of 2001–2002 and 2013–2014. Landsat 7 was launched in 1999 and provides satellite images with thermal bands through its enhanced thematic mapper plus (ETM+) sensor. However, a defect in scan line corrector (SLC) of Landsat 7 ETM+ in May 2003 resulted in some partial data loss and parallel stripes in satellite images. Therefore, the Landsat 7 ETM+ data was only used from 2001 to 2002 in the analysis. Landsat 8 was launched in February 2013, and its data for the 2013–2014 period was used in this research.

All of the available satellite images were considered against the maximum acceptable threshold of 10% cloud coverage of the study area. Two Landsat 7 ETM + images (captured in 2001–2002) and two Landsat 8 images (captured in 2013–2014) for the coldest and hottest days were chosen for further analysis. These best-fit images were selected based on maximum and minimum daily temperature of the images to present the coldest and hottest weather conditions during study periods (see Tables 1 and 2).

Table 1 Best-fit Landsat 7 ETM+ and Landsat 8 images for Adelaide that represent coldest (*blue*) and hottest (*red*) thermal images during 2001–2002 and 2013–2014 (*weather data* Australian Bureau of Meteorology)



Date	Image ID	Min. Daily Temp. (°C)	Max. Daily Temp. (°C)	Mean Daily Temp. (°C)	Cloud cover
5/1/2001	LE70970842001005ASA00	16.9	27.4	● 22.15	7% (0% CBD)
6/2/2001	LE70970842001037EDC00	20.5	36.5	● 28.5	0%
22/2/2001	LE70970842001053ASA00	14.6	29.9	◕ 22.25	0%
30/6/2001	LE70970842001181EDC00	3.3	15.5	○ 9.4	0%
18/9/2001	LE70970842001261EDC00	9.3	24.1	◔ 16.7	0%
20/10/2001	LE70970842001293ASA00	5.9	20.4	○ 13.15	0%
23/12/2001	LE70970842001357EDC00	16.3	23.2	◑ 19.75	2% (0% CBD)
24/1/2002	LE70970842002024ASA00	17.2	31.6	◕ 24.4	3% (0% CBD)
25/2/2002	LE70970842002056EDC00	16.7	33.2	● 24.95	0%
5/9/2002	LE70970842002248EDC00	8.2	22.8	◔ 15.5	10% (0% CBD)
21/9/2002	LE70970842002264ASA00	9.9	25.2	◑ 17.55	5% (0% CBD)
8/11/2002	LE70970842002312EDC00	14.6	26.5	◑ 20.55	0%
27/9/2013	LC80970842013270LGN00	9.1	24.5	○ 16.8	3% (0% CBD)
14/11/2013	LC80970842013318LGN00	8.4	21.9	○ 15.15	3% (0% CBD)
30/11//2013	LC80970842013334LGN00	11.2	29.8	◔ 20.5	0%
16/12/2013	LC80970842013350LGN00	11	30.4	◔ 20.7	0%
2/2/2014	LC80970842014033LGN00	28.7	44.7	● 36.7	1% (0% CBD)
6/3/2014	LC80970842014065LGN00	13.5	23.9	○ 18.7	0%
22/3/2014	LC80970842014081LGN00	11.2	22.6	○ 16.9	2% (0% CBD)
29/8/2014	LC80970842014241LGN00	7.8	24.7	○ 16.25	0%
3/12/2014	LC80970842014337LGN00	20.6	32.8	◑ 26.7	3% (0% CBD)

Table 2 Heat stress and excess heat conditions for the selected best-fit Landsat 7 and Landsat 8 images for Adelaide (*weather data* Australian Bureau of Meteorology)

Weather Condition	Season code	Date	Image ID	Min. Daily Temp. (°C)	Max. Daily Temp. (°C)	Mean Daily Temp. (°C)	Temp at 12:00pm (°C)	3-days before Min. Average Temp. (°C)	3-days before Max. Average Temp. (°C)	3-days before Mean Temp. (°C)	Lowest Temp. Month (°C)	Highest Temp. Month (°C)	Mean Monthly Min. Temp. (°C)	Mean Monthly Max. Temp. (°C)	Mean Monthly Temp. (°C)	Mean 30-years Monthly Min. Temp.(°C)	Mean 30-years Monthly Max. Temp.(°C)	Mean 30-years Monthly Temp. (°C)	Air Temp in the time of image (°C)
Hot	SUM	6/2/2001	LE70970842001037EDC00	20.5	36.5	28.5	30	20.9	31.8	26.4	13.8	40	19.9	31.6	25.8	17.3	29.4	23.4	23
Cold	WIN	30/6/2001	LE70970842001181EDC00	3.3	15.5	9.4	14	6	16.3	11.2	2.8	23.6	8.9	16.2	12.6	8.2	16.1	12.2	11
Hot	SUM	2/2/2014	LC80970842014033LGN00	28.7	44.7	36.7	41	21.8	39	30.4	10.7	44.7	17.8	29.8	23.8	17.3	29.4	23.4	30
Cold	WIN	29/8/2014	LC80970842014241LGN00	7.8	24.7	16.3	17	5.9	21.6	13.8	0.9	25	6.8	17.4	12.1	8.2	16.7	12.5	10

Selected satellite images were then assessed against heat stress, excess heat and climate normality conditions based on:

- average daily maximum and minimum temperature of three days before the date of the images to reflect heat stress intensity
- maximum and minimum average monthly temperature of the images to reflect normality of the date of images in respective months
- 30-year maximum and minimum average temperatures to reflect excess heat values.

Thus, these selected satellite images represent the coldest and hottest available Landsat 7 and Landsat 8 surface temperature data for Adelaide metropolitan area and its inner suburbs. The images were analysed for their surface cover classification and surface temperature.

As shown in Table 1, the targeted cold-labeled images have a minimum daily temperature of 3.3 °C (2001) and 7.8 °C (2013) in Adelaide. Table 2 indicates the comparison of these minimum daily temperature values over the long-term 30-year minimum monthly temperature values in that the selected images are taken on typical cold days for their climate context. For the hot-labeled images, the daily maximum temperature was 36.5 °C (2001) and 44.7 °C (2014) in Adelaide. A comparison of these minimum daily temperature values to the long-term 30-year minimum monthly temperature values in Table 2 indicates that the selected images were taken on typical hot days for their climate context. Weather data were taken from the Australian Bureau of Meteorology's official weather station at Kent Town (no. 23090) in Adelaide.

3.2 *Urban Surface Covers Classification*

Urban heat island literature argues that surface cover materials alter the magnitude of heat stress in urban settings (Gartland 2008; Ichinose et al. 2008; Oke 1988;

Santamouris et al. 2012; Tapper 1990; Wong and Jusuf 2010). All GeoTIFF files except those related to the Panchromatic, Cirrus, Coastal Aerosol and Thermal Bands had to be processed. This includes B1, B2, B3, B4, B5, B7 layer-bands for Landsat 7 and B2, B3, B4, B5, B6, B7 layer-bands for Landsat 8. The number of bands dictates the maximum number of surface cover feature classes (six for this study). Urban surface cover materials were categorised under six classes as follows:

- Tree canopy class included tree canopies, bushes, and shrubs
- Grass cover class included grassland areas and other ground cover greeneries including shrubs
- Paving cover class included building rooftops, concrete and other paved areas with materials such as clay
- Asphalt cover class included asphalt and bitumen in streets and parking areas
- Natural-hard cover class included all bare surfaces, beaches, vacant lands and temporary hard-landscape covers without greenery
- Water feature class included surface water of rivers, sea, and urban water features

For every data set, these layer-bands were stacked together and classified in tree, grass, street, urban, land and water feature classes using supervised classification process of satellite images in ENVI software. For each cover class, at least 20 areas covered dominantly by the targeted surface cover classes were used as benchmarks (120 samples in total for each image). To validate the classified surface covers, random area samples were compared with Google Earth maps of the same area and similar timeframe. Emissivity and atmospheric correction of thermal data were applied in ArcGIS, and urban surface cover temperatures were calculated based on thermal bands 6 (Landsat 7) and 10 (Landsat 8). Resulting surface cover temperatures are compared to urban land cover classes.

3.3 Surface Temperature Extraction from Multi-spectrum Satellite Data

An ideal thermal image for surface class-temperature measurement is to have match values of surface coverage and temperature for every identical pixel, meaning that the surface temperature is measured in the same area of surface cover classes. Thus, an ideal urban surface heat investigation depends on the simultaneous mapping of visible and thermal data in overlapped images. Such simultaneous RGB-NIR-Thermal mapping is available via Landsat 7 ETM+ and Landsat 8 satellite imagery.

Landsat 7 ETM+ (since 1999) and Landsat 8 (since 2013) provide surface temperature data from different spectral bands (see Table 3). For the evaluation of land surfaces temperatures in Landsat 7, the thermal infrared (TIR) channel (Band 6-1 from 10.31 to 12.36 μm) were used. Similar surface temperature data are available in the thermal infrared (TIRS) channel of Landsat 8 (Band 10 from 10.6 to 11.19 μm). The in-nadir resolution of the surface temperatures is 30 m.

Table 3 Average surface temperature of six urban land cover classes in Adelaide local council areas

Thermal Code	Satellite	local day	Tree canopy (°C)	Grass cover (°C)	Paving (°C)	Asphalt (°C)	Natural-hard (°C)	water (°C)	Air temp. (°C)	Max surface temp. variation from air temp. (°C)
C	L7	30-Jun-01	11.3	13.3	14.4	14.6	13.3	10.2	11.0	3.6
C	L8	29-Aug-14	21.0	23.4	25.1	25.2	23.8	18.5	10.0	15.2
H	L7	6-Feb-01	35.0	37.9	39.5	39.6	38.4	31.4	23.0	16.6
H	L8	2-Feb-14	38.5	41.3	43.0	43.3	41.8	34.3	30.0	13.3

Satellite image data consist of digital numbers ranging from 0 to 255. Such digital numbers can be converted into degrees Kelvin in three steps:

- calculation of radiance for digital number
- atmospheric correction
- calculation of degrees Kelvin for the final radiance values (denoted the Planck function) and degree Kelvin to degrees Centigrade conversion.

The spectral radiation density of the thermal sensors was calculated in ENVI software. Since the surface temperatures of the emitting areas of the ground were the final objects of interest, two influences should be eliminated from the satellite images: the deviation of the surface from a "black body" and the influence of the atmosphere on heat radiation.

The first step was handled by introducing an emissivity value (ε) between 0 and 1 for the reduction factor of real-body emission compared to the black-body (the emissivity value is commonly generalised to be 0.95 for large-scale urban surfaces). More accurate emissivity values for the selected surface cover classes in this study are suggested to be 0.91 for street, 0.90 for building rooftops (urban), 0.91 for open land and 0.98 for greenery (Weng et al. 2004; Voogt and Oke 2003; Nichol 1996; Coll et al. 2010).

Radiation gets absorbed when passing through transparent mediums such as the Earth's atmosphere, an atmospheric correction of the estimated radiances is required for more accurate surface temperature results, using the transmission values (τ) between zero and one that was obtained from Landsat 7 and Landsat 8 complementary metadata files. In the final step, the surface temperature in degrees Kelvin was calculated from the corrected radiances using this formula (Coll et al. 2010; Li et al. 2004):

(surface temperature calculation equation)

$$T = \frac{K2}{\ln\left(\frac{K1}{L_y} + 1\right)} \tag{1}$$

T	at-satellite surface temperature (K)
K1	Band-specific thermal conversion constant from metadata (666.09 for Landsat 7 ETM+ B6; 774.89 for Landsat 8 B10)
K2	Band-specific thermal conversion constant from metadata (1282.71 for Landsat 7 ETM+ B6; 1321.08 for Landsat 8 B10)
L_y	atmospherically corrected spectral radiance
In ( )	natural logarithm function

Surface cover class reconstruction and temperature calculation were done via Exelis Visual Information Solutions (ENVI) software. Final representation of remote sensing data was carried out in Q-GIS and ARC-GIS software.

4 Results

Distribution of the urban surface covers temperature in Adelaide is presented in Figs. 1 and 2. The surface temperature values were averaged and therefore, present the mean value of all pixels belonging to each surface class in each image.

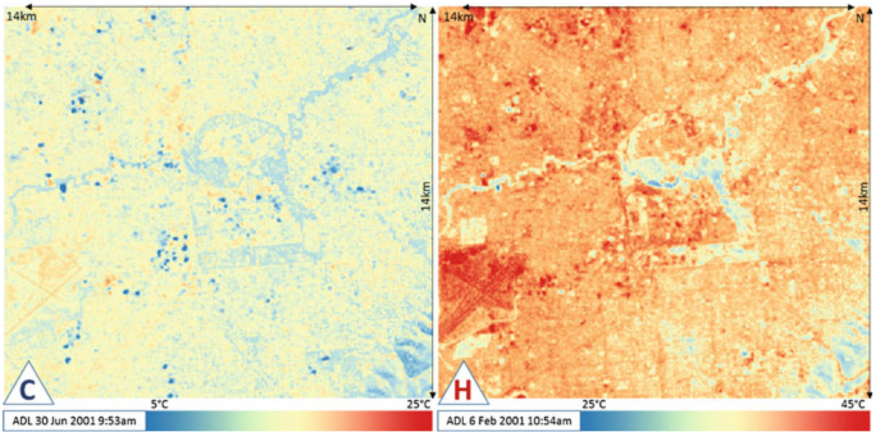


Fig. 1 Surface temperature variation in cold (30 June 2001) and hot (6 February 2001) satellite images of Adelaide CBD and its inner suburbs—area: 14 km × 14 km (*Map data* Landsat 7 ETM + 2014)

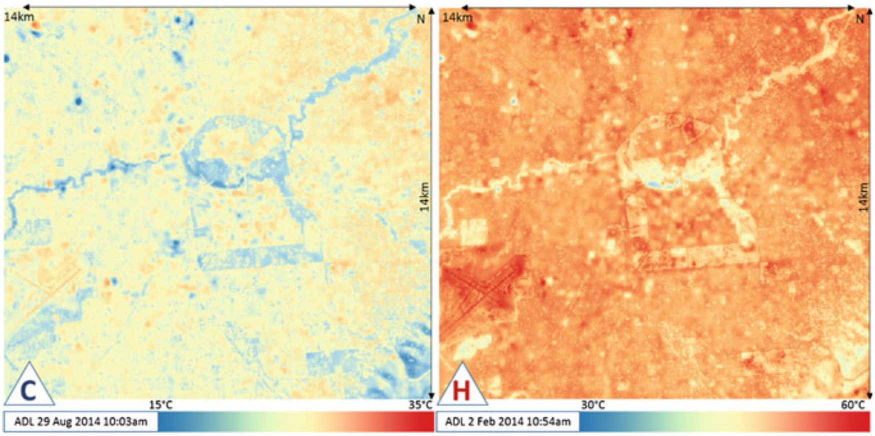


Fig. 2 Surface temperature variation in cold (29 August 2014) and hot (2 February 2014) satellite images of Adelaide CBD and its inner suburbs—area: 14 km × 14 km (*Map data* Landsat 8 2014)

Detailed variations in the surface temperature of urban covers are presented in Table 3. The reported surface temperature of water in Adelaide is mostly related to the River Torrens. Therefore, a relatively higher surface water temperature is reported in Adelaide. Diurnal urban surface cover temperature tends to fluctuate more during the hot seasons (see the last column in Table 3). Daily surface temperature of urban covers varies more when the overall temperature is higher, and hotter surface covers have more variation from the average urban temperatures.

Table 4 shows that the tree canopy variable had the least surface minimum and maximum temperatures, especially during hot seasons. The highest surface temperature difference of 5.65 °C was recorded between the tree canopy variable and artificial-hard landscapes including paving and asphalt (hot image of February 2001). The minimum surface temperature of tree canopy cover was at least 2.8 °C lower than that for asphalt. Meanwhile, the averaged maximum surface temperature of tree canopy was up to 4.1 °C lower than for asphalt and 4.0 °C lower than for paving cover. Due to the close thermal characteristics of hard paving and asphalt in urban settings, these two cover classes were combined into an artificial-hard landscape cover class in further discussion.

Surface water had the least fluctuating temperature due to the high thermal capacity of water. Surface water temperatures in Adelaide show higher temperatures than expected due to its semi-isolation from the large water volume of the sea. It mostly indicates the surface water temperature of the slow-running river Torrens in the CBD area.

Paving and Asphalt had the most fluctuating and highest relative temperatures during the study. Grass cover had lower temperature variation in colder seasons, whereas they showed very high temperature variations of 11.2 °C in February 2014. The high variation of grass cover temperature in hot seasons was associated with its moisture and its level of irrigation.

Table 4 Detailed variations in surface temperature of urban covers in Adelaide during 2001–2002 and 2013–2014

		Tree canopy (°C)	Grass cover (°C)	Paving (°C)	Asphalt (°C)	Natural-hard (°C)	water (°C)
C	Min.	9	11.41	9.85	11.9	10.69	7.14
	Max.	13.47	15.28	16.51	16.55	15.27	12.26
	Var.	4.47	3.87	6.66	4.65	4.58	5.12
C	Min.	18.3	21.55	21.93	23.11	21.92	16.17
	Max.	23.18	25.31	27.23	27.19	25.9	20.61
	Var.	4.88	3.76	5.3	4.08	3.98	4.44
H	Min.	31.03	34.2	36.66	36.68	35.58	25.03
	Max.	40.67	43.15	43.3	43.31	42.14	32.43
	Var.	9.64	8.95	6.64	6.63	6.56	7.4
H	Min.	33.67	35.73	39.12	40.64	38.83	23.17
	Max.	43.81	46.96	45.82	46.15	44.59	34.19
	Var.	10.14	11.23	6.7	5.51	5.76	11.02

4.1 Normalised Surface Temperature (NST)

Variation in the absolute surface temperature of six urban covers in Tables 3 and 4 reveals that tree canopy and surface water tend to have cooler surfaces during hot weather conditions. The temperature difference between surface covers and air temperature provides a better measure for comparison since it decreases the effect of seasonal climate. A normalised surface temperature (NST) measure is suggested for further discussion (air temperature needs to be measured at 2–3 m from the surface to avoid near-surface temperature effect).

(normalised surface temperature (NST))

$$NST = T_{surface\,cover} - T_{air} \tag{2}$$

As Fig. 3 shows, surface water, and tree canopy have the lowest NST in the range. Surface water had the lowest NST value during heat stress conditions. It means that surface water is the most significant microclimate moderator in hot weather conditions. Application of surface water is limited in urban settings due to space availability, infrastructure requirements, and functional constraints.

The second best performance is related to tree canopy cover, which had 5 °C (on average) lower NST than artificial-hard landscapes during hot weather conditions. Meanwhile, grass cover had 1.9 °C (on average) lower NST than artificial-hard landscapes. Natural-hard landscape cover had a similar variation as grass cover in Adelaide. Average tree canopy cover was 11% cooler than hard-landscapes during

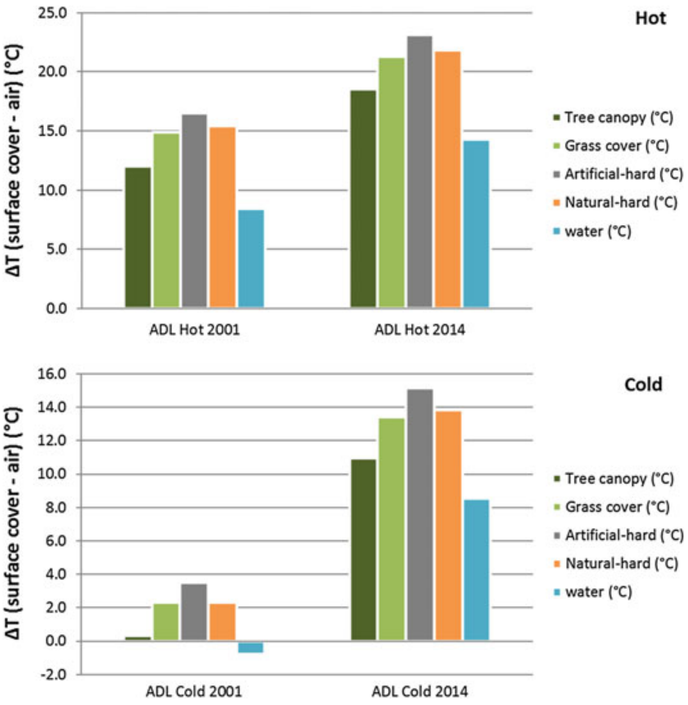


Fig. 3 Normalised surface temperature of urban cover classes in hot and cold seasons in Adelaide (2001–2002 and 2013–2014)

hot weather conditions in Adelaide. Thus, average tree canopy facilitates 13% lower surface temperatures compared with artificial-hard landscapes.

