THE VALUE AND USE OF URBAN HEALTH INDICATOR TOOLS IN THE COMPLEX URBAN PLANNING POLICY AND DECISION-MAKING CONTEXT

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PHD THESIS

I, Helen Pineo, confirm that the work presented in this thesis is my own.
Where information has been derived from other sources I confirm
that this has been indicated in the thesis.

Signed ____

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Abstract

Urban health indicator (UHI) tools are promoted as an evidence-based form of information to influence urban planning policy and decision-making. However, there is a lack of research on their value and use. Indicator producers, often from health fields, tend to have a linear and rational view of indicator use and policy-making that is starkly contrasted by urban policy scholars who see these processes as complex and socially constructed. It is therefore unclear how UHI tools might function within the complex planning policy and decision-making process to promote health considerations.

This mixed-methods research investigates the use and value of UHI tools using collaborative rationality and systems theories. A two-part systematic review included a census of 145 UHI tools and a narrative synthesis of 10 qualitative studies on the use of UHI tools. The results were used to develop a taxonomy of UHI tools and theory of change. A series of 22 semi-structured interviews were conducted with indicator producers and users in San Francisco, Melbourne and Sydney. These data were analysed using thematic analysis and systems thinking approaches to produce causal loop diagrams (CLD) of participants' mental models. The CLDs were tested and improved in a participatory modelling workshop.

Indicator users and producers had significant overlap in their mental models. The development and application of UHI tools increased inter-sectoral relationships which supported actors to better understand each other's opportunities and constraints for health promotion. Relationships helped to create new advocates for health in diverse organisations, supporting health in all policies or whole-of-society approaches to health promotion. Community involvement in UHI tools and the effectiveness of advocates helped to challenge constraints to health-promoting policy development and implementation. However, the high number of new indicators being created can create confusion and reduce indicator use, particularly when they are not designed to meet users' needs.

Impact Statement

This research on the use of UHI tools has value for researchers and practitioners in the fields of urban planning, public health and knowledge translation. The researcher has already disseminated findings to inform policy, research and commercial activity in the United States (US), Australia and the United Kingdom (UK). The research has been disseminated through two peer-reviewed journal publications, book chapters, industry reports, two academic conferences, and two invited presentations (see Thesis Associated Publications).

The research impact outside academe relates to policy-makers (and others) who use UHI tools. Initial dissemination occurred through presentation of early systematic review findings at a House of Commons roundtable on ‘A cross-sector approach to creating healthy cities – delivering quality housing in post-Brexit Britain’ in 2016. The review findings were also shared with NHS England staff administering the NHS Healthy New Towns Programme to inform their indicator development. The researcher used PhD findings to help Southwark Council’s planning and public health department develop policy and monitoring indicators about health and place. An output publication from this work (Pineo, 2017) was awarded a Royal Town Planning Institute (RTPI) Research Excellence 2018 Award. Early findings from the research were published in BRE Trust reports and informed development of the BRE Healthy Cities Index (see Pineo et al., 2018b).

The research impact inside academe relates to knowledge and methods contributions, supporting teaching and informing the production of new UHI tools. The findings contribute new knowledge to academic disciplines including urban planning (and policy studies), public health and knowledge translation (see section 1.7.1). The research applied a systems thinking approach to model practitioners’ mental model of UHI tool use for the first time (to the researcher’s knowledge). Future research can investigate the value of this model as a representation of wider cases. The research has contributed to methods development through the application of a mixed-methods sequential explanatory systematic review and the use of thematic analysis to code interview data for qualitative system dynamics model development (see section 1.7.2). Data from the systematic review have been used by researchers evaluating UHI tools in low- and middle-income settings, and their findings have been submitted to a peer-reviewed journal (Thompson et al., 2019). The research findings have informed lectures on University College London (UCL) master's programmes in the Institute of Environmental Design and Engineering (IEDE) and Department of Science, Technology, Engineering and Public Policy (STEaPP).