Tree canopy also had lower NST in cold weather. However, the averaged surface temperature was 4 °C lower than artificial-hard landscape cover. As such, a surface temperature reduction of tree canopy cover is 1 °C higher in hot weather compared to cold conditions. Thus, tree canopy cover contributes to outdoor temperature reduction in hot weather, while its temperature reduction is less significant in cold thermal environments.

5 Discussion

Australian cities are among the least densely populated cities in the world mainly due to urban sprawl (SoAC 2014–2015). Urban development is a slow process and the built environment comprising of housing, commercial, industrial and institutional buildings have a lifespan of several decades before substantial changes or redevelopment can occur.

However, with emphasis on more medium and high-density housing and urban consolidation policies, density is likely to increase marginally over the medium term. More and more existing old detached housing is gradually replaced with semi-detached housing leading to an increase in building footprint in urban areas. This is likely to increase the surface temperature in critical summer months.

5.1 Urban Transformation Towards Heat Resilience

To some extent, current planning and building guidelines exacerbate the issue of urban heat. For example, planning rules prescribe minimum open space standards for various types of dwelling on various lot sizes usually as a percentage of the block area. The nature of open space—lawns and trees or concrete or stone paving —is not prescribed. This has led to concrete and stone paving on the sides and rear of properties. The purpose of open space can be made more effective towards mitigating the urban heat island effect if limits on open space paving are imposed so that green surface cover on private land can be maintained in residential areas. Public spaces comprising of parks, open spaces, and roads and other transport networks together account for over one-third of the urban gross area. Water sensitive pavement design provides a useful solution to mitigate urban surface temperature and promote the subsoil water table in central parts of the city.

5.2 Application in Urban Policy Making and Design

The use of freely available satellite urban surface temperature data can assist urban planning authorities in formulating planning policy and regulation to plan and develop heat resilient urban spaces in the context of local climate and climate change. The results presented here demonstrate that materials used in building and urban spaces impact on urban surface temperature. In general, urban planning policies and regulations prescribe a percentage of mandatory open space and ground coverage for various urban land uses.

Seldom do planning regulations focus on the percentage of hard surface and soft surfaces. The research highlights the role of various urban surface covers, and it emerges that effective ways to minimise urban heat islands require planning norms and standards for hard surface covers such as paving and asphalt surfaces. Prescribing building coverage and open space as a ratio of block area alone would not address the issue. Using urban surface temperature data for land uses planners could develop policy for various types of activity spaces to make cities more resilient. Urban surface temperature data will assist urban designers to create a land use pattern that could mitigate urban heat effects and adapt to climate change. This will help create functional spaces that could increase space utilisation as well as reduce the need for artificial surface covers. Urban heat measurement and mitigation strategies need to be incorporated in both urban policy making and development control for more resilient urban futures.

6 Conclusions

Urban temperatures are predicted to increase due to climate change. The temperatures in our cities are likely to increase further because more heat will be stored and re-radiated by expanses of asphalt, concrete and other heat-storing building materials. In this context, it is crucial to understand the possibilities for the transformation of existing urban fabrics towards a more livable and sustainable future (Bosselmann 2008). This can be implemented by spatial transformation and heat-proofing interventions in existing urban spaces (Santamouris et al. 2011).

The basic argument underlined in this research is that the higher UHI effect at precinct scale correlates with a greater hard-landscaped public space ratio and a lower urban greenery ratio. Therefore, increasing urban greenery and decreasing hard-landscaped urban features such as conventional concrete, paving and asphalt covers can contribute to urban cooling in existing precincts, where a fine distribution of urban greenery could reduce the UHI effect.

Remote sensing surface temperature data analysis is a planning support tool to create a smarter and more resilient urban futures. Freely available satellite urban surface temperature data can assist urban planning authorities in planning heat resilient urban spaces for smarter urban futures in the context of climate change.

7 Research Limitations and Further Opportunities

This research is based on remote sensed thermal images and analysis of spatial data normally used by planners and urban designers. Remote sensing data analysis is subject to uncertainty due to invisible urban surfaces that are only visible from a satellite view such as surfaces under the tree canopy and vertical surfaces.

To move towards more certain research outcomes, on-the-spot microclimate measurement and urban surface mapping at smaller scales could be beneficial. Local climate affects heat transfer in the built environment. Therefore, application of research findings in cities with different climate regimes needs further investigation. This is also essential for generalisation of the findings.

This study utilised surface temperatures which is different from the actual feeling of the temperature in public space experienced by individuals. Further studies could benefit from including on-the-spot climate measurements and air temperature data. The effect of local airflow on UHI effect is a subject for further investigation.

References

Bosselmann, P. (2008). *Urban transformation: Understanding City Design and Form*. Washington DC: Island Press.

Coll, C., Galve, J. M., Sanchez, J. M., & Caselles, V. (2010). Validation of Landsat-7/ETM+ Thermal-Band Calibration and Atmospheric Correction With Ground-Based Measurements. *Geoscience and Remote Sensing, 48*(1), 547–555. doi:10.1109/TGRS.2009.2024934.

Coutts, A., Beringer, J., & Tapper, N. J. (2007). Impact of increasing urban density on local climate: Spatial and temporal variations in the surface energy balance in Melbourne, Australia. *Journal of Applied Meteorology and Climatology, 46*(4), 477–493. doi:10.1175/JAM2462.1.

CSIRO. (2007). Climate change in Australia: Technical report csiro and australian bureau of meteorology, Aspendale VIC.

DESA. (2014). World urbanization prospects: Highlights. United Nations New York.

Erell, E., Pearlmutter, D., & Williamson, T. (2011). *Urban microclimate: Designing the spaces between buildings*. London: Earthscan.

Gartland, L. (2008). *Heat Islands: Understanding and mitigating heat in urban areas*. Washington, DC: Earthscan.

Guest, C. S., Willson, K., Woodward, A. J., Hennessy, K., Kalkstein, L. S., Skinner, C., et al. (1999). Climate and mortality in Australia: Retrospective study, 1979–1990, and predicted impacts in five major cities in 2030. *Climate Research, 13*(1), 1–15.

Ichinose, T., Matsumoto, F. & Kataoka, K. (2008). Counteracting urban heat islands in Japan. In: D. Peter (Ed.)*, Urban energy transition: From fussil fuels to renewable power* (pp. 365–380). Amsterdam: Elsevier. http://dx.doi.org/10.1016/B978-0-08-045341-5.00015-3.

Landsat 7 ETM+ (2014).

Landsat 8 (2014).

Li, F., Jackson, T.J., Kustas, W.P., Schmugge, T.J., French, A.N., Cosh, M.H. & Bindlish, R. (2004). Deriving land surface temperature from Landsat 5 and 7 during SMEX02/SMACEX. *Remote Sensing of Environment*, *92*(4), 521–534. http://dx.doi.org/10.1016/j.rse.2004.02.018.

Nichol, J.E. (1996). High-resolution surface temperature patterns related to urban morphology in a tropical city: A satellite-based study. *Journal of Applied Meteorology,* 35(1), 135–146. 10.1175/1520-0450(1996)035<0135:HRSTPR>2.0.CO; 2.

OECD. (2010). *Cities and Climate Change*. Paris: Organisation for Economic Cooperation and Development.

Oke, T. R. (1987). *Boundary layer climates* (2nd ed.). New York: Wiley.

Oke, T. R. (1988). The urban energy balance. *Progress in Physical Geography, 12*(4), 471–508. doi:10.1177/030913338801200401.

Oke, T. R. (2006). *Initial guidance to obtain representative meteorological observations at urban sites: Instruments and observing methods. IOM Report No. 81*. Canada: World Meteorological Organization.

Santamouris, M., Gaitani, N., Spanou, A., Saliari, M., Giannopoulou, K., Vasilakopoulou, K. & Kardomateas, T. (2012). Using cool paving materialsto improve microclimate of urban areas—design realization and results of the flisvos project. *Building and Environment*, *53*(0), 128–136. http://dx.doi.org/10.1016/j.buildenv.2012.01.022.

Santamouris, M., & Kolokosta, D. D. (2015). Urban microclimates: Mitigaing urban heat. In S. Lehmann (Ed.), *Low carbon cities* (pp. 282–292). New York: Routledge.

Santamouris, M., Synnefa, A., & Karlessi, T. (2011). Using advanced cool materials in the urban built environment to mitigate heat islands and improve thermal comfort conditions. *Solar Energy, 85*(12), 3085–3102.

SoAC. (2014–2015). *State of Australian Cities*. Canberra: Department of Infrastructure and Transport, Commonwealth of Australia, Major Cities Unit.

Stone, B. (2012). *City and the coming climate: Climate change in the places we live*. New York: Cambridge University Press.

Tapper, N. J. (1990). Urban influences on boundary-layer temperature and humidity—results from Christchurch, New-Zealand. *Atmospheric Environment Part B-Urban Atmosphere, 24*(1), 19–27.

UN-Habitat. (2014). *Planning for climate change. A strategic values-based approach for urban planners.* London: Cities and Climate Change United Nations Human Settlements Programme.

UNECE. (2011). *Climate neutral cities: How to make cities less energy and carbon intensive and more resilient to climatic challenges*. New York and Geneva: United Nations Economic Commission for Europe.

Voogt, J.A. & Oke, T.R. (2003). Thermal remote sensing of urban climates. *Remote Sensing of Environment*, *86*(3), 370–384. http://dx.doi.org/10.1016/S0034-4257(03)00079-8.

Weng, Q., Lu, D. & Schubring, J. (2004). Estimation of land surface temperature–vegetation abundance relationship for urban heat island studies. *Remote Sensing of Environment*, *89*(4), 467–483. http://dx.doi.org/10.1016/j.rse.2003.11.005.

Wong, N. H., & Jusuf, S. K. (2010). Study on the microclimate condition along a green pedestrian canyon in Singapore. *Architectural Science Review, 53*(2), 196–212.

Wong, N. H., Jusuf, S. K., & Tan, C. L. (2011). Integrated urban microclimate assessment method as a sustainable urban development and urban design tool. *Landscape and Urban Planning, 100*(4), 386–389.

Chapter 25
Urban Improvement Policies for Reducing Human Damage in a Large Earthquake by Using Wide-Area Evacuation Simulation Incorporating Rescue and Firefighting by Local Residents

Takuya Oki and Toshihiro Osaragi

Abstract In Japan, there are still many densely built-up wooden residential areas. For estimating the effects of specific measures for disaster mitigation, we utilize an agent-based simulation system, which can describe property damage (such as building-collapse, street-blockage, and fire-spread) and activities of local residents (including rescue, firefighting, and evacuation) in a large earthquake. More specifically, we compare the effects of the following policies of improving cities for reducing property and human damage (the number of burnt-down buildings and casualties): (1) installing fire-extinguishers for all households; (2) installing seismo-sensitive breakers for all households; and (3) improving specific streets and their roadside buildings.

Keywords Large earthquake · Property damage · Casualty · Agent-based simulation · Disaster mitigation

1 Introduction

In Japan, densely built-up wooden residential areas, which consist of many wooden houses and narrow street networks, are prevalent in major cities such as Tokyo and Osaka. In such areas, the urban vulnerability to disasters should be improved as soon as possible because it is highly likely that devastating property and human damage will occur at the time of a major earthquake.

T. Oki (✉) · T. Osaragi
School of Environment and Society, Tokyo Institute of Technology,
2-12-1-M1-25 Ookayama, Meguro-Ku, Tokyo 152-8552, Japan
e-mail: oki.t.ab@m.titech.ac.jp

T. Osaragi
e-mail: osaragi.t.aa@m.titech.ac.jp

S. Geertman et al. (eds.), *Planning Support Science for Smarter Urban Futures*, Lecture Notes in Geoinformation and Cartography,
DOI 10.1007/978-3-319-57819-4_25

Property damage includes the following aspects: building-collapse (completely destroyed/partially collapsed); street-blockage due to debris of collapsed buildings/block walls; and burnout caused by the uncontrolled spread of fire, et cetera. Human damage is caused by property damage mentioned above. For instance, people are injured/killed by falling furniture, by the debris from collapsed buildings, or fire-spread. In addition, building-collapse and street-blockage are dangerous because people may be trapped in a building/on a street, and forced to take a large detour avoiding blocked streets when heading to an evacuation area, or delayed in their escape from fires.

For reducing the risk of property and human damage, there are various kinds of methods to improve urban vulnerability. For instance, old wooden houses are rebuilt and converted into quake-resistant/fire-resistant buildings (such as reinforced concrete, steel, or steel-reinforced concrete) to prevent the building from burning or collapsing due to earthquake ground motion. In some cases, relatively new wooden buildings are also construction with anti-earthquake reinforcement. For preventing street-blockage, it is effective not only to reduce the risk of building-collapse but also to widen the street so as to make it difficult to be completely blocked. Moreover, if a plurality of alternative routes are secured similar to the inside of buildings, it is possible to reduce the possibility that people cannot reach any evacuation areas and the time required for travelling there greatly increases due to street-blockage. Also, providing large open spaces (such as parks) and wide streets are also effective measures to prevent the spread of fires.

In general, the improvement of urban vulnerability to disasters mentioned above requires a lot of time and cost, and many stakeholders (e.g., local residents, residential developers, the government, and municipalities) to be involved in the project. Therefore, it is very important to consider how to extract and prioritize buildings/streets that should be improved and which methods are effective/efficient. The importance of this has been realized so far, and the discussion has been mainly made from a qualitative viewpoint. However, it is difficult to intuitively judge which improvement methods are the most effective and efficient to reduce the risk of property and human damage because the mechanism causing property/human damage is not simple and many factors interact with each other.

In order to advance new improvement projects to prepare for large earthquakes (such as Tokyo Metropolitan Earthquake and Nankai Trough Earthquake) in an effective and efficient manner, it is important to make a convincing and concrete proposal for improvement projects based on quantitative evidence. As a tool to support the decision-making by stakeholders, Osaragi and Oki (2017) developed a simulation system, which described rescue and firefighting activities of local residents and wide-area evacuation behaviors under various situations of property damage at the time of a large earthquake. Users can estimate the number/locations of occurrences of property and human damage after a certain period of time from disaster.

In this chapter, using the simulation system mentioned above, we attempt to quantitatively evaluate the effects on reducing property and human damage in a large earthquake by several urban improvement policies. More specifically, we compare the effects on reducing the number of burnt-down buildings and casualties by implementing the following policies: (1) installing fire-extinguishers for all households; (2) installing seismo-sensitive breakers for all households; and (3) improving specific streets and their roadside buildings. Also, we demonstrate the influence of the order of improving streets and buildings as another example of using the simulation system.

2 Related Work

Kunugi and Tsuboi (2009) compared the effects of the actual projects for improving densely built-up wooden residential areas based on various indices (such as population composition by age group, number of households, number of buildings, total area of streets, and density of buildings) before/after implementing the projects. However, the study did not focus on the effects on disaster prevention by such improvement projects.

There are a few studies to validate the effects of improvement projects from the viewpoint of disaster prevention/mitigation. For instance, Igarashi and Murao (2007) evaluated the progress of improvement projects based on the density of wooden buildings, the risk of building-collapse, et cetera. However, it is difficult to apply the proposed method to small areas (such as city blocks and streets). Noda et al. (2011) categorized real city blocks on the basis of the accessibility to wide streets, and proposed improvement methods in the blocks by category. Nevertheless, there are few studies which quantitatively analyze the effects of specific measures.

Kugai and Kato (2007) proposed an analytical method to understand which aspects of spatial characteristics were important to improve disaster prevention performance of a street network at a town level by using percolation theory, virtual grid-based cities, and multiple regression analysis. Though there is a problem of applicability to actual cities, the results enable general discussion independent of urban-area characteristics.

Some studies attempted to evaluate the effects of specific methods used in actual improvement projects by simulation analyses. For instance, using the fire-spread simulation model, the effects achieved by converting wooden buildings into fire-resistant ones or removing them according to a specific rule for reducing the damaged area or the number of casualties by fire, were estimated (Fukumoto et al. 2004; Wada et al. 2007; Ikeda et al. 2010; Oriyama and Kotaki 2015; Iwami 2005). Also, Sekizawa et al. (2003) analyzed the effects on reducing the damage by fire and the risk that fatalities occurred in cases where disaster prevention equipment was installed (such as smoke alarms, fire alarms, or fire-extinguishers). By contrast, there are a few studies considering multiple kinds of property damage and indices. Okada et al. (1981) developed a mesh-based general simulation system that described the damage by fire in a dense city. In the study, the effectiveness of several measures for disaster prevention (such as newly established evacuation areas, fireproofing specific districts, and securing firebreak belts) was evaluated in terms of human damage. Kojima et al. (2005) executed simulations of building-collapse, street-blockage, and fire-spread, and estimated possibilities of evacuation, rescue, and firefighting based on the accessibility of pedestrians/vehicles under the assumption of implementing each urban improvement policy. Oki and Osaragi (2016a) showed the effectiveness of the method to provide a new evacuation route that could be passed only in emergency situations between houses. In this case, both the costs of the project and the number of people with difficulty in an area-wide evacuation were reduced more than would have resulted from the case of widening a street. Besides these studies, there are some quantitative approaches using simulation, but few studies have considered all the aspects as follows:

- Various situations affecting people at the time of a large earthquake (entrapment in a building/on a street, rescue activity, firefighting activity, and area-wide evacuation)
- Various evaluation indices regarding property and human damage
- Numerous simulation cases
- Concrete and practical examples
- Comparison among various methods for improving vulnerability
- Measures according to the characteristics of a town (i.e., where universal measures are not always effective in any region).

3 Overview of the Simulation System

Figure 1 shows the overview of the simulation system (Osaragi and Oki 2017). In this chapter, we only outline the main points of the system because the explanation of each sub model adopted in the system is described in detail in our previous study (Osaragi and Oki 2017).

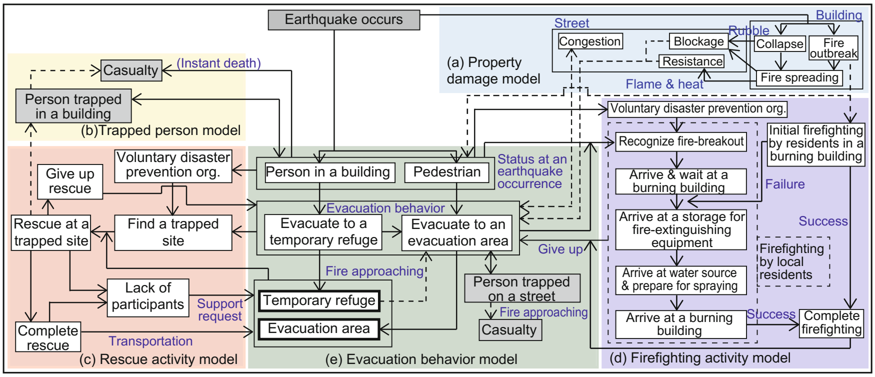


Fig. 1 Overview of the simulation system (Osaragi and Oki 2017)

Human factors (such as ability and behavior) are too complicated and diverse to completely describe in the simulation. Therefore, we have focused on specifically important aspects related to disaster prevention/mitigation and incorporated them into our simulation model. In addition, the individual differences in ability and decision-making are artificially expressed by using random numbers.

3.1 Property Damage Model

The property damage considered in this system includes building-collapse (complete collapse), street-blockage, fire-outbreak, and fire-spreading. The probabilities of complete collapse and fire-outbreak are set for each building based on detailed research about past major earthquakes. Based on these probabilities, the hazard locations (i.e., locations of building-collapse, street-blockage, and fire-outbreak) are probabilistically estimated for each simulation case. Therefore, the locations of property damage vary by case. The detailed explanation about the probabilities is described in a previous paper by the authors (Oki and Osaragi 2016a). Street-blockage is caused by debris of collapsed buildings and by airflow and radiant heat generated from burning buildings. Even if a street is blocked, people are assumed to be able to overcome the rubble whose height is lower than a certain value, although their walking speed is reduced. Also, it is assumed that fires make the streets in front of burning buildings impassable and affect the route selection of people as a sense of resistance according to the distance from burning buildings. The spread of fires depends on the structure/material of buildings, the distance between buildings, the scale of an earthquake, the direction and speed of wind, et cetera. In our simulation system, the fire-spread is described on the basis of the fire-spreading speed formulas by Tokyo Fire Department (2001). The detail of the formulas is provided in Hirokawa and Osaragi (2016).

3.2 Trapped Person Model

A certain percentage of people in completely collapsed buildings except for those who instantly die are assumed to be trapped in buildings. 54% of those who can escape by themselves do so when the set time individually passes. However, others cannot escape by themselves, and die unless they are rescued from the buildings within the grace period of time according to their degree of injury. Also, if the building where a person is trapped catches fire while he/she remains, he/she is considered to be killed by the fire. More detailed explanation of some aspects (e.g., how to determine people who die instantly and people trapped in a building, or what is the grace period of time according to the degree of injury) can be found in the previous papers (Oki and Osaragi 2016b; Osaragi and Oki 2017).

3.3 Rescue Activity Model and Firefighting Activity Model

Local residents try to evacuate to a temporary refuge or an evacuation area in the time that has passed since an earthquake occurs. However, in cases where a fire approaches within a certain distance from his/her location, they are assumed to immediately start evacuating. If an evacuee on his/her way to the temporary refuge or evacuation area finds a building with a trapped person, he/she participates in rescue activities. When the cumulative time considering the number of rescue participants passes, the trapped person is assumed to be released and transported to a temporary refuge or an evacuation area. Likewise, in cases where an evacuee finds a burning building, he/she participates in firefighting activities using any fire-extinguishing equipment (stand pipe/class D light-weight portable pump) equipped in the district. If spraying water to a burning building can be started before the fire spreads to the adjacent buildings, fire extinguishing is considered to have succeeded after 30 min have passed after the start of water being sprayed. In addition, it is assumed that 1.7% of all residents in the district belong to a "Voluntary Disaster Prevention Organization" and engage in rescue and firefighting activities while traveling around the district immediately after an earthquake occurs.

3.4 Evacuation Behavior Model

When an evacuee arrives at a temporary refuge or an evacuation area, the evacuation is considered to be completed. However, if a fire approaches within a certain distance from the temporary refuge, people in the refuge try to evacuate to an evacuation area. Initially, local residents are assumed not to have any information on the condition of a street-blockage in the district, and they grasp the condition whilst travelling. After a person notices that he/she cannot reach any temporary refuges and evacuation areas, he/she moves hither and thither in the movable range. If there are no available streets when a person reaches an intersection, he/she stays there, and is treated as a casualty in cases where a fire approaches within 30 m radius of his/her location.

More detailed explanation of evacuation modeling can be seen in the previous papers by the authors (Oki and Osaragi 2016a, b; Osaragi and Oki 2017).

4 Application to Evaluating Urban Improvement Policies

4.1 Study Area and Assumption of Studies

The study area (about 1 km square) examined in this chapter is located in the Senju district of Adachi Ward, Tokyo, which is surrounded by wide streets, and one of the most typical densely built-up wooden residential areas (Fig. 2). There are few relatively wide streets and large open spaces that can prevent the spread of fire, and therefore most of the buildings in this area form a large fire-spread cluster. It can be said that there is a high possibility that most of the area burns out rapidly due to uncontrolled fire-spreading. In addition, at the time of a major earthquake, it is highly likely that activities of emergency vehicles and local residents and wide-area evacuation behavior are obstructed by many blocked streets with a width of less than 4 m. According to the 7th Community Earthquake Risk Assessment Study published by Tokyo Metropolitan Government (2013), the study area contains many *chomes* (traditional Japanese address units) with a high risk of building-collapse and fire-spread.

The assumption of the case studies in this chapter is set as Table 1 with reference to the damage estimate by Tokyo Metropolitan Government (2012) and from a previous study (Osaragi and Oki 2017).

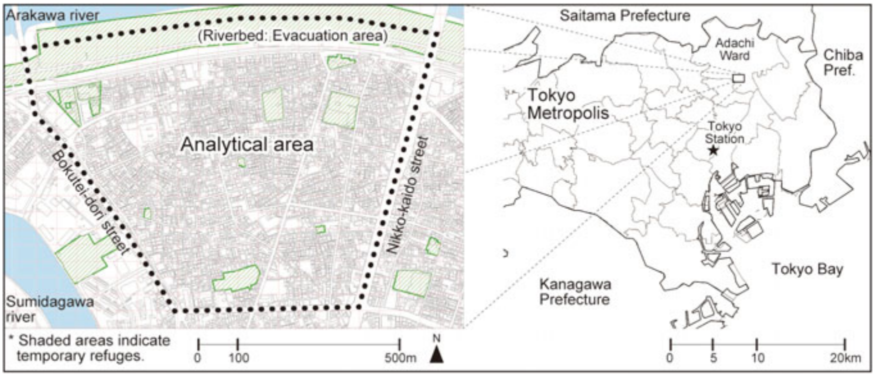


Fig. 2 Study area

Table 1 Assumption of the case studies in this chapter

Seismic intensity level	Greater than 6
Instrumental seismic intensity	6.16
Peak ground velocity	81.0 [cm/sec (kine)]
Peak ground acceleration	828 [cm/s^2 (gal)]
Earthquake occurrence time	6:00 pm on a weekday in winter
Calculation time	24 h after an earthquake occurs
Weather condition	Sunny with 8 m/s north wind
Total number of people	13,487 (based on the Person-Trip Survey within the Tokyo Metropolitan Area conducted in 2008)

This assumption can be freely changed to another assumption and users can execute the simulation on the basis of the assumption. Firstly, in Sect. 4.2, we executed the simulation under the situation experienced in 2011 as a basic scenario, and estimated property damage (number of burnt-down buildings) and human damage (number of casualties). Next, in Sects. 4.3, 4.4, 4.5 and 4.6, we attempt to conduct a quantitative evaluation of the effects of reducing the damage by specific disaster prevention/mitigation measures in buildings or cities by comparing the simulation results.[1]

Here, we consider the three different approaches: (i) installing fire-extinguishers for all households; (ii) installing seismo-sensitive breakers for all households; and (iii) widening specific streets and improving their roadside buildings.

If we adopt approach (iii), it is expected to improve sunshine, the ventilation of each house, and also the accessibility of vehicles. In terms of disaster prevention/mitigation, the reachability of ambulance and fire engines would be improved, and evacuation routes for local residents could be secured. Namely, the safety and comfortableness of the area could be improved by the adoption of approach (iii). On the other hand, the government or municipalities have to spend a large amount of money for implementing this measure. Also, residential developers and residents would be forced to pay money for the reconstruction of buildings along the widened streets. Therefore, the total cost for completing the measure would be much higher than for the other measures. By contrast, approaches (i) and (ii) are only effective for preventing fire-outbreaks. Although residents have to pay the cost of installing such equipment by themselves (additionally, the government provides a grant to encourage residents to install seismo-sensitive breakers), the total cost for completing the measures could be suppressed.

---

[1] It is important but difficult to validate the effects by specific measures in real residential areas because there are few examples of large-scale disasters in the past. Therefore, we executed the simulation using the same simulation system under the different assumptions, and attempted to relatively evaluate the difference of simulation results derived from the difference of assumptions.

Some sub models adopted in the simulation system were validated on the basis of surveys in the past earthquakes. For instance:

- For estimating whether each building completely collapsed or not, we used the collapse probability model proposed by Murao and Yamazaki (2000) based on the survey report of building damage by the Hyogo-ken Nambu Earthquake (or the Great Hanshin-Awaji Earthquake) in 1995. Furthermore, the timing of the fire-outbreak was assumed to follow the cumulative function based on another survey in the same earthquake (Tokyo Fire Department 2015).
- The timings of escaping from a collapsed building and the total activity time required for relieving a person trapped in a building by rescue participants were based on a survey by Takeda et al. (2001). Additionally, the grace period of time according to the degree of injury was based on another survey by Ohta et al. (2001). Both surveys were also conducted in the aftermath of the Great Hanshin-Awaji Earthquake.
- The timing for people in a building that start evacuating was assumed to follow a Poisson distribution ($\lambda = 3.35$) based on the survey (Nishida 2009) of the literature on the Great Kanto Earthquake in 1923.

The research question posed was to ask by how much could the number of burnt-down buildings or casualties be reduced by implementing these measures? We attempt to answer these questions by executing the simulations in Sects. 4.3, 4.4, 4.5 and 4.6. In order to consider the uncertainty of the simulation results derived from the difference of locations of property damage and human behaviors, we executed 100 simulations for each assumption and showed the effects of each measure based on the value of each case, average, median, maximum, and minimum.

Figure 3 shows the operation process flows of the analyses for this chapter. The simulation system is implemented in C#. The input data for the system consisted of GIS data (including street node, street link, building, et cetera), the data on people in the study area based on the Person-Trip Survey, and the data on property damage estimated in advance by using another simulation system (Osaragi and Oki 2017). Additionally, users have to set some parameters (such as earthquake occurrence time, calculation time, calculation step interval [e.g., 30 s], number of simulation cases, et cetera) as shown in Table 1. Also, the seed of random numbers is necessary to set by case. After that, the simulations are performed repeatedly under the conditions of the preset number of cases, and several kinds of log data are outputted. Based on the outputted data, we demonstrated the simulation results as

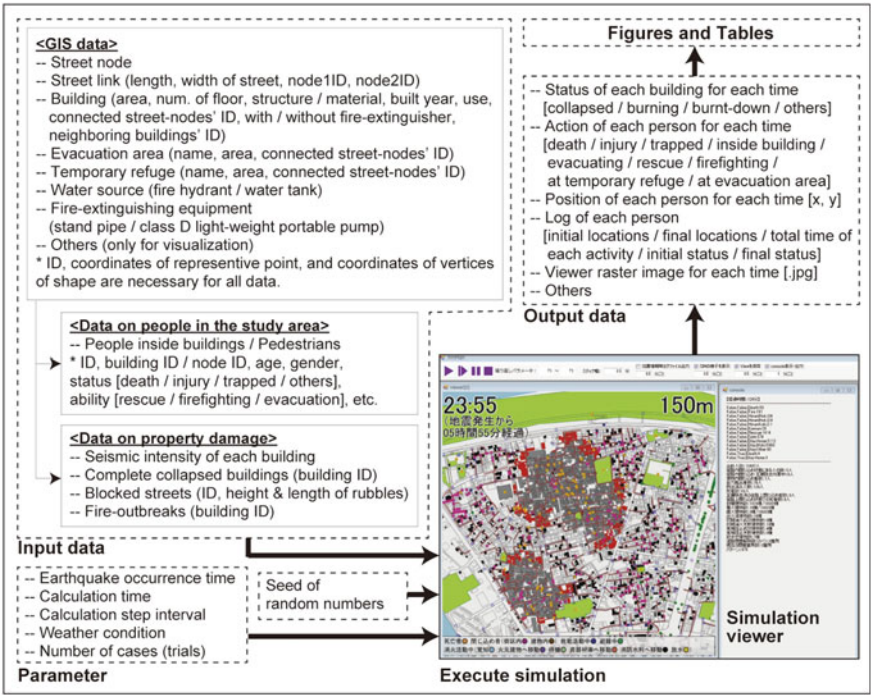


Fig. 3 Operation process flows of the analyses for this chapter

figures or tables. When users want to implement the simulations under the different assumption, they only have to replace a part of the input data or change the values of some parameters.

4.2 Simulation Results Under the Basic Assumption ("Basic")

On the basis of the simulation results under the basic assumption ("**Basic**" in Figs. 6, 7 and 8), 1880 buildings (42.8% of all the buildings in the area) are burnt down and 458 people (3.4% of all the local residents) die on average. At a maximum, there are the critical cases so that the percentage of burnt-down buildings is 91.9% (4036 buildings, property damage case No. 14) or the percentage of casualties is 9.4% (1264 people, No. 64). Also, in approximately 60% of all cases, more than 60% of buildings in the area are burnt out. This is because buildings on the western part of the study area form one large fire-spread cluster. That is, all the buildings which consist of the cluster would be burnt down if a fire breaks out from only one of the buildings and fails to be extinguished.

As we mentioned above, more than 500 local residents die in almost all the cases where the entire western part of the study area is burnt up to 24 h after the occurrence of an earthquake. On the other hand, in the case where the percentage of burnt-down buildings is zero or low as a result of the success of extinguishing fires by local residents, the number of casualties decreases to about 200 people (equal to less than half of the average number of casualties). Most of these casualties are instantly crushed to death in the buildings regardless of the damage case. In other words, the degree of the number of casualties highly depends on the number of burnt-down buildings, and it suggests the utmost importance of reducing human casualties to prevent fires from breaking out and spreading widely.

4.3 Effects by Fully Equipping Each Building/Dwelling Unit with a Fire-Extinguisher ("Extinguisher")

In cases where a fire breaks out from cookware or a heating appliance immediately after the occurrence of a major earthquake, it is important to determine whether people in the building can quickly extinguish the fire using fire-extinguishers. According to a survey by Tokyo Fire Department (2011), the ownership rate of fire-extinguishers was 68.1% in all households as of 2011 (and we used this rate in the simulation detailed in Sect. 4.2).

Here, we have assumed that the installation rate of household fire-extinguishers becomes 100% because each building/dwelling unit has been obliged to install fire-extinguishers. Only people inside burning buildings are assumed to be able to use fire-extinguishers. The other conditions (such as the spatial distribution of property damage, et cetera) are fixed for easier comparison with the basic assumption (number of property damage cases: 100 cases).

Figures 6, 7 and 8 (“**Extinguisher**”) shows the estimation results of the number of burnt-down buildings and casualties in a situation where the installation rate of fire-extinguishers has reached 100%. The number of burnt-down buildings becomes zero only in 9 cases out of 85 cases where at least one building is burnt-down according to the basic assumption (Sect. 4.2), and a certain level of decrease of the number of burnt-down buildings can be seen in only 15 cases. Also, the average number of burnt-down buildings is 1557 (35.5% of all buildings; this decreases by 323 buildings [7.3 points] compared to the basic assumption), and the average number of casualties is 409 (3.0% of all local residents; which decreases by 49 people [0.4 point] compared with the basic assumption). As for the maximum value, the number of casualties still exceeds 1200 people.

Although fire-extinguishers at home are important for firefighting activities just after a fire breakout, the effects of reducing property and human damages by improving the installation rate are slight based on the simulation results. In some cases, a fire breaks out from the building where the residents are absent. In other cases, fire-extinguishing activities are not implemented because the residents are trapped, injured, or killed inside the building.

4.4 Effects by Installing Seismo-Sensitive Breaker for Each Building/Dwelling Unit (“Breaker”)

Among the cases where the initial extinguishment is not carried out because the residents in the building are absent, there are the cases where a fire breaks out from damaged appliances or electric wiring due to re-energizing after a certain time has passed after the occurrence of an earthquake. In fact, 85 cases (61%) out of 139 fires in the Great Hanshin-Awaji Earthquake (January, 1995) and 71 cases (65%) out of 110 cases in the Great East Japan Earthquake (March, 2011) were caused by electricity (Study Group on Suppression of Electric Fire at Large Scale Earthquake 2015). Therefore, in order to prevent the occurrence of fires caused by electricity, “*seismo-sensitive breaker*” have been installed in each house. The breaker senses shake above a certain level and automatically shuts off the energization. In other words, the breaker is effective for preventing fire-outbreak, but not for preventing fire-spread. There are various types of breakers such as a distribution board type and an outlet type (Fig. 4).

Here, we examine the effects of reducing the number of burnt-down buildings and casualties by installing such seismo-sensitive breakers in all buildings and dwellings. We then randomly extracted 60% of all the buildings where a fire breaks out under the basic assumption (Sect. 4.2) and considered them as being prevented from being affected by the fire-breakout because of the operation of the breakers.

Fig. 4 Various types of seismo-sensitive breaker for households (*source* Study Group on Suppression of Electric Fire at Large Scale Earthquake 2015)

As shown in Fig. 6 ("**Breaker**"), the number of burnt-down buildings greatly decreases in many cases where most buildings in the area were burnt down under the assumption stated in the previous sections. As a result of installing seismo-sensitive breakers, the number of cases where few or no buildings are burnt down increased from 32 cases in the basic assumption to 59 cases in this assumption. Simultaneously, the average ratio of burnt-down buildings became 23.0% (19.8 points decrease compared with the basic assumption), and the number of casualties decreased to 331 (Figs. 7 and 8). However, the maximum numbers of both burnt-down buildings and casualties are not significantly different between the cases of "**Basic**" and "**Breaker**". These results suggest that seismo-sensitive breakers contribute to reducing the average number of burnt-down buildings and casualties probabilistically, but there still remains a possibility that devastating damages occur even after the complete installation of breakers.

4.5 *Effects by Improving Specific Streets and Their Roadside Buildings ("Street"/"Street & Extinguisher"/ "Street & Extinguisher & Breaker")*

As mentioned in the basic assumption (Sect. 4.2), it is highly likely that the entire western part of the study area burns when at least one fire breaks out from one of the buildings in the area because most streets in the area are narrow. Additionally, many street-blockages due to the debris of collapsed buildings occur in the area, resulting in that many local residents are trapped on the streets and killed by fire-spread.

Based on the present situation mentioned above, the Adachi Ward government has actually started to consider widening specific streets with a width of 4 m or less in the western part of the study area. According to the plan by the government, the streets from A to F (Fig. 5) will be widened in alphabetical order. However, the effects of the plan for reducing property and human damage have not been quantitatively discussed enough. Here, it is assumed that streets A to F are widened to

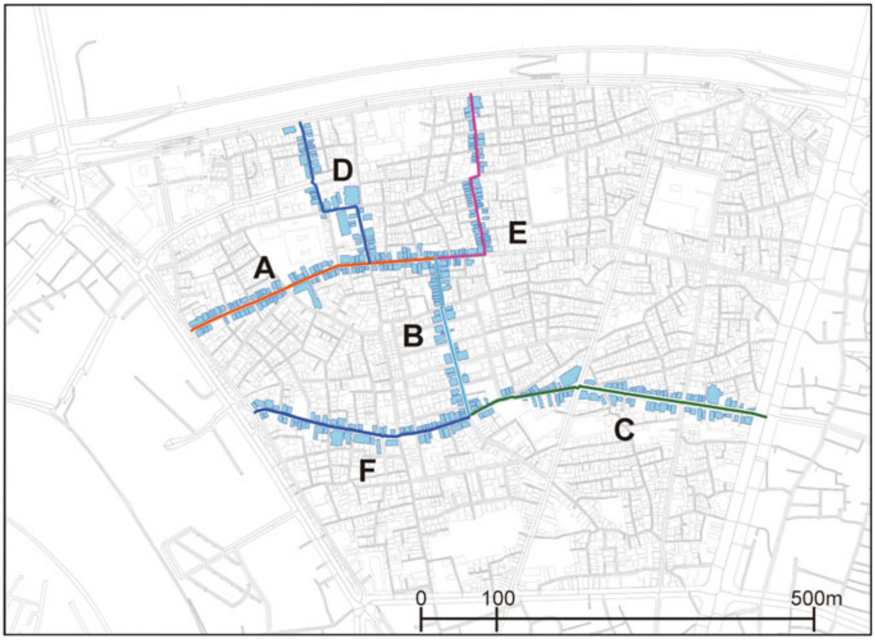


Fig. 5 Spatial distribution of streets and buildings assumed to be improved

6 m and that all the buildings along those streets are converted into fire-resistant and quake-resistant buildings (RC construction). Through this example, we attempted to evaluate the effects by strengthening the street network to the main streets at the time of disaster and by forming firebreak belts.

Figure 5 shows the spatial distribution of streets and buildings that are assumed to be improved in this section. In the study area surrounded by major streets (serving as evacuation routes in disaster), streets with a width of 6 m are assumed to be distributed at approximately 250 m intervals. The total number of roadside buildings is 383 (equivalent to 8.7% of all the buildings in the study area). Here, we assume that these 383 buildings after the improvement neither collapse nor cause a fire-spread to adjacent buildings. For simplification, the structure of buildings and the width of streets are virtually changed without updating the shape of roadside buildings and streets in the simulation. The simulation is executed for 100 cases as well as for the previous sections.