The impact of this research for indicator producers (who are often academic researchers) could alter how indicators are developed and applied. The findings show that in the case studies, UHI tools influenced policy and decision-making through relationships, advocacy, ability to challenge 'business as usual' approaches and re-framing stakeholder knowledge. Therefore, traditional models of knowledge translation and indicator use are challenged by this research. The implication for indicator producers who seek to influence policy and decision-making is that they should consider how they might co-produce UHI tools with a wide range of stakeholders and continue working with these actors over time to further apply the indicators.

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Acronyms and Abbreviations

ASSIA	Applied Social Sciences Index and Abstracts
AU	Australia
B	Box
BE	Built environment
BRE	Building Research Establishment
BRN	Building relationships and networks
BSEER	Bartlett School of Energy, Environment and Resources
CAQDAS	Computer-aided qualitative data analysis software
CDC	Centers for Disease Control and Prevention
CIV	Community Indicators Victoria
CLD	Causal loop diagram
CSDH	Commission on the Social Determinants of Health
DES	UHI tool design and use strategies
DIAD	Diversity, interdependence and authentic dialogue
DPSEEA	Driving force, Pressure, State, Exposure, Effect and Action
ECON	Economic constraints and opportunities
EIA	Environmental Impact Assessment
EU	European Union
FAIL	Reasons that UHI tools fail (or how to avoid)
Gov.	Government
HEADLAMP	Health and Environment Analysis for Decision-making
HiAP	Health in All Policies
IEDE	Institute of Environmental Design and Engineering
LET	Legal and technical constraints and opportunities

MeSH	Medical Subject Headings
MOV	Motivation and value
MPhil	Master of Philosophy
NBHD	Neighbourhood
NIMBY	Not in my backyard
NHS	National Health Service
NICE	National Institute for Health and Care Excellence
NGO	Non-governmental organisations
No.	Number
NORM	Professional norms, knowledge, values, ways of working and remit
OECD	Organization for Economic Cooperation and Development
PAHO	Pan American Health Organization
PhD	Doctor of Philosophy
POINT	Policy Influence of Indicators
POL	Political constraints and opportunities
PRISMA-P	Preferred Reporting Items for Systematic review and Meta-Analysis Protocols
QUAL	Qualitative
QUAN	Quantitative
RKU	Re-framing knowledge and understanding
RTPI	Royal Town Planning Institute
RQ	Research question
SCU	Science Communication Unit
SDG	Sustainable Development Goal
SEA	Strategic Environmental Assessment
SFIP	San Francisco Indicators Project

STEaPP	Department of Science, Technology, Engineering and Public Policy
ToC	Theory of change
UCL	University College London
UH	Urban health
UHI	Urban health indicator
UK	United Kingdom
Uni.	University
US	United States
UV	Ultraviolet
WHO	World Health Organization

Thesis Associated Publications

Peer reviewed journal papers

Pineo, H., Glonti, K., Rutter, H., Zimmermann, N., Wilkinson, P., Davies, M. (2019) Use of urban health indicator tools by built environment policy and decision-makers: a systematic review narrative synthesis. Manuscript submitted.

Pineo, H., Glonti, K., Rutter, H., Zimmermann, N., Wilkinson, P., Davies, M. (2018a) Urban Health Indicator Tools of the Physical Environment: a Systematic Review. *Journal of Urban Health*. 95(5), 613–646.

Pineo, H., Zimmermann, N., Cosgrave, E., Aldridge, R.W., Acuto, M., Rutter, H. (2018b) Promoting a healthy cities agenda through indicators: development of a global urban environment and health index. *Cities & Health.* 2(1), 27–45.

Pineo, H., Glonti, K., Rutter, H., Zimmermann, N., Wilkinson, P., Davies, M. (2017a). Characteristics and use of urban health indicator tools by municipal built environment policy and decision-makers: a systematic review protocol. *Systematic Reviews.* 6, 1–6.

Conference presentations

Pineo, H., Glonti, K., Rutter, H., Zimmermann, N., Wilkinson, P., Davies, M. (2017b) Census, characteristics, and taxonomy of urban health indicator tools: a systematic review. UK Lancet Public Health Science Conference. November 24, 2017; London. *The Lancet*. 390, S70.