Figures 6, 7 and 8 ("**Street**") show the number of burnt-down buildings and casualties after 24 h have passed since an earthquake occurs. The effects of improving the evacuation route network, which also serves as firebreak belts, are large in reducing property and human damage. As a result, there are few cases where the major part of the study area is burnt down as shown in the previous assumptions. The percentage of burnt-down buildings can decrease to 15.0% (657 buildings) on average and 51.9% (2281 buildings) at most. Moreover, the number

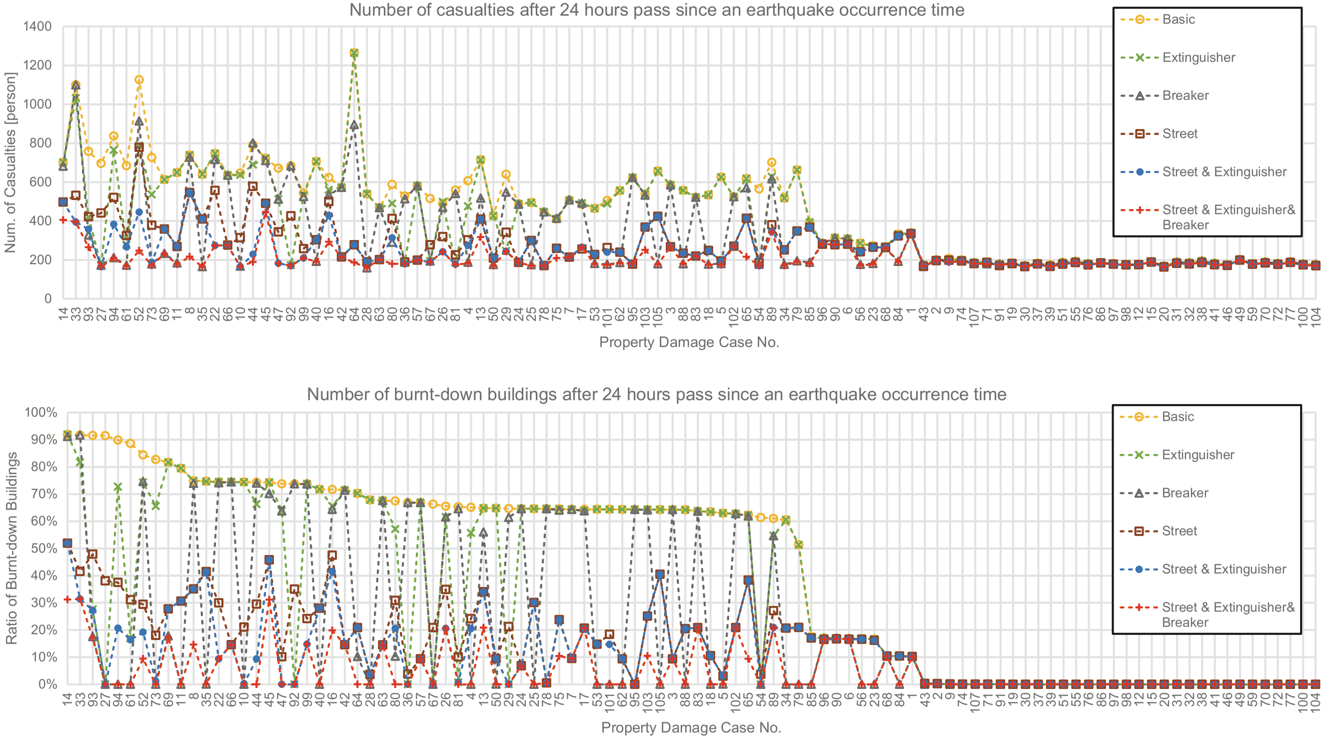


Fig. 6 Number of burnt-down buildings and casualties by property damage case

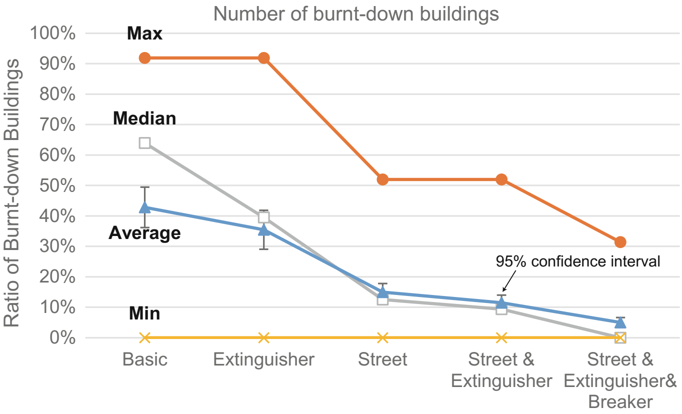


Fig. 7 Number of burnt-down buildings by assumption (100 cases)

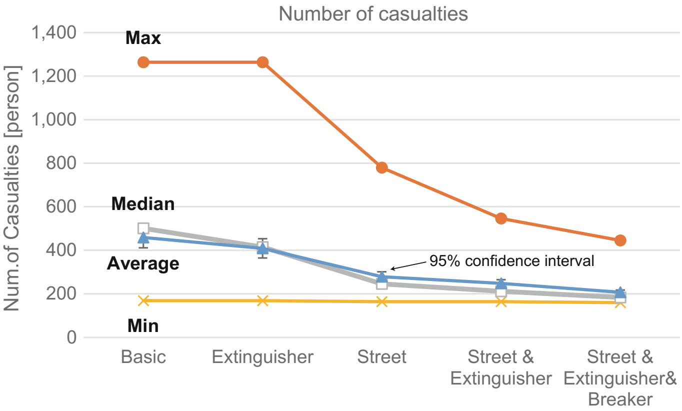


Fig. 8 Number of casualties by assumption (100 cases)

of casualties significantly decreased to 278 (2.1%) on average and 779 (5.8%) at the maximum because the possibility that evacuees are trapped on streets is reduced and the occurrence of large fire-spread can be prevented. In addition, if fire-extinguishers and seismo-sensitive breakers are completely installed in each building and dwelling as assumed in Sects. 4.3 and 4.4, it is expected to further reduce the number of burnt-down buildings and casualties ("**Street & Extinguisher**" and "**Street & Extinguisher & Breaker**" in Figs. 6, 7 and 8). Specifically, the ratio of burnt-down buildings and the number of casualties can be reduced to 5.0% and 207 people respectively on average if the measures both by installing fire-extinguishers and seismo-sensitive breakers and by improving specific streets and their roadside buildings are simultaneously implemented.

4.6 Order of Improving Specific Streets and Their Roadside Buildings

Although securing evacuation routes and converting wooden buildings into fire-resistant ones are important as described in the previous section, it takes a certain period of time to complete such projects to improve specific streets and their roadside buildings. On the other hand, it is said that large earthquakes can occur at any time in the near future. Therefore, it is an important issue regarding the most appropriate way to proceed with improvements. For instance, the streets and buildings might not serve as firebreak belts or safe evacuation routes depending on the way of the improvement (such as the case where the improvement is promoted randomly along a roadside).

In this section, we demonstrate the influence of the order of improving specific streets and their roadside buildings from the viewpoint of the effectiveness and efficiency of reducing property and human damage by using the simulation system. More specifically, assuming that all the streets subject to improvement in Sect. 4.5 are divided into two groups (improved in the first and second half), we compare the number of burnt-down buildings and casualties among multiple scenarios, where the combinations of streets in groups are different. Here, the simulation under each scenario is executed for the common 10 cases, which are randomly extracted from 100 cases of property damage in the previous sections.

Figures 9 and 10 show the ratio of burnt-down buildings and the number of casualties in the first half by pair of improved streets. Herein, the three streets that

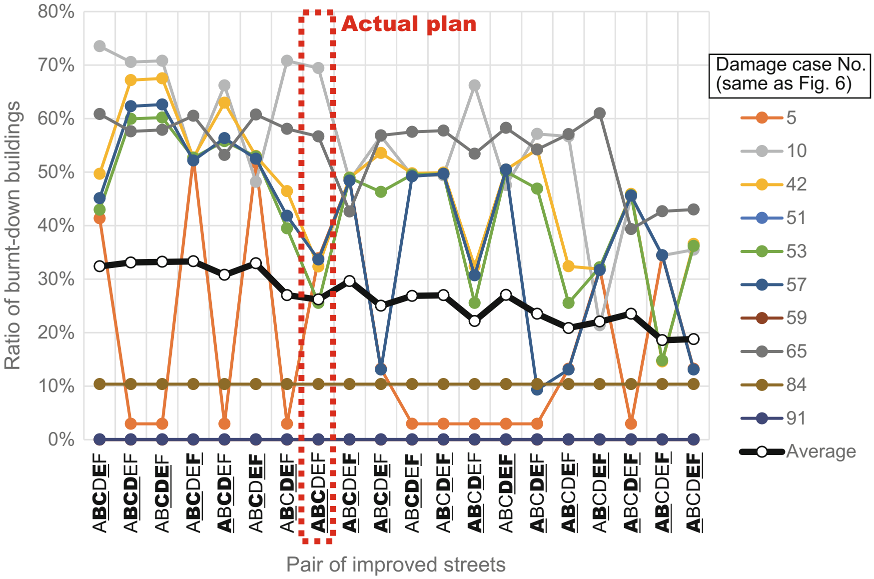


Fig. 9 Ratio of burnt-down buildings in the first half by pair of improved streets

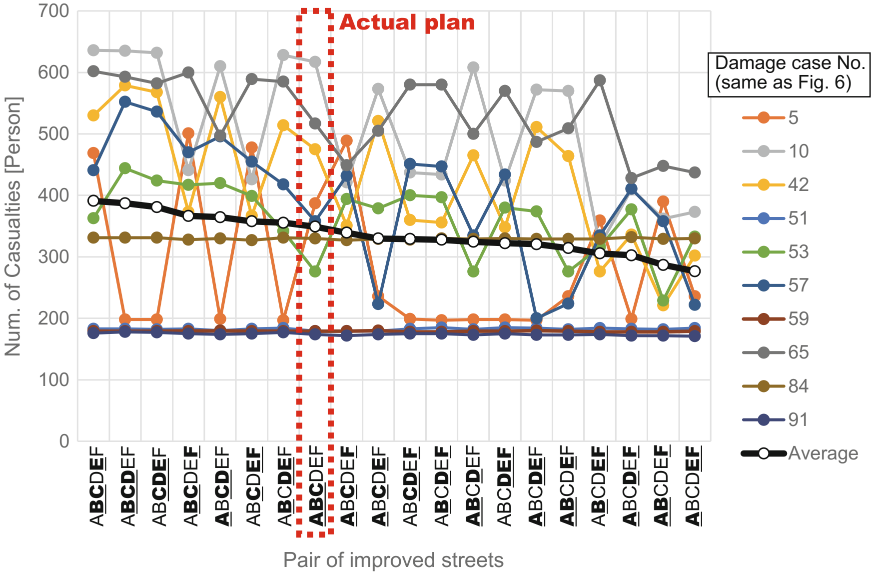


Fig. 10 Number of casualties in the first half by pair of improved streets

Table 2 Relationships between pairs of streets and rank in a descending order of the number of casualties in the first half

Actual plan

		Rank																			
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Street	F				■		■			■		■	■		■			■	■	■	■
	E	■		■			■	■			■				■	■	■	■			■
	D		■	■		■		■				■	■	■	■	■			■		
	C	■	■	■	■	■	■		■	■	■	■									
	B	■	■		■			■	■				■	■			■	■		■	
	A					■			■	■	■			■		■	■		■	■	■

were improved in the first half are highlighted in the 6-character string (e.g., "A**<u>BC</u>**D**<u>E</u>**F" indicates the scenario where the streets B, C, and E are improved in the first half). Based on the simulation result, it is likely that property and human damage can be kept low in case the streets A, E, and F are improved as priority (Table 2). On the other hand, it is found that the effects and efficiency (Fig. 11) of improving street C in the first half are comparatively low even though the street can serve as the main evacuation route connected to the eastern wide street (Nikko-kaido Street). These results suggest that it is effective to improve specific streets and roadside buildings so as to divide a fire-spread cluster into multiple small areas.

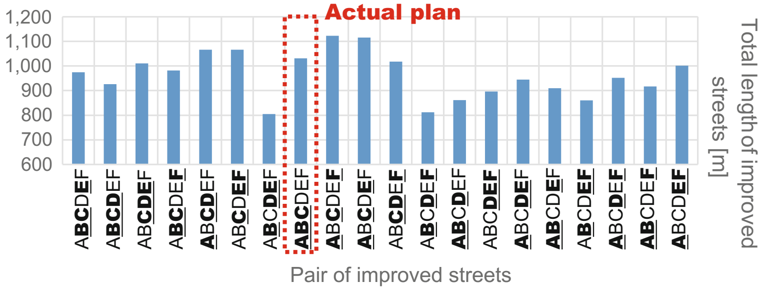


Fig. 11 Total length of improved streets in the first half by pair

5 Summary and Conclusions

Using the simulation system considering property damage and the activities of local residents (such as rescue, firefighting, and evacuation) in a large earthquake, we attempted to evaluate the effects by specific measures to reduce property and human damage in densely built-up wooden residential areas. The ratio of burnt-down buildings and the number of casualties after 24 h passed since an earthquake occurrence time were used as the indices of property and human damage respectively.

In cases where fire-extinguishers were installed in all buildings/dwelling units, the number of burnt-down buildings became zero or significantly decreased only in 24 cases out of 85 cases, where at least one building was burnt-down in the assumption referring to the situation in 2011. One reason for this was the absence of residents in the building where a fire broke out, and another was that residents were trapped, injured, or killed inside the building. By contrast, assuming that seismo-sensitive breakers were installed in all buildings/dwelling units for preventing fires caused by electricity, the number of cases where few or no buildings were burnt down increased to 59 cases, and the average number of casualties could be reduced to 331 (approximately 72% of those in the basic assumption). However, the degree of property and human damage in critical cases could not be reduced because the breakers were not effective for fires caused by other reasons than electricity. Equipment such as fire-extinguishers and seismo-sensitive breakers are comparatively cheap to install for households, but the simulation results show that the limitation of proceeding with the disaster prevention/mitigation measures only in the individual household.

Next, we executed the simulation under the assumption that the specific streets in the west part of the study area were widened to 6 m (distributed at approximately 250 m intervals) and their roadside buildings were converted into fire-resistant and quake-resistant buildings. As a result, there were few cases where the most buildings were burnt down, and the number of casualties greatly decreased. This is because these types of improvement projects serve as both firebreak belts and an evacuation route network. It was further confirmed that the effects in reducing property and human damage were further enhanced by installing fire-extinguishers and seismo-sensitive breakers simultaneously. Furthermore, we demonstrated the influence of the order of improving streets and their roadside buildings, and the effects of improvement tended to become high in cases where the fire-spread cluster was divided into multiple small areas.

For sustainable urban futures, it is important to consider not only the efficiency and comfortableness of towns in daily life but also the safety and security against large-scale disasters. Our simulation system can assist developers and planners to make a decision about selecting specific measures that will improve urban earthquake vulnerability using a quantitative, evidence based planning science.

Acknowledgements This chapter represents the partial results of research that was supported by CREST (Core Research for Evolutionary Science and Technology) and JST (Japan Science and Technology Agency).

References

Fukumoto, K., Murosaki, Y., & Hokugo, A. (2004, May). A study on the effect of group fire prevention method against urban fire in wooden high density urban areas (in Japanese). In *Proceeding of Architectural Research Meetings (Kinki Chapter)*, *44*, 585–588.

Hirokawa, N., & Osaragi, T. (2016). Earthquake disaster simulation system: Integration of models for building collapse, road blockage, and fire spread. *Journal of Disaster Research (Special Issue on Disaster and Big Data), 11*(2), 175–187.

Igarashi, M., & Murao, O. (2007). Effectiveness of Tokyo Metropolitan Government Promotional Project for improvement of wooden house congested districts for area vulnerability reduction (in Japanese). *Journal of Social Safety Science, 9,* 235–244.

Ikeda, S., Hasemi, Y., Yasui, N., & Nakayama, H. (2010, March). Possibility of applying quake-resistant and fire-prevention simultaneous reinforcement technology in densely built-up wooden residential areas and its effects on preventing fire-spread: A case study in Kyojima district, Sumida Ward (in Japanese). In *Proceeding of Architectural Research Meetings (Kanto Chapter)*, *81*(I), 533–536.

Iwami, T. (2005). Evaluation of city performance against fire using a simulation of city fire: A study on an effect of city improvement in a virtual city (in Japanese). *Journal of the City Planning Institute of Japan, 40*(3), 727–732.

Kojima, W., Iwata, K., Nakamura, J., & Akasaki, K. (2005, May). A comparative analysis of the effects and problems of district improvement methods for mitigating the damage from a big earthquake in the densely built-up areas on the basis of the simulation of multiple disasters (in Japanese). In *Proceeding of Architectural Research Meetings (Kinki Chapter)*, *45*, 397–400.

Kugai, T., & Kato, T. (2007). The structure of disaster mitigation performance of road network from the viewpoint of road blockade: The basic study on the evaluation of disaster mitigation performance of the local area road network based on percolation theory (in Japanese). *Journal of architecture and planning, 615,* 113–120.

Kunugi, K., & Tsuboi, Y. (2009, March). Effects on implementing projects for improving densely built-up wooden residential areas in Tokyo: A case study in Ohta, Shinagawa, Meguro, and Shinjuku (in Japanese). In *Proceeding of Architectural Research Meetings (Kanto Chapter)*, *79*, 145–148.

Murao, O., & Yamazaki, F. (2000). Development of fragility curves for buildings based on damage survey data of a local government after the 1995 Hyogoken-nanbu Earthquake (in Japanese). *Journal of Structural and Construction Engineering, 527,* 189–196.

Nishida, Y. (2009). Fire-spreading and evacuation in Great Kanto Earthquake (in Japanese). *Historical Earthquakes, 24,* 166.

Noda, A., Ichikawa, M., Arakawa, Y., & Mano, Y. (2011, August). A case of object street district caught from improvement technique in Ichidera-Kototoi area: Improvement technique of alley net in densely populated wooden building districts as escape route 1 (in Japanese). In *Summaries of technical papers of Annual Meeting Architectural Institute of Japan (F-1)*, 851–852.

Ohta, Y., Koyama, M., & Watoh, Y. (2001). Attempt of figuring life span characteristics after an earthquake: Revision and supplement—In case of the Hyougoken-Nanbu Earthquake—(in Japanese). *Reports of Tono Research Institute of Earthquake Science, 7,* 93–100.

Okada, K., Yoshida, K., Kashihara, S., Tsuji, M., & Suzuki, K. (1981). Presumption of human injury in case of earthquake's fire and consideration of its countermeasure: Part 2, Presumption of human injury and evaluation of countermeasure effect by a simulation method (in Japanese). *Transactions of the Architectural Institute of Japan*, 308, 110–119.

Oki, T., & Osaragi, T. (2016a, May). Wide-area evacuation difficulty in densely-built wooden residential areas. In *Proceedings of the 13th International Conference on Information Systems for Crisis Response and Management (ISCRAM 2016).*

Oki, T., & Osaragi, T. (2016b, June). Effects of rescue activities by local residents considering property damage and wide-area evacuation immediately after an earthquake. In *Conference proceedings of the 13th International Conference on Design and Decision Support Systems in Architecture and Urban Planning (DDSS 2016).*

Oriyama, K., & Kotaki, A. (2015). Targeted removal of fire spreading wooden buildings (in Japanese). *Journal of Environmental Engineering, 80*(711), 389–396.

Osaragi, T., & Oki, T. (2017). Wide-area evacuation simulation incorporating rescue and firefighting by local residents. *Journal of Disaster Research*, *12*(2), 296–310.

Sekizawa, A., Notake, H., Mammoto, A., Kobayashi, M., & Ebihara, M. (2003, March). Effects of disaster prevention equipment for households on reducing risk that fatalities occur (in Japanese). In *Proceeding of Architectural Research Meetings (Kanto Chapter)*, *74*, 263–266.

Study Group on Suppression of Electric Fire at Large Scale Earthquake. (2015). *Performance evaluation guideline of seismo-sensitive breaker, etcetera* (in Japanese). http://www.bousai.go.jp/jishin/syuto/denkikasaitaisaku/pdf/kanden_guideline_gaiyou.pdf. Accessed December 16, 2016.

Takeda, H., Murakami, H., Ohta, Y., Kuwata, Y., & Takada, S. (2001, November). Comparison of occupant entrapment in Higashinada Ward and Hokudan Town in the 1995 Hyogo-ken Nanbu Earthquake (in Japanese). In *Proceedings of the Annual Conference of the Institute of Social Safety Science*, *11*, 49–52.

Tokyo Fire Department. (2001). *The development and practical use policy of assessment technique of disaster prevention for earthquake fires* (in Japanese). Tokyo: Tokyo Fire Department.

Tokyo Fire Department. (2011). *Provision for earthquake that should be immediately implemented in densely built-up wooden residential areas in order to achieve objectives for disaster mitigation* (in Japanese). Tokyo: The 19th Report of Fire Prevention Council, Tokyo Fire Department.

Tokyo Fire Department. (2015). *Measures to reduce human damage from fires after earthquakes* (in Japanese). Tokyo: The 21st Report of Fire Prevention Council, Tokyo Fire Department.

Tokyo Metropolitan Government. (2012). *Estimated damage from a Tokyo-Epicenter Major Earthquake* (in Japanese). Tokyo: Tokyo Metropolitan Government.

Tokyo Metropolitan Government. (2013). *The 7th community earthquake risk assessment study*. Tokyo: Bureau of Urban Development, Tokyo Metropolitan Government.

Wada, A., Yoshida, M., & Akasaki, K. (2007, May). Examination of effect of reconstructive building group on delay the spread of fire in the densely built-up areas (in Japanese). In *Proceeding of Architectural Research Meetings (Kinki Chapter)*, *47*, 533–536.

Chapter 26
Advanced Spatial Analysis for Vegetation Distributions Aimed at Introducing Smarter City Shrinkage

Kiichiro Kumagai, Hitoshi Uematsu and Yuka Matsuda

Abstract In this study, an advanced approach for the analysis of the spatial continuity of vegetation distributions is proposed through the statistical testing of the spatial features of a Normalized Difference Vegetation Index (NDVI) derived from remotely sensed data. The new approach can achieve the detection of the spatial continuity of vegetation distributions in accordance with the types of land use: a completely urbanized area, a suburban area, a rural area, and a mountainous area. We also apply a hedonic approach with a Geographically Weighted Regression (GWR) to the analysis of the relationship between the assessed values of land and geographical information in order to estimate the importance of landscape factors. The detected areas seem to contribute to a substantial extent to predict the land prices of suburban areas.

Keywords Vegetation distributions · NDVI · Spatial continuity · Land use · Hedonic approach · GWR

1 Background

Japanese cities are facing a rapidly aging society with birthrates, lower than the average rates of developed world. The National Institute of Population and Social Security Research (2012) suggests that the population will keep declining until 2060.

K. Kumagai (✉)
Department of Civil and Environmental Engineering, Setsunan University,
17-8 Ikeda-Nakamachi, Neyagawa, Osaka 572-8508, Japan
e-mail: kumagai@civ.setsunan.ac.jp

H. Uematsu
Kyoto City Board of Education, Kyoto, Japan
e-mail: hitoshi.uematsu@gmail.com

Y. Matsuda
Division of Social Development Engineering, Graduate School of Science
and Engineering, Setsunan University, Neyagawa, Japan
e-mail: 111053my@gmail.com

S. Geertman et al. (eds.), *Planning Support Science for Smarter Urban Futures*, Lecture Notes in Geoinformation and Cartography,
DOI 10.1007/978-3-319-57819-4_26

Population decline generates many problems such as depopulation in rural areas, expansion of lower population density in urban areas, as well as a boost in spending for the maintenance of infrastructure under the pressure of lower revenue. The Ministry of Land, Infrastructure, Transport and Tourism (2014a) is now taking measures against low density urbanization. One of the measures implemented is a land use strategy for living space and urban function. In this measure, Residence Attraction Districts and Urban Function Attraction Districts are defined as core areas for maintaining sufficient population density given current and predicted population dynamics. There are also planned to be additional public transport networks linking the core areas, such as on-demand taxis, community buses and other transport systems. The core areas are expected to play a key role as the fundamental building blocks of future cities in an aging society facing population decline.

On the other hand, there is a potential for the surroundings of the core areas to be run-down because vacancies generate many problems such as crime, susceptibility to fire, as well as a vicious circle of flight from areas of vacancy which reinforces the decline of housing areas and increasing abandonment. The government has developed several measures to address the deterioration of the fringe regions of the core areas through the creation of some systems that encourage conversion from vacancies into allotments, citizens' parks, open spaces, and other green spaces (Ministry of Land, Infrastructure, Transport and Tourism 2014b). However, there have been few measures concerning the spatial distribution of parks and open spaces around the core areas.

Generally, parks and open spaces are covered with vegetation: grass, grove, woods, and other plants. The spatial continuity of vegetation distributions is required for the effective conservation of ecosystems, the reduction of the urban heat island phenomenon, and other landscape issues (Tilman et al. 1994; Carroll et al. 2004; Rogan et al. 2016). It is also expected to provide economic and social benefits like a green infrastructure around the core areas (Heckerta et al. 2016; Palmisanoa et al. 2016; Derkzen et al. 2017). We have developed a spatial analysis method for detecting the spatial continuity of vegetation distributions on a regional scale using remotely sensed data (Kumagai 2011).

In this study, an advanced approach for the analysis of the continuity of vegetation distributions is proposed through the statistical testing of spatial features of a Normalized Difference Vegetation Index (NDVI) derived from remotely sensed data. The new approach can achieve the detection of the spatial continuity of vegetation distributions according to the types of land use: a completely urbanized area, a suburban area, a rural area, and a mountainous area, including the boundaries of the core areas.

We also identify economic impacts of the spatial continuity of vegetation distributions. We apply a hedonic approach with Geographically Weighted Regression (GWR) to the analysis of the relationship between the assessed values of land and geographical information in order to estimate the importance of landscape factors such as the detected areas, public parks, and the local averages of NDVI. Through the comparison of local features, the detected areas seem to contribute to a substantial extent to predict the land prices of suburban areas around the core areas.

2 Data and Methodology

2.1 Study Area

In this study, the whole area of the Osaka prefecture was adopted as the area of interest. This area is located in the Kansai district in the western part of Japan. It covers about 1900 km^2 and contains 33 cities, 9 towns, and 1 village. There are also watercourses consisting of several rivers and many streams in the area. The Osaka prefecture has a master plan in place for parks and open spaces that includes a map of the vision of parks and open spaces for the prefecture. Several green networks indicated in the map are applied in verifying our proposed method as set out in Sect. 4.

2.2 Remote Sensing and Geographical Data

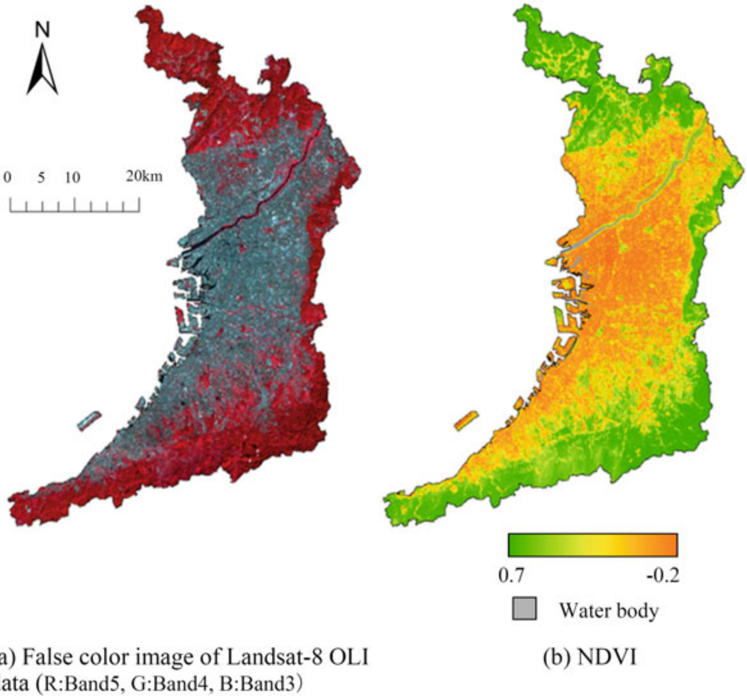
Landsat OLS data from September 2015 was adopted as basic data for this research. The data covers the whole area of interest since the observation swath of Landsat OLS is wide enough (185 km). The data contains hardly any temporal difference that would reflect a seasonal change of vegetation. We applied atmospheric corrections based on the MODTRAN for this study. We defined the NDVI calculated from the Landsat OLS data as the proxy of vegetation abundance. Figure 1 shows the false color image of Landsat OLS data and NDVI derived from the corrected data. In Fig. 1, it is shown that the urbanized areas are bounded on three sides by mountainous areas covered with high NDVI.

The Land Use Map generated by Geospatial Information Authority of Japan is used as the reference for the urban structure. We also apply National Land Numerical Information to a hedonic approach including GWR for studying the relationship between the land prices and the attributes of landscape.

2.3 Methodology

The spatial analysis method of vegetation distribution we have developed is composed of a spatial autocorrelation analysis, an overlay analysis, and a hydrological analysis (Kumagai 2011). The spatial autocorrelation analysis is described as

$$G_i(d) = \frac{\sum_{j=1}^{n} w_{ij}(d)x_j}{\sum_{j=1}^{n} x_i} \tag{1}$$



(a) False color image of Landsat-8 OLI data (R:Band5, G:Band4, B:Band3)

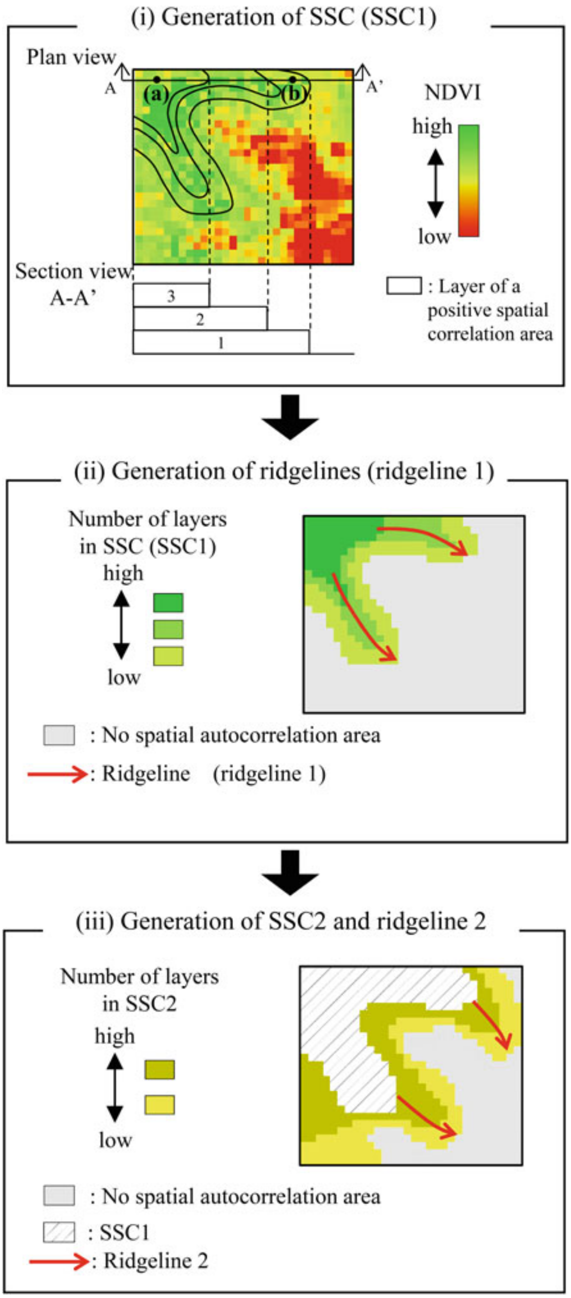
(b) NDVI

Fig. 1 Area of interest. The whole area of the Osaka prefecture was adopted

where G is the G statistic, x is a spatial variable of interest, n is the number of spatial variables, w_{ij} is a symmetric binary spatial weight matrix with ones for all links defined as being within distance d of a given i; all other links are coded zero, including the link of a point i to itself (Getis 1992). We assigned the NDVI to variable x. If the null hypothesis is that the set of x values (NDVI) within d of location i is a random sample, then we obtained a positive spatial autocorrelation (Ord 1995). As a result of the statistical tests with a significance level of 5%, the area of interest was initially divided into the two kinds of results: a positive spatial autocorrelation and no spatial autocorrelation.

Moreover, we focused attention on the relationship between d and the positive autocorrelation areas: the positive areas were expanding as d was increasing. The convergence of the expansion of the positive autocorrelation areas was also confirmed, so that the range of d was defined. We then overlaid the positive autocorrelation areas generated with the fluctuation of d: from a widest range to a narrowest range. The area which consists of the multiple layers of the positive autocorrelation area has been called the Spatial Scale of Clumping of vegetated areas (SSC). Figure 2i shows the basic generation of the SSC. The SSC has a layer structure of positive spatial correlation areas. The top layer of the SSC (e.g. (a) in Fig. 2i) means that a dense distribution area of high vegetation abundance exists

Fig. 2 Procedure of the advanced spatial analysis of vegetation distributions including the basic generation of the SSC and its ridgelines



from the narrowest range to the widest range, while the outskirts of the SSC (e.g. (b) in Fig. 2i) denotes that the dense distribution area of high vegetation exists solely within the widest range.

We also detected the ridgelines from the SSC as the backbones of the high spatial continuity of the vegetated areas by interpreting the SSC as topographic features (see Fig. 2ii). The ridgelines play an important role in acting as bridges between the widely dense distribution areas and sparse areas of vegetation, such as the areas (a) and (b) in Fig. 2i.

3 Advanced Approach

The core areas, such as Residence Attraction Districts and Urban Function Attraction Districts, will be generated in accordance with the type of land use. Several vegetation distribution types also occur on the basis of the type of land use: there are usually sparse vegetation distributions in completely urbanized areas, while there are mostly dense vegetation distributions around mountainous areas. The spatial continuity of vegetation distributions, however, needs to be formed regardless of the vegetation distribution type.

Under the spatial analysis method we have developed, SSC and its ridgelines could be detected around mountainous areas and rural areas because of the widely dense distributions of high NDVI. Improvement of the spatial analysis method is required in order to detect spatial continuity occurring in sparse distributions of high NDVI.

Figure 2 also shows the advanced spatial analysis we propose. Firstly, we applied the spatial analysis method to the area of interest, as mentioned above. The results of this application were renamed SSC1 and ridgeline 1. Secondly, we applied the spatial analysis method to the area excluding SSC1, which was initially detected as no spatial autocorrelation area. SSC2 and ridgeline 2 were then generated. Finally, we iterated this procedure to define successive SSCs. The differences between the ridgelines depend on the density of the high NDVI distributions. This advanced approach can divide the area of interest into several regions on the basis of the feature of vegetation distributions and detect the spatial continuity as ridgelines in every region.

4 Results

4.1 Detection of Spatial Continuity

Figure 3 shows the results of the analysis. SSC1 and its ridgelines appear around mountainous areas covered with trees densely distributed (see Fig. 1). The ridgelines in SSC2 were detected along large parks and open spaces, agricultural fields and other green spaces. The area of SSC3 is largest in this study. Long ridgelines in SSC3 are mainly extracted along rivers. SCC4 is detected at the center of Osaka prefecture.

4.2 Statistical Features

To evaluate the accuracy of the ridgelines, the analysis of the NDVI statistics around the ridgelines was carried out. We calculated the test statistics for the difference of the averages of the NDVI between the area within and the area located outside of the range d in Fig. 4 by varying d which was done from the widest range to the narrowest range.

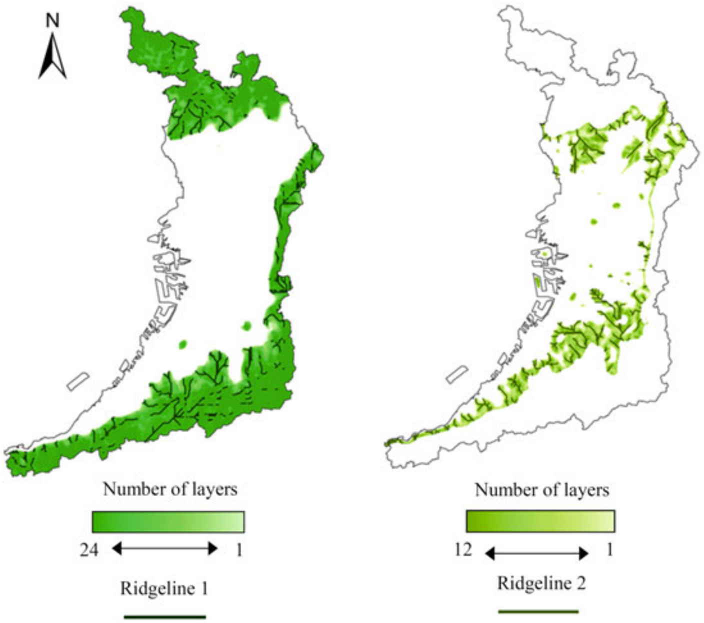
Figure 5 indicates the results of the analysis. The distance from the ridgelines is shown in the horizontal axis, while the statistics of the test between the inside and outside of range d was plotted in the vertical axis. In the case where the statistics of the test show a value above 0, the average of NDVI within the range d is greater than that of NDVI beyond distance d, i.e. the spatial continuity of relatively high NDVI distributions occurs nearby the ridgelines.

On the horizontal axis, the ranges of the ridgelines vary: the range of SSC1 is the widest, while that of SSC4 is the narrowest. This trend depends on the convergence between the expansion of the positive autocorrelation areas and the generation of each SSC. The differences between the ranges thus correspond to the scale variation of dense distribution of high NDVI.

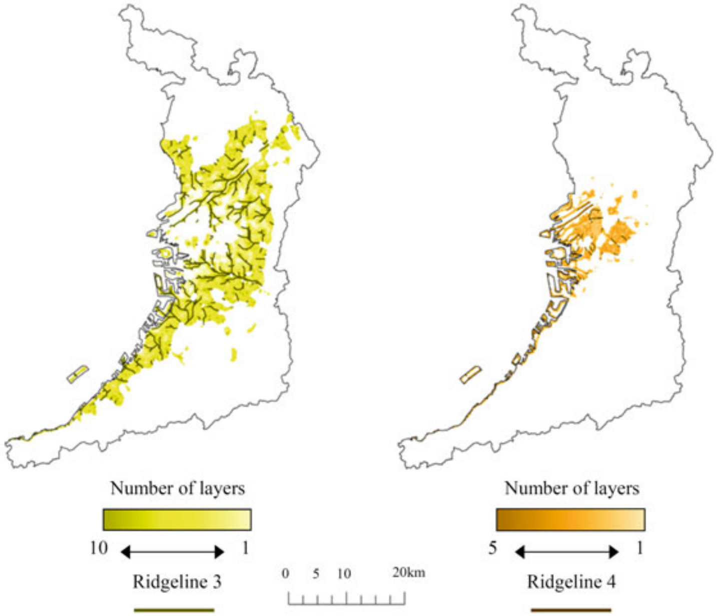
It is apparent that all the averages of NDVI within d are greater than those of NDVI beyond d. We can see that the differences of average values are decreasing from the ridgeline 1 to the ridgeline 4.

We also verify the representativeness of the spatial continuity derived from the ridgelines by comparing the averages of NDVI between the ridgelines and the green corridors mapped on the master plan of parks and open spaces. The green corridors consist mainly of watercourses and roads. Figure 6 shows the conceptual comparison of NDVI statistics between the ridgelines and the green corridors. We calculated the averages of NDVI within d of the ridgelines and those of the green corridors, respectively, in the area of each SSC. The statistics of the test derived from the differences between the averages were obtained for evaluating representativeness. Figure 7 indicates the results of the comparison. In the case where the value of the test is above 0, the average of NDVI along the ridgelines is greater than that of NDVI along the green corridors. It is obvious that the averages of NDVI along all the ridgelines are greater than those of NDVI along the green corridors. We can also see that the test statistics of the ridgeline 1 is the highest, while the test statistics are almost the same between the ridgelines 2, 3, and 4.

The representativeness of the spatial continuity of vegetation distributions along the ridgelines seems to be superior to that of the green corridors.