Pineo H, Zimmermann N, Wilkinson P, Davies M. (2016) Measuring environmental determinants of health: a review of complexity in benchmarking systems. *International Conference on Urban Health, 4 April, San Francisco*, *USA*.

Other invited presentations on this research

Presentation to Planning Institute of Australia event ‘Planning for Liveability & Healthy Outcomes with visiting UK planner Helen Pineo’; March 14, 2018. Melbourne.

Presentation to University of New South Wales, People and Place Cluster Seminar entitled ‘Urban Health Indicators – Just how useful are they in creating healthy cities?’; March 22, 2018. Sydney.

Other publications incorporating research findings

Pineo, H., Zimmermann, N., Davies, M. (2019) Leveraging the urban planning system to shape healthy cities, in: Galea, S., Vlahov, D. (Eds.) *Urban Health*. Oxford University Press.

Pineo, H., Rydin, Y., (2018) *Cities, health and well-being*. London, Royal Institution of Chartered Surveyors.

Pineo H, Bevan S, Ruck A, McNab D, Deidda C. (2018) Translating community perceptions of health and place into local planning policy and monitoring frameworks. *Salus*. Available from: http://www.salus.global/article-show/translating-community-perceptions-of-health-and-place-into-local-planning-policy-and-monitoring-frameworks-1.

Pineo, H. (2017) Healthy Planning and Regeneration: innovations in community engagement, policy and monitoring. Watford, Building Research Establishment. *Awarded an RTPI Research Excellence 2018 Award.*

CHAPTER 1

Introduction to urban health indicator use in urban planning

1.1 Introduction

Despite claims that many indicator reports do not inform policy-making (Innes and Booher, 2000), academics, thinktanks and governments continue to produce them with the aim of influencing policy-makers, potentially wasting valuable time and resources. This thesis investigates whether urban health indicators suffer the same fate as sustainability indicators in failing to inform policy (Pastille Consortium, 2002; Sébastien et al., 2014) focusing specifically on the urban planning policy domain. This chapter provides an introduction to the thesis, outlining the basis for this research and the overarching aims and objectives. The research approach is briefly outlined and the originality and new knowledge from the research are summarised. Finally, the thesis structure is explained to aid readers in navigating the document.

1.2 Basis for research

Indicators are succinct measures of complex phenomena that since the early 1970s, have been proposed as an accessible form of scientific evidence to influence planning policy and decision-making (Smith, 1973) on topics such as sustainability, liveability and quality of life. Researchers, think tanks and other experts have identified indicators as a tool to insert their evidence or worldview into policy discourses (Pastille Consortium, 2002; Sébastien et al., 2014). A prime example is the World Health Organization's (WHO) Healthy Cities movement which required cities to report on healthy city indicators to influence cross-sector urban policy, including built environment domains such as planning, housing and transport (Webster and Sanderson, 2013). However, those organisations which produce indicators are often criticised for misunderstanding policy processes, and indicators' role within these, as rational and linear (Innes and Booher, 2000; Pastille Consortium, 2002; Sébastien et al., 2014). There are continued calls from policy practitioners and researchers for more, better or different indicators (see Giles-Corti et al., 2016; Select Committee on National Policy for the Built Environment, 2016); yet little evidence that they are used to influence policy-makers, including in the areas of health and urban planning. Thus there is a need for research about the use of urban health indicators and their potential value in promoting health through the complex urban planning policy and decision-making process.