(a) SSC1 and its ridgelines (b) SSC2 and its ridgelines



(c) SSC3 and its ridgelines (d) SSC4 and its ridgelines

Fig. 3 Results of the analysis

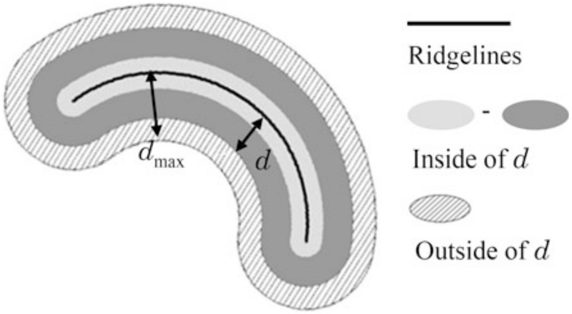


Fig. 4 Concept of reviewing the appropriateness of the ridgelines

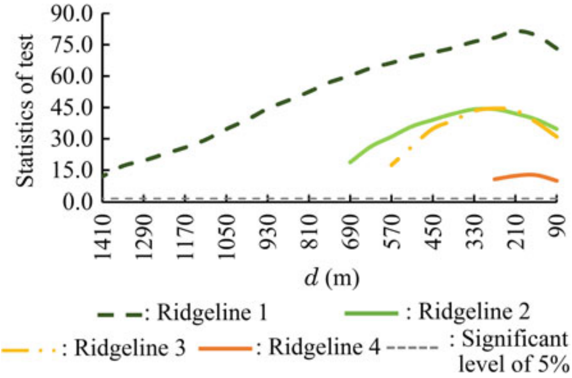


Fig. 5 Results of the statistical test for the difference of the averages of NDVI between the inside and outside of the distance *d*

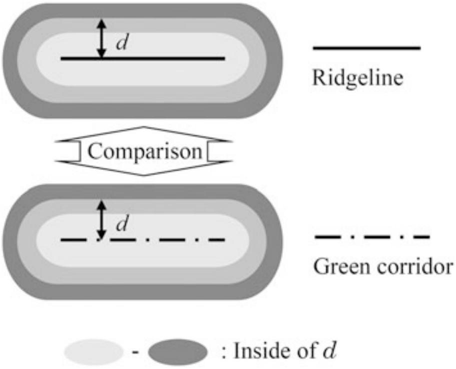


Fig. 6 Concept of the comparison of NDVI statistics between the ridgelines and the *green* corridors

5 Discussion

5.1 Land Use in SSCs

Figure 8 shows the land use ratio in each SSC. In SSC1, the mountainous land use dominates. From SSC1 to SSC4, the mountainous land use gradually decreases,

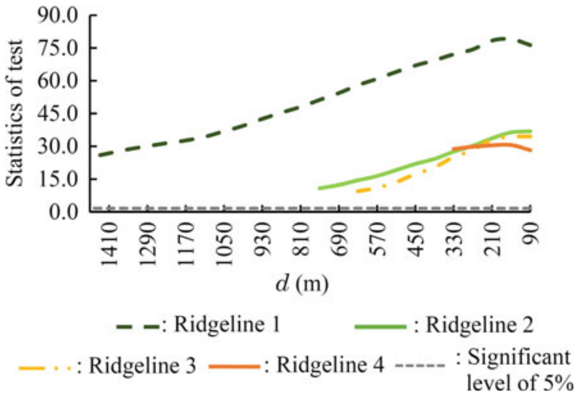


Fig. 7 Results of the statistical test for the difference of the averages of NDVI between the ridgelines and the *green* corridors

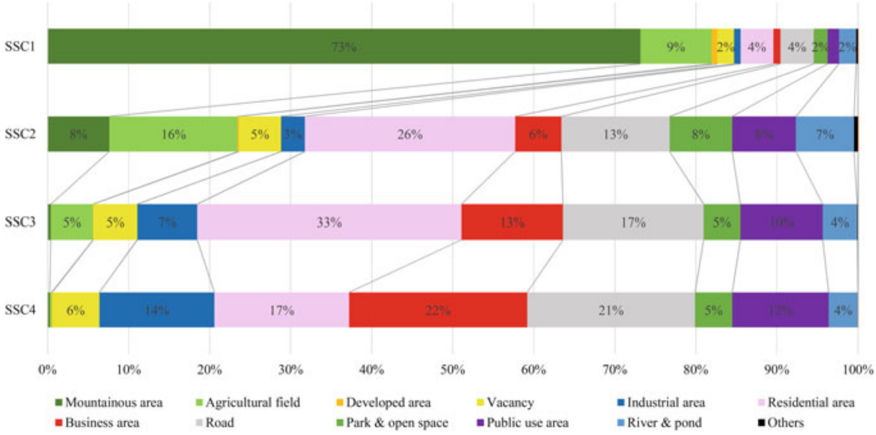


Fig. 8 Land use ratio in each SSC

while the business land use and the industrial land uses increase by degrees. We can also see that the residential land use is increasing from SSC1 to SSC3 and is decreasing from SSC3 to SSC4.

The agricultural land use shows almost the same pattern, but the peak of its ratio is in SSC2. Hence, from the viewpoint of urban structures, SSC1 mostly includes the mountainous areas. SSC2 seems to contain rural areas because the residential land use and the agricultural land use dominate. SSC3 seems to correspond to suburban areas because the residential land use shows highest ratio. SSC4 reveals the feature of completely urbanized areas: there seem to be widespread business and industrial land use.

5.2 Cluster of Vegetation Along the Ridgelines

The spatial continuity of vegetation distributions was detected as the ridgelines in this study. The ridgelines were generated from each SSC depending on the urban structure. We therefore analyzed the vegetation distributions around the ridgelines by checking the density and area of vegetation clusters.

Firstly, we determined a threshold of NDVI for detecting vegetation clusters on the basis of field survey results in a small test site. Table 1 shows the error matrix of the vegetation clusters between the field survey results and the threshold value (0.465) of NDVI after the maximization of a concordance rate. Secondly, we assumed that a pixel was a vegetation pixel if NDVI was more than 0.465 and we clustered spatially consecutive vegetation pixels. Finally, we detected vegetation clusters along the ridgelines referring to the maximum in the statistical test in Fig. 5: within 210 m of the ridgeline 1, within 270 m of ridgelines 2 and 3, and within 150 m of ridgeline 4.

Figure 9 indicates the cumulative relative frequency curves of the size of the vegetation clusters. There are many large clusters around ridgeline 1 and the small size clusters are relatively few. Variety in the size of vegetation clusters were detected along ridgeline 2: they ranged from 0.001 to 1 km^2. Ridgelines 3 and 4 showed almost the same curves, but the maximum size of the cluster along ridgeline 4 is 0.1 km^2. Figure 10 shows the partial images of vegetation clusters with each ridgeline. Around the ridgeline 1, there are some large vegetation clusters. It has been confirmed that the clusters mainly consist of forests covering the foothills of mountains. Vegetation clusters along ridgeline 2 seem to have various sizes and a variety of shapes. They are mostly parks, small and large woods, and agricultural fields neighbouring residential areas. Ridgelines 3 and 4 seem to be generated along small and medium cluster distributions.

Table 1 Error matrix of the vegetation clusters between the field survey results and the threshold value (0.465) of NDVI after the maximization of a concordance rate

		Field survey	
		Vegetation	Other
NDVI	Vegetation	89.1	14.9
	Other	10.9	85.1

(%)

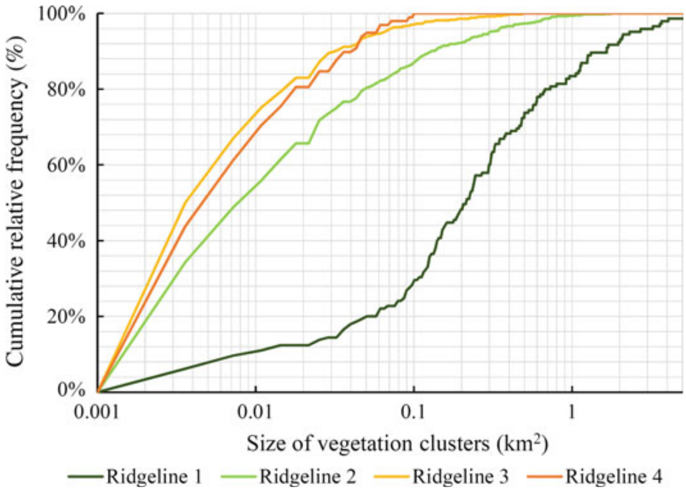
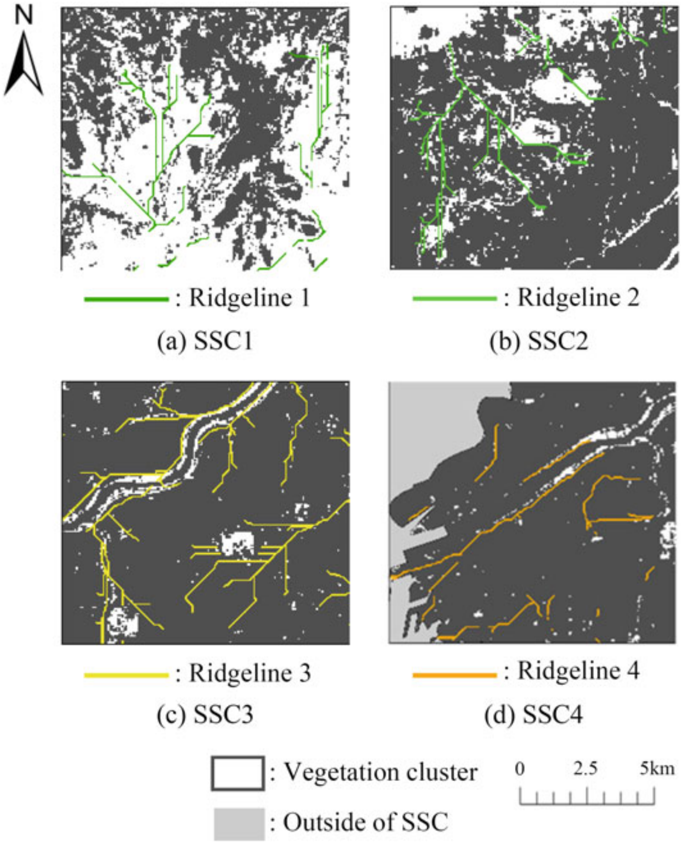


Fig. 9 Cumulative relative frequency *curves* of the size of vegetation clusters along the ridgelines



(a) SSC1

(b) SSC2

(c) SSC3

(d) SSC4

Fig. 10 Partial images of vegetation clusters with each ridgeline

It is shown that the ridgelines seem to be produced by distinct vegetation distribution types for each urban structure.

5.3 Comparison Between Landscape Factors with GWR

Advanced spatial analysis can be used to divide the area of interest into several regions and detect the spatial continuity of vegetation distributions for each urban structure type. Parks and open spaces around the ridgelines generated as the spatial continuity of vegetation distributions should be conserved for improving landscape issues. To avoid land deterioration around the core areas experiencing population decline in the near future, it is also desirable to be able to conduct a suitable changeover in land use: the substitution of parks and open spaces for vacancies. The changeover should contribute to the maintenance and improvement of the spatial continuity of vegetation distributions despite the limited number of strategies for land use changes regarding maintaining spatial continuity. If spatial continuity plays a role in ensuring a rise in value with respect to its surroundings, it will be a good motivating factor to encourage an appropriate changeover of land use. We therefore used a hedonic method with GWR to measure the relationship between the spatial continuity of vegetation distributions and land prices (Brunsdon et al. 1998; Harris et al. 2013; Mulley et al. 2016; Yoo et al. 2016; Hu et al. 2016).

As a basic approach to test the relationship with land prices, we applied GWR to geographical information including landscape factors such as the ridgelines, NDVI, and public parks. The specification of a basic GWR model is described as

$$y_i = \beta_0(u_i, v_i) + \sum_k \beta_k(u_i, v_i)x_{ik} + \varepsilon_i \tag{2}$$

where (u, v) is the vector of coordinates of the fit points in a two-dimensional space, $\beta_0(u_i, v_i)$ is the intercept value at point, i, and $\beta_k(u_i, v_i)$ is the coefficient of variable x_k at the same point i. β is estimated on the basis of Eq. (3):

$$\beta(u_i, v_i) = (X^t W_{(i)} X)^{-1} X^t W_{(i)} Y \tag{3}$$

where $W_{(i)}$ is a diagonal matrix defining the inverse distance weighting of the observations around the point i. The diagonal element, w_{ij}, of $W_{(i)}$ is denoted as

$$w_{ij} = \exp(-\left(\frac{d_{ij}}{\theta}\right)^2) \tag{4}$$

where d_{ij} is the distance between locations i and j, θ is the bandwidth.

1466 points where the assessed value of land was appraised were used as fit points. We made a logarithmic conversion of the land prices before the application of GWR.

We adopted the shortest distance from the ridgeline to the point as the factor of spatial continuity of vegetation distributions. The shortest distance to public parks was used as one of the factors of urban facilities. We also calculated the local average of NDVI within 2 km of the point as the local feature of vegetation distributions. We finally computed these landscape factors for each point.

Table 2 shows the variables that we applied to GWR and the combinations of the variables included in the model. The variables of Geographic Information (GI) are obtained from National Land Numerical Information provided by National Spatial Planning and Regional Policy Bureau, Ministry of Land, Infrastructure, Transport and Tourism. We basically used the variables of GI in all cases, which have been used in the land price model showing a better goodness of fit [Shimizu and Nishimura (2006)]. In cases 1, 2, and 3, we added one of the landscape factors to the other variables, respectively. The difference between these cases is the usage pattern of dummy variables dividing the landscape factors into several regions on

Table 2 Variables we applied to OLS and GWR

	Variables	Case 1			Case 2			Case 2			Case 4
		A	B	C	D	E	F	G	H	I	
GI	Acreage (m^2) Shortest distance to a railway station (m) Building coverage (%) Floor area ratio (%) Commercial area (dummy) Industrial area (dummy) Fire protection area (dummy) Gas supply (dummy) Sewerage (dummy)	(All variables of GI are applied in all cases)									
Landscape factors	Shortest distance to the ridgeline derived from SSC (m) Ridgelines 1, 2, 3, and 4	O			O			O			O
	Local average of NDVI		O			O			O		O
	Shortest distance to public parks (m) Woods, Small park, and Large park			O			O			O	O
Division of landscape factors	SSCs 1, 2, 3, and 4 (dummy)				O	O	O				O
	Land use zones:Residential, Commercial, and Industrial area (dummy)							O	O	O	

"O" in the table means the variable is applied to GWR the basis of the type of vegetation distributions and urban structures: SSCs and land use zones. Equation (1) is modified in cases 2 and 3 as

$$y_i = \beta_0(u_i, v_i) + \sum_m \beta_m(u_i, v_i)x_{im} + \sum_l \sum_n \gamma_n(u_i, v_i)\beta_l(u_i, v_i)x_{il} \tag{5}$$

where γ is one/zero dummy variable with respect to the variable l of the landscape factors: if the point i is within a region n, γ is one, otherwise it is zero.

The combination of variables in Case 4 contains all of the landscape factors. We examined the contributions of the landscape factors to land prices through using 3 kinds of factors simultaneously. Before the application of GWR, we examined the relationship between the variables by calculating the VIF. It has been confirmed that there is no multi-collinearity between the variables in Table 2.

Initially, we examined the validation of GWR using the statistics of F_1, F_2, and F_3 (Leung et al. 2000). The variables in case 4 are applied to both OLS and GWR for this examination. The small value of F_1 means that the GWR model has a better goodness of fit than the OLS model, while the large value of F_2 means that the GWR model and the OLS model do not describe the data equally well. The results show that $F_1 = 0.467$ (p value < 0.001), $F_2 = 5.715$ (p value < 0.001). F_3 is the test statistic F_k of the spatial differences among $\beta_k(u_i, v_i)$ $(i = 1, \ldots, 1466)$. The large value of F_3 means that not all $\beta_k(u_i, v_i)$ are equal. Table 3 shows the results of F_3. The p values, in 24 out of 30 variables, show significance. The validity of the GWR model thus is clarified in this study.

Table 4 indicates the results of GWR in cases 1, 2, and 3. The minimum of AIC, which is the basic measure of the relative quality of the models, is obtained in Case 2-F that the shortest distance of public parks is applied under the division of SSCs. Generally, a model can be considered better than another model if its AIC is at least 2 points lower. The average of AIC in Case 3 is more than that of AIC in Case 1 where the division of the landscape variables is not conducted. It is, however, shown that the average of AIC in Case 2 is less than in Case 1. It appears that dividing the landscape factors based on SSCs can contribute to make an appropriate model to explain land prices.

Table 5 shows the result of OLS in Case 4, indicating the global relationship between the independent and dependent variables. There are 20 variables corresponding to landscape factors. For 14 of them, the p value shows significance in this model. We can also see that the t values show positive and negative significance. It means that the direction (e.g. positive or negative) of an impact on land prices depends on the type of variables. Table 6 shows the result of GWR in Case 4. In Table 6, the proportions of t values of the variable for landscape factors are indicated on the basis of the significance level of 5%. In the variable of the shortest distance to public parks, the large park in SSC4 mostly provides a positive impact on nearby land prices (96.04%), while the small park in SSC4 almost gives a negative impact on nearby land prices (95.15%). The local averages of NDVI in SSC1, SSC2, and SSC3 show a negative impact on nearby land prices within the range of 59.68–68.10% even though there is no positive impact on all of the local

Table 3 Results of the test statistic of F_3 in case 4

Variables	F statistic	*p* value
Intercept	3.57466	<0.001***
Acreage (m^2)	3.65419	<0.001***
Shortest distance to a railway station [m]	10.84123	<0.001***
Building coverage (%)	2.41216	0.002**
Floor area ratio (%)	2.47179	<0.001***
Commercial area (dummy)	6.4446	<0.001***
Industrial area (dummy)	4.17232	<0.001***
Fire protection area (dummy)	4.40981	<0.001***
Gas supply (dummy)	2.62236	<0.001***
Sewerage (dummy)	14.05164	<0.001***
Shortest distance to the ridgeline derived from SSC (m)		
Ridgeline 1 in SSC1	2.69681	<0.001***
Ridgeline 2 in SSC2	0.5608	0.984
Ridgeline 3 in SSC3	2.08488	<0001***
Ridgeline 4 in SSC4	0.82044	0.630
Local average of NDVI		
NDVI in SSC1	2.96935	<0.001***
NDVI in SSC2	1.09484	0.273
NDVI in SSC3	2.24707	0.001**
NDVI in SSC4	2.03415	0.003**
Shortest distance to public parks (m)		
Woods in SSC1	1.9737	0.001**
Woods in SSC2	3.65156	<0.001***
Woods in SSC3	3.41129	<0.001***
Woods in SSC4	1.18919	0.287
Small park in SSC1	4.83792	<0.001***
Small park in SSC2	1.92616	<0.001***
Small park in SSC3	3.13509	<0.001***
Small park in SSC4	14.26964	<0.001***
Large park in SSC1	1.9665	<0.001***
Large park in SSC2	1.07236	0.315
Large park in SSC3	1.68034	<0.001***
Large park in SSC4	0.6672	0.855

***0–0.001%, **0.001–0.01%

Table 4 Results of GWR in cases 1, 2, and 3

	Case 1			Case 2			Case 3		
	A	B	C	D	E	F	G	H	I
R^2	0.850	0.861	0.880	0.861	0.870	0.905	0.850	0.854	0.866
AIC	680.7	570.7	385.7	578.3	486.5	101.1	688.9	648.3	540.9
Average of R^2	0.864			0.879			0.857		
Average of AIC	545.7			388.6			626.1		

Table 5 Results of OLS in Case 4

Variables	Estimate	Std. Error	t value	p value
Intercept	1.11E+01	1.22E−01	91.311	<0.001***
Acreage (m^2)	−5.53E−07	2.39E−06	−0.232	0.817
Shortest distance torn a railway station (m)	−8.96E−05	1.10E−05	−8.149	<0.001***
Building coverage (%)	−8.96E−03	1.68E−03	−5.327	<0.001***
Floor area ratio (%)	3.13E−03	1.18E−04	26.545	<0.001***
Commercial area (dummy)	6.20E−02	4.35E−02	1.424	0.155
Industrial area (dummy)	−2.45E−01	3.19E−02	−7.689	<0.001***
Fire protection area (dummy)	1.20E−0I	2.74E−02	4.394	<0.001***
Gas supply (dummy)	3.21E−01	4.48E−02	7.171	<0.001***
Sewerage (dummy)	4.34E−01	4.65E−02	9.333	<0.001***
Shortest distance to the ridgeline derived from SSC (m)				
Ridgeline 1 in SSC1	−8.90E−06	5.40E−05	−0.165	0.869
Ridgeline 2 in SSC2	6.28E−05	3.77E−05	1.663	0.096[a]
Ridgeline 3 in SSC3	−4.30E−05	1.68E−05	−2.562	0.010*
Ridgeline 4 in SSC4	2.26E−05	3.70E−05	0.61	0.542
Local average of NDVI				
NDVI in SSC1	−9.37E−01	1.58E−01	−5.914	<0.001***
NDVI in SSC2	−3.85E−01	1.04E−01	−3.704	<0.001***
NDVI in SSC3	−1.94E−01	7.66E−02	−2.532	0.011*
NDVI in SSC4	−6.56E−02	2.49E−0I	−0.264	0.792
Shortest distance to public parks (m)				
Woods in SSC1	−3.71E−06	2.82E−05	−0.132	0.895
Woods in SSC2	6.04E−05	167E−05	3.612	<0.001***
Woods in SSC3	5.31E−05	6.06E−06	8.763	<0.001***
Woods in SSC4	5.83E−05	1.39E−05	4.188	<0.001***
Small park in SSC1	−6.99E−05	3.39E−05	−2.064	0.039*
Small park in SSC2	−1.97E−04	4.51E−05	−4.37	<0.001***
Small park in SSC3	−2.61E−04	3.97E−05	−6.569	<0.001***
Small park in SSC4	−1.18E−04	6.62E−05	−1.778	0.076[a]
Large park in SSC1	2.81E−05	2.02E−05	1.387	0.166
Large park in SSC2	−8 31E−05	2.34E−05	−3.548	<0.001***
Large park in SSC3	−3.49E−05	1.42E−05	−2.468	0.014*
Large park in SSC4	−3.13E−05	2.87E−05	−1.092	0.275
R^2	0.7658			
AIC	1356.408			

***0–0.001%, **0.001–0.01%, *0.01–0.05%, [a]0.05–0.1%

averages of NDVI. It appears that the local averages of NDVI perform a general role in this model: usually, the land prices of urbanized areas including very few green spaces are relatively high, while the land prices of rural areas surrounded by large green spaces are relatively low. The local averages of NDVI therefore do not

Table 6 Results of GWR in Case 4. The proportions of t values of the variable in landscape factors are indicated on the basis of the significance level of 5%

	t > 1.960 (p(>t) = 0.025)	1.960 ≥ t ≥ −1.960	−1.960 > t (p(<t) = 0.025)
Shortest distance to the ridgeline derived from SSC (m)			
Ridgeline 1 in SSC1	0.00	98.59	1.41
Ridgeline 2 in SSC2	0.00	100.00	0.00
Ridgeline 3 in SSC3	0.00	20.95	79.05
Ridgeline 4 in SSC4	4.85	95.15	0.00
Local average of NDVI			
NDVI in SSC1	0.00	40.85	59.15
NDVI in SSC2	0.00	40.92	59.08
NDVI in SSC3	0.00	31.90	68.10
NDVI in SSC4	0.00	96.48	3.52
Shortest distance to public parks (m)			
Woods in SSC1	0.00	81.69	18.31
Woods in SSC2	2.64	91.42	5.94
Woods in SSC3	52.15	47.85	0.00
Woods in SSC4	5.29	94.71	0.00
Small park in SSC1	0.00	81.69	18.31
Small park in SSC2	0.00	42.24	57.76
Small park in SSC3	0.00	55.65	44.35
Small park in SSC4	95.15	4.41	0.44
Large park in SSC1	0.00	92.96	7.04
Large park in SSC2	0.00	92.74	7.26
Large park in SSC3	0.00	27.24	72.76
Large park in SSC4	0.00	3.96	96.04

(%)

seem to contribute to increasing the value of nearby land in this model. On the other hand, in the shortest distance to the ridgeline derived from SSC, the relative frequency with which the ridgeline 3 in SSC3 makes a positive impact on nearby land prices is 79.05%. SSCs and their ridgelines are derived from NDVI distributions; nevertheless, there is also no negative impact of the ridgelines 1, 2, and 3.

Figure 11 shows the spatial distribution of *t* values of the shortest distance to ridgeline 3 in SSC3. Warm color points mean that the *t* value of ridgeline 3 is above the significance level of 5%. In Fig. 11, it is obvious that warm color points are distributed along the ridgelines. There seems to be some relationship between the spatial continuity of vegetation distributions and land prices. The areas around the long ridgelines in SSC3 contain a diversity of green spaces: large green spaces around watercourses and an airport, agricultural fields, as well as large and small parks. There are also both residential areas and industrial areas caused by historical urban sprawl in these areas. The diversity around ridgeline 3 seems to increase the

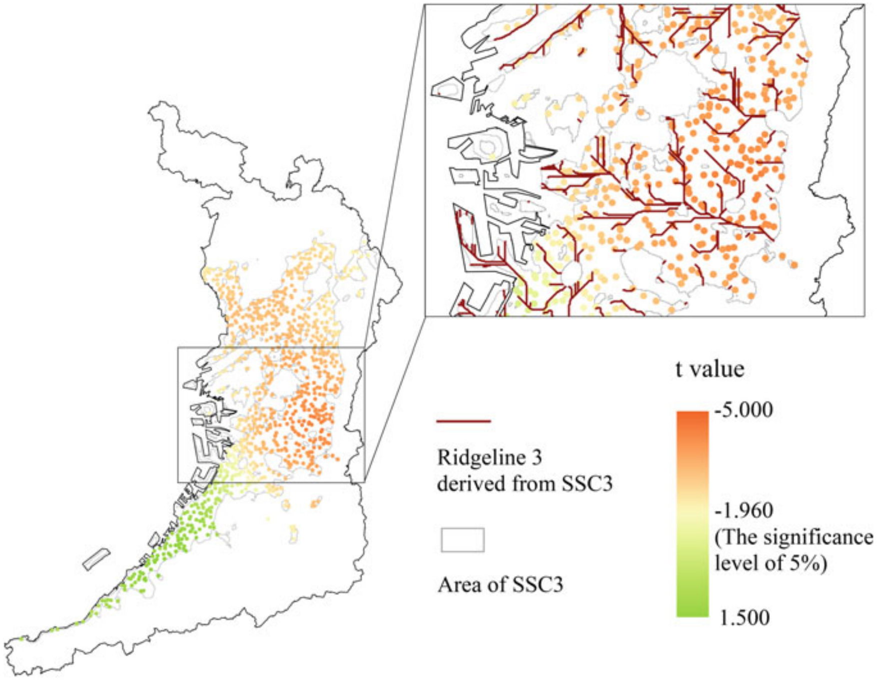


Fig. 11 Spatial distribution of t values of the shortest distance from the ridgeline 3 in SSC3

value of land because the scarcity value of land is created by the spatial continuity of the green spaces.

NDVI was applied to the spatial analysis discussed in this chapter. NDVI derived from Landsat data generally corresponds to vegetation cover ratio, so that the spatial analysis is not useful in determining the type of vegetation, but it is appropriate to support laying out the master plan of parks open spaces. It is desired that the master plan based on the results of the spatial analysis would be integrated into other plans with respect to urban development, zoning, building codes, and other urban issues.

6 Conclusions

In this study, we proposed an advanced procedure for detecting spatial continuity of vegetation distributions associated with the types of land use. We obtained 4 kinds of SSC and its ridgelines by applying the proposed method on NDVI derived from Landsat OLI data. The accuracy of the spatial continuity derived from the ridgelines was clarified according to several verifications with statistics of NDVI distributions. The generation of SSCs seemed to depend on land use structures: mountainous areas, rural areas, suburban areas, and completely urbanized areas. The size and density of vegetation clusters along the ridgelines were calculated in order to qualify the feature of spatial continuity. The differences in the structure of vegetation clusters were shown with relation to the ridgeline locations.

We also verified the relevance of the spatial continuity to land prices by using GWR. The goodness of fit of the model we used was the highest where SSCs were applied to the division of the landscape factors into several regions. It was confirmed that the local averages of NDVI did not contribute to an increase in the value of nearby land but one of the ridgelines seemed to make a positive impact on nearby land prices.

As a tool in planning support systems, the spatial analysis discussed in this chapter can currently detect potential areas that should be conserved with respect to vegetation distributions. In the near future, vacancies will increase around the core areas according to city shrinkage. The decision making about how to address these vacancy issues will be required. Improved spatial analysis is expected to play a pivotal role in suggesting potential areas that will enhance the current spatial continuity of vegetation distributions.

Acknowledgements The source data were downloaded from AIST's LandBrowser, (http://landbrowser.geogrid.org/landbrowser/index.html/). Landsat 7/8 data courtesy of the U.S. Geological Survey. We would like to thank Clémentine Cottineau for the valuable support, as well as the helpful comments from anonymous reviewers and the book editors.

References

Brunsdon, C., Fotheringham, A. S., & Chariton, M. (1998). Geographically weighted regression-modelling spatial non-stationarity. *The Statistician, 3*(47), 431–443.

Carroll, C., Noss, R. E., Paquet, P. C., & Schumaker, N. H. (2004). Extinction debt of protected areas in developing landscapes. *Conservation Biology, 18,* 1110–1120.

Derkzen, L. M., Teeffelen, J. A. A., & Verburg, H. P. (2017). Green infrastructure for urban climate adaptation: How do residents' views on climate impacts and green infrastructure shape adaptation preferences? *Landscape and Urban Planning, 157,* 106–130.

Getis, A., & Ord, J. K. (1992). The analysis of spatial association by use of distance Statistics. *Geographical Analysis, 24*(3), 189–206.

Harris, R., Dong, G., & Zhang, W. (2013). Using Contextualized geographically weighted regression to model the spatial heterogeneity of land prices in Beijing, China. *Transactions in GIS, 17*(6), 901–919.

Heckerta, M., Rosan, D. C. (2016). Developing a green infrastructure equity index to promote equity planning. *Urban Forestry & Urban Greening*, 19, 263–270.

Hu, S., Yang, S., Li, W., Zhang, C., & Xu, F. (2016). Spatially non-stationary relationships between urban residential land price and impact factors in Wuhan city, China. *Applied Geography, 68,* 48–56.

Kumagai, K. (2011). Verification of the analysis method for extracting the spatial continuity of the vegetation distribution on a regional scale. *Computers, Environment and Urban Systems, 35,* 399–407.

Leung, Y., Mei, C., & Zhang, W. X. (2000). Statistical tests for spatial nonstationarity based on the geographically weighted regression model. *Environment and Planning A, 2000*(32), 9–32.

Ministry of Land, Infrastructure, Transport and Tourism. (2014a). Promotion Promotion of Urban Renovation Renovation and Compact Compact Cities. http://www.mlit.go.jp/common/000996976.pdf. Accessed December 21, 2016.

Ministry of Land, Infrastructure, Transport and Tourism. (2014b). 2. Need for parks and green spaces. http://www.mlit.go.jp/common/000996960.pdf. Accessed December 21, 2016.

Mulley, C., Ma, L., Clifton, G., Yen, B., & Burke, M. (2016). Residential property value impacts of proximity to transport infrastructure: An investigation of bus rapid transit and heavy rail networks in Brisbane, Australia. *Journal of Transport Geography, 54,* 41–52.

National Institute of Population and Social Security Research. (2012). Population Projections for Japan (January 2012). http://www.ipss.go.jp/site-ad/index_english/esuikei/gh2401e.asp. Accessed December 21, 2016.

Ord, J. K., & Getis, A. (1995). Local spatial autocorrelation statistics: Distributional issues and an application. *Geographical Analysis, 27*(4), 286–306.

Palmisanoa, G. O., Govindanb, K., Loisi, R. V., Sasso, P. D., & Roma, R. (2016). Greenways for rural sustainable development: An integration between geographic information systems and group analytic hierarchy process. *Land Use Policy, 50,* 429–440.

Rogan, J., Wright, T. M., Cardille, J., Pearsall, H., Ogneva-Himmelberger, Y., Riemann, R., et al. (2016). Forest fragmentation in Massachusetts, USA: a town-level assessment using Morphological spatial pattern analysis and affinity propagation. *GIScience & Remote Sensing, 53*(4), 506–519.

Shimizu, C., & Nishimura, K. G. (2006). Biases in appraisal land price information: The case of Japan. *Journal of Property Investment and Finance, 26*(2), 150–175.

Tilman, D., May, R. M., Lehman, C. L., & Nowak, M. A. (1994). Habitat destruction and the extinction debt. *Nature, 371,* 65–66.

Yoo, J., & Ready, R. (2016). The impact of agricultural conservation easement on nearby house prices: Incorporating spatial autocorrelation and spatial heterogeneity. *Journal of Forest Economics, 25,* 78–79.

Chapter 27
Does Activity Fulfil Aspiration? A Contextual Comparison of Smart City Applications in Practice

Lisanne de Wijs, Patrick Witte, Daniel de Klerk and Stan Geertman

Abstract Research on smart city projects and applications has been increasing in recent years (Meijer and Bolivar 2015). The smart city concept is mostly considered from a technology-oriented perspective that stresses the use of data technologies, big data and ICT to 'smarten up' cities. In contrast, attention to soft aspects of the smart city—namely smart governance, people and social learning—seems to be limited in both academia and practice. Moreover, what seems to be largely missing from the literature is empirical insight into the extent to which different smart city aspects are factually known of and applied in different geographical contexts. This contribution presents a contextual comparison of smart city applications based on a mainly quantitative empirical analysis. Particular emphasis is put on the knowledge that government practitioners in the Netherlands have of smart aspects and the extent to which they are willing and able to implement smart aspects in their specific local and regional contexts. The results of the analysis show that both in the Netherlands and worldwide there are great aspirations to develop and implement smart city applications, but that to some extent factual activities are lagging behind. The reasons for this are mostly related to a lack of awareness of the possibilities and

---

L. de Wijs
Research Master Urban Studies, Graduate School of Social Sciences,
University of Amsterdam, Nieuwe Achtergracht 166, 1018, WV Amsterdam,
The Netherlands
e-mail: lisanne.dewijs@student.uva.nl

P. Witte (✉) · S. Geertman
Department of Human Geography and Planning, Faculty of Geosciences,
Utrecht University, Heidelberglaan 2, 3508, TC Utrecht, The Netherlands
e-mail: p.a.witte@uu.nl

S. Geertman
e-mail: s.c.m.geertman@uu.nl

D. de Klerk
VICREA Solutions, Vanadiumweg 11K, 3812, PX Amersfoort, The Netherlands
e-mail: d.deklerk@vicrea.nl

S. Geertman et al. (eds.), *Planning Support Science for Smarter Urban Futures*, Lecture Notes in Geoinformation and Cartography,
DOI 10.1007/978-3-319-57819-4_27

a lack of financial and political priority. This especially applies to smaller cities in the Netherlands. When this is resolved, actual activities are more likely to live up to the great aspirations regarding the smart city concept.

Keywords Smart city · Smart governance · Policy · Implementation · Contextualization

1 Introduction

Smart city initiatives continue to be implemented worldwide. In recent years, a wide variety of smart city aspirations have been realized and projects accomplished, either in the form of complete smart cities or by means of individual smart projects. Examples of the first form can be found in, for instance, China, where firms like IBM and Siemens have been involved in setting up several hundred complete smart cities, such as Yinchuan. Examples of the second form can be found in many places, such as Barcelona (Barcelona Digital City 2016), which has its own overall smart city framework composed of smaller projects, and Amsterdam (Amsterdam Smart City 2016), whose smart city platform is made up of a variety of smaller smart city projects and initiatives.

However, even though in practice there seems to be a lot happening in terms of smart city projects and applications, academic research into smart city projects, applications and the concept itself has been relatively scarce, although there has been more in recent years (see e.g., Meijer and Bolivar 2015). Furthermore, research into smart city developments has been mainly limited to conceptual research or to the empirical investigation of individual projects. What is lacking is empirical research that provides a more state-of-the-art overview of smart city developments. One of the very few examples of such research is provided by Neirotti et al. (2014), who present an empirically based worldwide overview of the geographic distribution of smart city developments. To complement this worldwide overview, we provide a more detailed but still empirically based overview of smart city developments in the Netherlands. We also provide some additional background insights. As such, in comparison to the Neirotti et al. (2014) paper, this chapter provides both a more detailed overview of a specific area (the Netherlands) and a more detailed insight into the background to differences with respect to smart city developments.

The chapter is structured as follows. The following section gives an extensive overview of existing literature on the smart city and its applications. First, special consideration is given to the smart city domains as identified by Giffinger et al. (2007) to be able to differentiate the smart city concept. Thereafter, based on Neirotti et al. (2014) we shed light on the outcomes of a worldwide comparison of smart city initiatives to see how the concept is geographically differentiated.

In addition, we elaborate on our own empirical research in the Netherlands related to smart city aspects. Subsequently, our results are contrasted with the outcomes of Neirotti et al. (2014). This contrast is used as a basis for an overall discussion and conclusion based on both the literature and the empirical results.

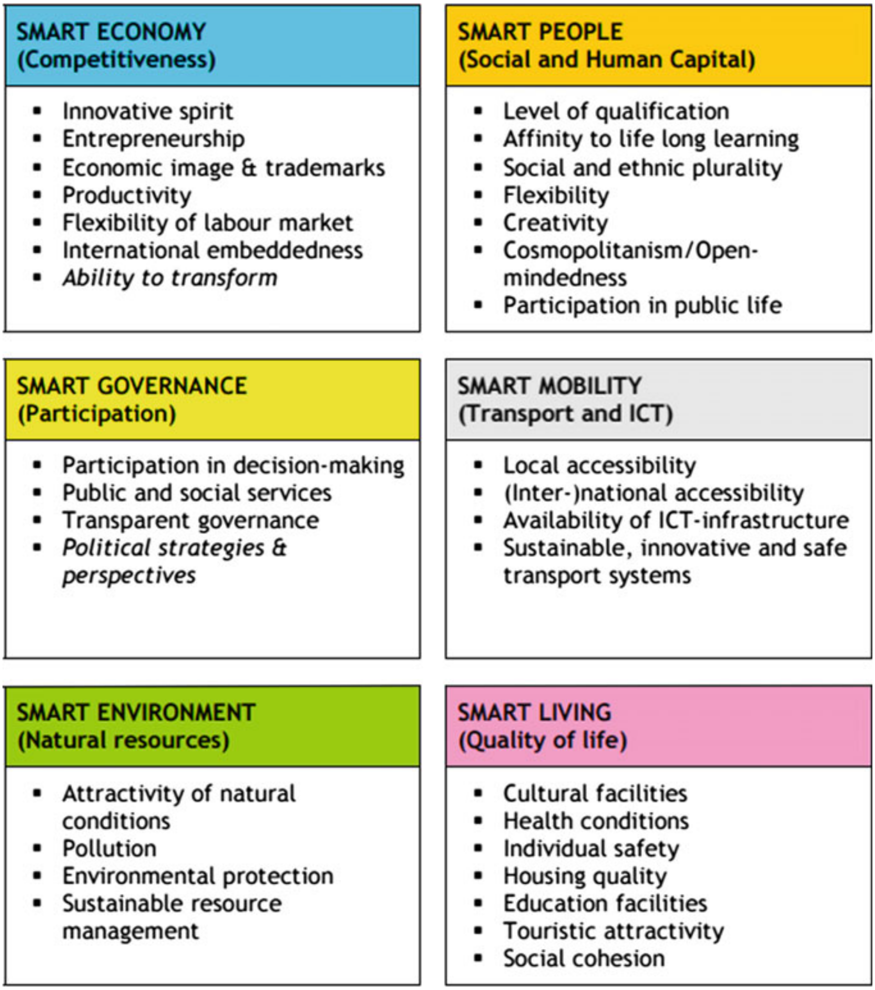
2 Smart City: Making Sense of a Fuzzy Concept

Smart city is a very timely and contemporary concept that seems to be becoming increasingly important for various stakeholder groups, such as businesses, governments and the wider public or civil society. There are many different descriptions and definitions of the smart city concept (e.g., Stimson and Pettit 2016). There is no universal consensus on its meaning and therefore it can be regarded as a fuzzy concept (see e.g., Batty et al. 2012; Caragliu et al. 2011; Lombardi et al. 2012; Papa et al. 2013). However, for the sake of clarity, and despite its fuzziness, in this chapter we adhere to the smart city definition given by Caragliu et al. (2011, p. 50) *"… when investments in human and social capital and traditional (transport) and modern (ICT) communication infrastructure fuel sustainable economic growth and a high quality of life, with a wise management of natural resources, through participatory governance."*

2.1 Smart City Domains: The Conceptual Picture

To shed more light on this fuzzy concept we turn to Giffinger et al. (2007), who in a report for the European Union conceptualized smart city into six domains, namely governance, economy, living, environment, people and mobility (see Fig. 1). Here, we briefly explain the main characteristics of each domain based on Giffinger et al. (2007) and associated literature.

- *Smart governance* is related to the policy aspect of the city, such as participation, e-governance and transparency of governments (Giffinger et al. 2007). Hollands (2008) stated that social integration with e-governance is the main characteristic of a smart city. A bottom-up approach plays an important role in smart governance. Governments can have a facilitating role or actively seek input from citizens and businesses and in that way be communicative towards the public (Chourabi et al. 2012). E-governance is also used internally, to improve existing public administrative processes (Tranos and Gertner 2012). Smart governance can bring about a change in norms and values towards smart city applications (Chourabi et al. 2012). Working more digitally and with increased transparency could require a change in the mind-set on the part of public administration.