There are diverse understandings of how policy-making occurs and where evidence, including in the form of indicators, fits in this process. Urban planning largely abandoned a rational policy approach in the 1980s following criticisms that technical and quantitative models of development ignored the needs of some communities, leading to planning's *communicative turn* which viewed knowledge as socially constructed (Healey, 1997; Bolan, 2017). Rationality in planning refers to 'instrumental use of objective information to produce desired outcomes' using 'specifiable rules for decisions by individuals' (Innes, 2004, p.52). More generally, policy-making and evidence use are still understood by many to be linear staged processes moving from analysis to decisions, despite decades of evidence to the contrary (Weiss, 1998; Cairney, 2012a). In some fields, including health, researchers' misconception of policy-making informs their expectation that policy-makers will use research outputs in a similar manner to evidence-based medicine (Cairney and Oliver, 2017). There are multiple challenges to this rational linear view of evidence use in the policy and decision-making process, including: different interpretations of what constitutes evidence (Lorenc et al., 2014) and which types would be prioritised (i.e. through a hierarchy of evidence) (Cairney and Oliver, 2017); the influence of competing demands, political pressures, time limits, and resource constraints (Ingold and Monaghan, 2016); and difficulty accessing research outputs and interpreting equivocal results (McGill et al., 2015). Despite this unclear picture of how evidence informs policy, there has been very little research on the use of indicators by policy and decision-makers; with most of the indicator literature focusing on their development and validation (Innes and Booher, 2000; Pastille Consortium, 2002; Wong, 2006; Sébastien et al., 2014). It is unclear whether indicators may have the same difficulty informing policy as other types of research evidence.

The use of urban health indicators in urban planning practice represents an example of health professionals seeking to promote health in non-health policy fields; an activity known as health promotion, health in all policies, or a whole-of-government approach. Recognition that 23 percent of global deaths can be attributed to the environment (Prüss-Üstün et al., 2016) demonstrates the need for inclusion of health in built environment policies. Although the concept of health promotion has been present since the 1970s (Lalonde, 1974), this type of policy advocacy remains a small part of public health activities and budgets (Hancock, 2011). One route that public health professionals have sought to influence urban planning is through provision of evidence about local health needs and the health impact of the urban environment in the form of indicators and data. As previously mentioned, this was heavily promoted through the WHO Healthy Cities Movement (Breuer, 1998). Urban health indicators continue to be proposed as a valuable resource to inform planning policy and monitor impact, among other functions (Corburn and Cohen, 2012; Bhatia, 2014; Giles-Corti et al., 2016). Yet planning policy researchers have critiqued the potential for indicators to influence planning policy and decision-making (Innes and Booher, 2000; Pastille Consortium, 2002; Sébastien et al., 2014; Decoville, 2018). They argue that indicators as a technical rational tool do not, or cannot, simply be inserted into the complex and social urban planning context. Despite these criticisms, there are examples where indicators are claimed to have influenced planning policy and decision-making (Bhatia, 2014; Wong, 2006). There are two significant challenges inherent in understanding the potential role of UHI tools in city planning characterised by 1) opposing conceptualisations of indicators and their use and 2) the complexity of urban health and the policy/decision-making process.

First, there are divergent perspectives in the literature about the nature of indicators and their role in the policy process. Lawrence (2008) claimed that without indicators, professionals and politicians would struggle with 'identifying, describing, measuring, and explaining constancy, change, ruptures, and disparities in the condition and in the development of human settlements' (p.301). Thus, he observed a 'growing reliance on indicators' to inform policy-making (ibid), essentially adopting the rational evidence-based policy approach. Yet Innes and Booher (2000) suggested that it is not indicators themselves which inform policy, but the process of developing and agreeing indicators with multiple stakeholders. These views are characterised by seemingly opposing epistemological positions, positivism and constructivism. Different researchers conceptualise indicators as either A) rational technical tools in a linear policy and decision-making process (Briggs et al., 1996) or B) a social construct which is defined and interpreted according to local negotiation and context (Pastille Consortium, 2002). These opposing views of the nature of indicators and their function in the policy process pose a challenge for indicator producers and those investigating their utility. Such views of how UHI tools inform policy and decision-making could be described as mental models. Mental models represent the 'psychological core of understanding' of a phenomenon (Johnson-Laird, 1983, p.81).