SMART ECONOMY
(Competitiveness)

- Innovative spirit
- Entrepreneurship
- Economic image & trademarks
- Productivity
- Flexibility of labour market
- International embeddedness
- *Ability to transform*

SMART PEOPLE
(Social and Human Capital)

- Level of qualification
- Affinity to life long learning
- Social and ethnic plurality
- Flexibility
- Creativity
- Cosmopolitanism/Open-mindedness
- Participation in public life

SMART GOVERNANCE
(Participation)

- Participation in decision-making
- Public and social services
- Transparent governance
- *Political strategies & perspectives*

SMART MOBILITY
(Transport and ICT)

- Local accessibility
- (Inter-)national accessibility
- Availability of ICT-infrastructure
- Sustainable, innovative and safe transport systems

SMART ENVIRONMENT
(Natural resources)

- Attractivity of natural conditions
- Pollution
- Environmental protection
- Sustainable resource management

SMART LIVING
(Quality of life)

- Cultural facilities
- Health conditions
- Individual safety
- Housing quality
- Education facilities
- Touristic attractivity
- Social cohesion

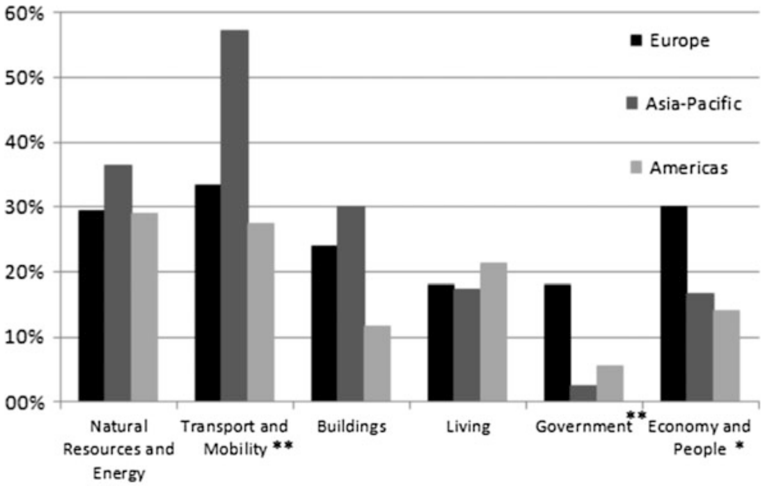
Fig. 1 Characteristics and factors of smart city (Giffinger et al. 2007)

- *Smart economy* asks for urban development that is mostly led by businesses, rather than by governments (Giffinger et al. 2007) Additionally, the availability of creative and innovative entrepreneurship is important. The general urge to be innovative is important, because innovation can improve a city's competitiveness (Tranos and Gertner 2012). Information networks and social and financial capital are important for a smart economy. Tranos and Gertner (2012) emphasized the importance of creative and innovative people in the city in stimulating urban economic growth.

- *Smart living* looks explicitly at the social aspect of smart cities in terms of quality of life. Themes within this domain include culture, health, safety, tourism, education and social cohesion (Giffinger et al. 2007). ICT could help improve the quality of life in a city by means of sensors that analyse certain aspects of quality of life. Smart living can be seen as a domain of contemporary urban issues, such as safety in the city, caring for a growing group of elderly, and so on.
- *Smart environment* is a domain that occurs in different processes and projects and mostly looks at ecological or physical sustainability that might be dependent on the existing conditions of a city (Tranos and Gertner 2012; Giffinger et al. 2007). Smart city policies seem to have a sustainable component and cities are focusing on decreasing negative environmental impacts such as pollution (Tranos and Gertner 2012). ICT and data could help resolve environmental issues, for example, through the use of sensors or sustainable technologies in the city, such as energy-saving streetlights.
- *Smart people* bears similarities with the domain of smart living, but smart people looks more at the individual in the city, rather than at society as a whole. Smart city also has a 'softer' side that focuses on knowledge and people's abilities (Hollands 2008). Smart people relates to human and social capital and looks at characteristics of society such as age, education, creativity and open-mindedness (Giffinger et al. 2007).
- *Smart mobility* is related to the combination of ICT and mobility. Smart mobility distinguishes between physical and digital infrastructure: the physical infrastructure consists of roads, train tracks, station areas, et cetera, and the digital infrastructure includes technologies and data (Frost and Sullivan, White Paper, n.d.). The intelligence of transport could be measured with the help of ICT infrastructure that is related directly to transport (Debnath et al. 2014). An example is traffic data gathered from sensors that are then used to adjust the maximum speed on a certain route.

2.2 Smart City Domains: Empirical Evidence at the Global Scale

Looking from an empirical perspective at these six smart city domains, it appears that there is hardly any empirical data that provide insight into their application. Neirotti et al. (2014), however, empirically researched current trends in smart city initiatives worldwide, which closely resemble the domains of Giffinger et al. (2007). They conducted an empirical analysis on a sample of 70 cities worldwide that claim to have developed projects and best practices in one or more of the smart city domains (see Fig. 2).



** = p-value < 0.01 in the ANOVA
* = p-value < 0.05 in the ANOVA

Fig. 2 Smart city development trends in three major world regions (Neirotti et al. 2014)

Although the categories in the research by Neirotti et al. (2014) only partly overlap the domains of Giffinger et al. (2007), a clear general picture can be distilled from this. First, it shows in general some similarity in focus on natural resources and energy, transport and mobility, and buildings. The other categories (living, government and economy and people) have received less attention. Besides this general picture, there are some significant differences across continents, in particular for transport and mobility, government, and economy and people. Asian cities have paid particular attention to the transport and mobility domain, and less to the government and economy and people domains. European cities have paid much more attention to the government domain than the other continents. Both North and South American cities have fewer smart city initiatives than their European and Asian counterparts.

Furthermore, Neirotti et al. (2014) stressed that the number of domains covered by smart city initiatives seems not to be correlated with the size of the city. This implies that both large and small cities are capable of showing innovation with regard to smart city implementation. This reinforces the need for more empirical scrutiny of the smart city concept in various geographical contexts and at different scale levels. Building on this, we are especially interested in how these results translate to a more detailed context like the one of the Netherlands. In the following section, we elaborate on the methodology applied and the results of this study.

3 Smart City in the Netherlands

Using the conceptual study by Giffinger et al. (2007) and the empirical study by Neirotti et al. (2014) as reference points, we looked in more detail at the spread of smart city developments in one specific country, namely the Netherlands. This is of interest given that the Netherlands is a relatively densely populated country with a variety of different-sized cities and a high degree of internet coverage.

The empirical data used for this chapter are derived from an empirical research project carried out by Utrecht University and Vicrea Solutions, a Dutch geo-IT company. In this explorative empirical research, the focus was on getting an overview of and a deeper insight into the smart city knowledge of government practitioners and the implementation of smart city applications in Dutch municipalities. The research project used a mix of qualitative and quantitative research methods, with a broad approach at the beginning and a more detailed one later on.

The quantitative data collection consisted of a survey to gather empirical data on smart city aspects and their implementation in Dutch municipalities. The survey questions were drawn from an extensive literature review (as summarized briefly in the previous section) and were focused on the six smart city domains of Giffinger et al. (2007). The questions asked were related to the municipalities' current implementations of smart city initiatives and to their future smart city aspirations. The questionnaires were filled in by 131 employees from 94 municipalities, which is about a quarter of all Dutch municipalities. The quantitative data were analysed in detail with the use of SPSS statistics software.

The qualitative part of the research consisted of in-depth interviews with stakeholders at six municipalities and two private companies. These semi-structured interviews focused on the knowledge that municipalities had of the smart city concept and explored whether there were practical examples of smart city applications in that municipality. The smart city domains discussed in the theoretical section were also discussed in-depth with the interviewees, using a topic list. However, the interviews mostly served as an open discussion platform to make sure that the interviewees could communicate their knowledge and ideas about the smart city concept. In the Netherlands, municipalities are seen as important actors that can stimulate and facilitate smart city initiatives. Interviews were conducted with four large municipalities (>50,000 inhabitants), one middle-sized one (20,001–50,000 inhabitants) and one small one (<20,000 inhabitants), according to the sizes that CBS Statistics Netherlands suggests (CBS 2015). In the following section, other categories are also used, because of the response on the quantitative survey and to create a better overview of the results. The interviews were transcribed, summarized and analysed. The analysis was used to support the interpretation of the quantitative data.

Since smart city can be seen as a fuzzy concept, both the interviews and the survey started off with a brief explanation of the smart city concept, based on academic literature. Furthermore, the survey was long and relatively complex because of its specific content, especially for some employees who might not have worked with the smart city before. As a result, not all respondents were able to complete the entire survey; thus the N-value varies per question. In the next section, we therefore report the N-value for each figure. Still, the results from a quarter of all Dutch municipalities in 2016 represent an interesting and informative overview of the state of the art of smart city applications and intentions in the Netherlands, which is outlined in the following section.

4 Smart City Domains in Dutch Municipalities: Unknown Is Unloved?

This section describes the most important results of the empirical research in the Dutch context. Quantitative data were analysed with the use of graphs. The qualitative data served to support or explain the numerical data.

4.1 Smart City Awareness

With regard to awareness, quite remarkably, almost half of the survey respondents had never heard of the smart city concept before and only a very few respondents had already worked with smart city applications or considered themselves specialists in this field (Fig. 3).

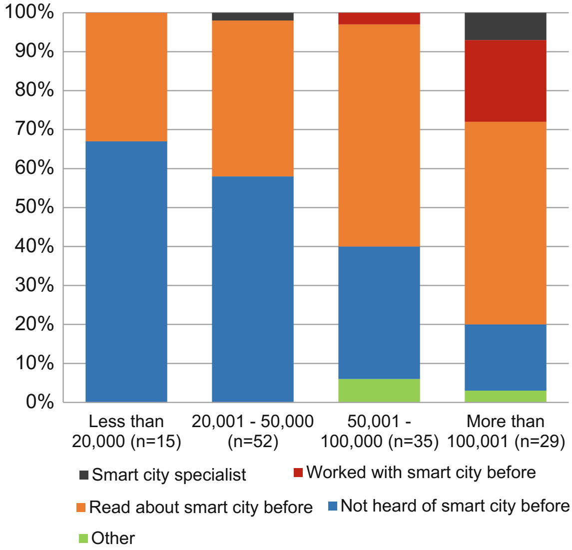


Fig. 3 Smart city awareness, by population size of municipalities (n = 131) (de Wijs 2015)

Fig. 4 Word cloud of the words most commonly used to describe smart city (de Wijs 2015, author's own translation)

When looking at municipal sizes, respondents in smaller municipalities were less often aware of the smart city concept in comparison to respondents from larger municipalities. At first sight this seems to contradict the evidence of Neirotti et al. (2014), who found that size or density is not necessarily correlated with the implementation of smart city aspects. The remarkable lack of awareness in the smallest municipalities leads to the suggestion that the size of cities or municipalities still needs to exceed a certain threshold level before awareness starts to increase significantly. In this study it could also have to do with the specific job description of the respondents. This all needs to be further tested.

Because of the fuzziness of the smart city concept, the survey asked respondents to name a maximum of three characteristics of the smart city concept. In Fig. 4, the terms most commonly used to describe the concept are in the largest fonts. The results suggest that most respondents think smart city is mainly about data, digital infrastructure, ICT, the city and, for example, the environment, mobility and efficiency. The qualitative analysis produced a similar result. The associations that respondents expressed concerning the smart city concept were in close accordance with the academic literature on the concept, which also has a predominant orientation towards ICT-related aspects. Still, when looking at the variety of academic literature and the number of smart city projects, we expected more respondents to be familiar with the smart city concept.

4.2 Aspirations for and Factual Application of Smart City Concepts

In a lot of Dutch municipalities, application of the smart city concept is still in its infancy. Respondents mostly rated their current application of the smart city concept as just sufficient or even insufficient. Interviewees mentioned that the application of smart technologies could be improved and that projects were just starting up. The importance of experimenting was addressed in the qualitative research.

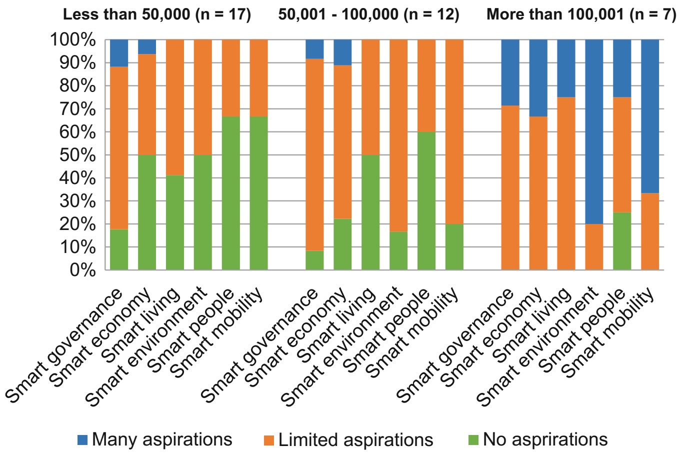


Fig. 5 Level of aspiration related to smart city domains, by population size of cities (n = 36) (de Wijs 2015)

Experimenting through, for instance, urban living labs could help municipalities to find the smart applications that are most suitable for them.

Due to the limited number of factual smart city applications in Dutch municipalities, it was not possible to directly compare the outcomes of the worldwide research by Neirotti et al. (2014) with our own results (de Wijs 2015). Instead, we took the differential aspirations related to the smart city domains identified by the Dutch municipalities to reflect their expected applications of the smart city concept (see Fig. 5).

As stated, in general the larger Dutch cities expressed more explicit smart city aspirations than the smaller towns. When divided along the domains of Giffinger et al. (2007), the smart governance aspects in Dutch municipalities seem to be more advanced than in the worldwide smart city applications described by Neirotti et al. (2014). This could possibly be explained by the relatively open and participatory nature of Dutch planning processes. Respondents emphasized the importance of internal and external efficiency in smart governance. The word cloud (Fig. 4) already showed the importance of efficiency and governance, as well as of social media, which are used by many municipalities for smart governance. Open data also play a crucial role in this.

When looking at the domains of smart people and smart living, there certainly are aspirations to, for example, improve social cohesion, although these aspirations are still limited, which is what Neirotti et al. (2014) also found. Furthermore, they seem to be not very explicit and the use of data and technology within these domains seems to be rather limited. About two thirds of the respondents indicated that these aspirations to bring about smart living are limited by, for example, a lack of political priority and a lack of finances. Furthermore, the research showed that for this domain, the links with ICT are still unclear. Municipalities are working on improving cohesion, but are not using technologies for this. In addition, more than half of the respondents said that they feel that privacy issues could have a limiting role when it comes to smart people applications, whereas a small group of respondents stated that privacy issues will probably decrease over time. Because there are only a few smart city applications, it is hard to establish whether and, if so, in what way citizens are open to these technologies and whether they are using them yet.

Smart economy seems to take a middle position in the smart city domains, both in the Dutch aspirations (de Wijs 2015) and in the worldwide smart city applications described by Neirotti et al. (2014). Municipalities stated that there are aspirations to realize a smart economy, especially because there is a demand from citizens and businesses to expand on this and because private actors can get started with this domain. Examples of smart economy are the openness of the municipality to economic innovation and the presence of creative and innovative businesses in the area. When a municipality has relatively little aspiration to realize a smart economy, this is something that businesses could work on.

Smart environment seems to be a domain with a lot of aspirations, which can also be read from the outcomes of the worldwide survey by Neirotti et al. (2014). The respondents stated that sustainability is always incorporated in policy and smart city projects, although according to Dutch respondents the link between this domain and ICT seems limited and we currently cannot speak of 'smart' sustainability everywhere.

Finally, the domain of smart mobility could be seen as a trans-boundary domain that goes beyond municipal jurisdictions. Aspirations to realize smart mobility are quite substantial, as are those concerning the environment. Examples found in the domain of smart mobility are the collection of traffic sensor data and smart parking systems, but these are not in place yet in every municipality.

These conclusions concerning the aspirations per domain seem to be in accordance with those found by Neirotti et al. (2014). The majority of respondents stated that they would like their municipality to become 'smarter' as a whole in the future. It seems that aspirations related to the environment and mobility corresponds to the smart city applications worldwide described by Neirotti et al. (2014).

5 Conclusion

This chapter focused on the current and widespread attention paid to smart city projects and applications. Although a dominant worldwide model for implementing the smart city seems a bridge too far, in this relative early stage of development it is interesting to see in what sense the different domains of smart city are actually realized. Until now, however, comparative empirical research on smart city implementation is very limited. Therefore, we executed empirical research in the Netherlands and compared its outcomes to the only other quantitative empirical study on smart city applications that we are aware of (i.e., Neirotti et al. 2014).

In that, we hope to shed more light on the priorities in the implementation and application of smart city domains and in the geographical commonalities and differences.

One of the most striking findings is that especially in the smaller-sized Dutch cities and municipalities the majority of our respondents (municipal employees) had never heard of the smart city concept, indicating only a limited awareness of the concept in Dutch policy practice. This was somewhat unexpected, given the widespread attention to the smart city concept in academia, business and public administration in many parts of the world (cf. Neirotti et al. 2014). This also seems to contradict the earlier findings of Neirotti et al. (2014) that city size or density is largely uncorrelated with the possibility of implementing smart city innovations. Our data suggest that a certain threshold in terms of the size of a city's population is still needed to significantly increase the awareness and implementation of smart city ideas.

We also found some interesting and important similarities and differences between our data concerning Dutch municipalities and the earlier worldwide empirical work of Neirotti et al. (2014). Similar to their findings, also in the Netherlands we found clear aspirations to develop and implement smart city applications, at least within the bigger cities. However, implementation of in particular the governance-related smart city applications seem to lag behind what we would expect. Reasons for this mostly relate to a lack of awareness, a lack of political and financial prioritization, and data security issues. There seems to be a gap between aspirations and implementation, which respondents suggested could be reduced by means of experiments and pilot projects. In addition, Dutch municipalities do seem to have the same aspirations in the domains of environment and mobility that Neirotti et al. (2014) identified in worldwide smart city applications.

This empirical research adds to the limited research data on smart city applications. It would be desirable to see more extensive comparative empirical smart city overview studies in order to compare countries in their smart city aspirations relative to their factual activities and to help them position themselves in this respect. Furthermore, additional empirical research will help academics to understand the smart city concept and its application and implementation more thoroughly and help countries that lag behind to catch up with these developments.

References

Amsterdam Smart City. (2016). http://amsterdamsmartcity.com/. Accessed online May 2016.

Barcelona Digital City. (2016). http://ajuntament.barcelona.cat/estrategiadigital/ca. Accessed online November 28, 2016.

Batty, M., Axhausen, K., Fosca, G., Pozdnoukhov, A., Bazzani, A., Wachowicz, M., et al. (2012). Smart cities of the future. *UCL Centre for Advanced Spatial Analysis, Paper, 188,* 1–40.

Caragliu, A., Del Bo, C., & Nijkamp, P. (2011). Smart cities in Europe. *Journal of Urban Technology, 18*(2), 65–82.

CBS Statistics Netherlands (Centraal Bureau voor de Statistiek). (2015). *408 Nederlandse gemeenten in 2013*. http://www.cbs.nl/nl-NL/menu/themas/dossiers/nederlandregionaal/publicaties/artikelen/archief/2013/2013–3753-wm.htm). Accessed online February 3, 2015.

Chourabi, H., Nam, T., Walker, S., Gil-Garcia, J., Mellouli, S., Nahon, K., et al. (2012). Understanding smart cities: An integrative framework. In *Proceedings of 2012 45th Hawaii International Conference on System Sciences IEEE* (pp. 2289–2297).

de Wijs, L. (2015). *Smart City toepassingen in Nederland; Een studie naar bekendheid met het concept Smart City en het gebruik van Smart City toepassingen in Nederlandse gemeenten*. Amersfoort: Vicrea Solutions: Amersfoort.

Debnath, A., Chin, H., Haque, M., & Yuen, B. (2014). A methodological framework for benchmarking smart transport cities. *Cities, 37,* 47–56.

Frost & Sullivan White Paper. (n.d.). A smarter transportation system for the 21st century. *IBM White Paper*. http://www-01.ibm.com/common/ssi/cgi-bin/ssialias?infotype=SA&subtype=WH&appname=SNDE_TT_TT_USEN&htmlfid=TTW03004USEN&attachment=TTW03004USEN.PDF. Accessed online February 23, 2017.

Giffinger, R., Fertner, C., Kramar, H., Kalasek, R., Pichler-Milanovic, N., & Meijers, E. (2007). *Smart cities—Ranking of European medium-sized cities*. Vienna: Vienna University of Technology.

Hollands, R. (2008). Will the real smart city please stand up? *City, 12*(3), 303–320.

Lombardi, P., Giordano, S., Farouh, H., & Yousef, W. (2012). Modelling the smart city performance. *Innovation: The European Journal of Social Science Research, 25*(2), 137–149.

Meijer, A., & Bolivar, M. (2015). Governing the smart city: A review of the literature on smart urban governance. *International Review of Administrative Sciences*, 1–17.

Neirotti, P., deMarco, A., Corinna Cagliano, A., Mangano, G., & Scorrano, F. (2014). Current trends in smart city initiatives: Some stylised facts. *Cities, 38,* 25–36.

Papa, R., Gargiulo, C., & Galderisi, A. (2013). Towards an urban planners' perspective on smart city. *Journal of Land Use, Mobility and Environment, 1,* 5–17.

Stimson, R., & Pettit, C. (2016, May 8–10). *Smart cities, big data: An overview*. Paper Presented at the IGU Applied Geography Commission Workshop. Rhodes Island, Greece.

Tranos, E., & Gertner, D. (2012). Smart networked cities? *Innovation: The European Journal of Social Science Research, 25*(2), 175–190.

Index

S. Geertman et al. (eds.), *Planning Support Science for Smarter Urban Futures*, Lecture Notes in Geoinformation and Cartography,
DOI 10.1007/978-3-319-57819-4