Second, complexity is a challenge for both indicator developers and users and it is manifest in multiple interrelated ways. Complex systems are characterised as interconnected, dynamic, non-linear, adaptive and governed by feedback, among other features (Sterman, 2006, p.507). The factors within urban environments that influence health and the policy systems that address these factors are characterised by complexity in several ways. First, the complexity of the urban health system makes it difficult to develop indicators which accurately represent this system. Indicators have been described as both a means of simplifying complexity (Holden, 2001; Saisana and Tarantola, 2002) and masking complexity (Rothenberg et al., 2015; Decoville, 2018). Second, the complexity of the urban health system reduces clarity about the potential effectiveness of specific policy options. Traditional epidemiological research methods have not been effective at separating out cause and effect in this system (Northridge et al., 2003; Galea and Vlahov, 2005; Rydin et al., 2012), although Naimi (2016) rejects assertions that the limitations of epidemiological methods prevent investigation of complex systems. It is difficult to anticipate what effect particular interventions may have over time and space (Rydin et al., 2012). Third, the complexity of the urban planning and decision-making process raises question about when and how indicators can function measure impact (Rae and Wong, 2012) and improve health. These complexity challenges require further investigation to understand the potential for indicators to promote health through urban planning.

The above arguments demonstrate that there are several research gaps in relation to the use of indicators in policy and decision-making. These are summarised as:

- Most indicator research has focused on the development and validation of indicators rather than their use by policy and decision-makers.
- Models of indicator/evidence use in policy have been depicted predominantly as linear, despite growing understanding that policy-making is a complex process.
- A model is lacking which depicts how UHI tools inform the complex policy and decision-making process.
- There is a lack of clarity on how UHI tools may simplify or represent the complexity of the urban health system and whether they are effective at enacting change or learning.

1.3 Research questions

On the basis of these gaps, the following research questions will be investigated:

1 How do UHI tools present and measure the impact of the urban environment on health, especially in relation to complexity?

2 What mental model(s) do indicator producers and users have regarding the use of UHI tools in urban planning policy and decision-making?

3 What is the potential value of UHI tools for health promotion in the planning policy and decision-making process, particularly in relation to the complexity of this process?

1.4 Research objectives

The research questions are addressed through nine objectives that relate to each component of the research, each with associated outputs (Table 1-1).

Table 1-1 Research objectives for each component of the research project, linked to the overall research questions and thesis chapters (Ch.: Chapter, No.: Number, RQ: Research question)

Ch.	Research component	Outputs	No.	Objectives	Link to RQs
4	Systematic review part A: census	Characteristics and taxonomy of UHI tools	1	To create a census and taxonomy of UHI tools.	RQ1
	Systematic review part B: narrative synthesis	Descriptions of policy-makers' perceptions and use of UHI tool, and facilitators/barriers	2	To understand how UHI tools are used in the policy and decision-making process, including facilitators/barriers to use.	RQ2, RQ3
			3	To explore the perceived impact of UHI tools on policy and decision-making.	RQ3
	Systematic review parts A & B	Description of how UHI tools address complexity	4	To investigate the value of UHI tools in relation to simplifying, representing or addressing complexity for urban planning policy and decision-making.	RQ1, RQ3
5	Model conceptualisation	Systems thinking model conceptualisation	5	To conceptualise a model of indicator users' and producers' mental models of the use of UHI tools & their value in relation to complex systems.	RQ2, RQ3
			6	To investigate the feedback relations influencing the use of UHI tools in the planning policy and decision-making process.	RQ2

Ch.	Research component	Outputs	No.	Objectives	Link to RQs
6	Semi-structured interviews of UHI tool users and producers	Descriptions of use and value of UHI tools in the form of themes	7	To explore participants' perceptions of the value of UHI tools for health promotion in the complex policy process, and in relation to the complexity of urban health.	RQ3
			8	To develop a preliminary causal loop diagram (CLD) of indicator users' and producers' mental models of the use of UHI tools & their value in promoting health and addressing complexity.	RQ2, RQ3
7	Development and testing of CLD	High-level Causal Loop Diagram (CLD) and detailed CLDs of components of larger model	9	To test and further develop the preliminary CLD with indicator users and producers.	RQ2, RQ3

1.5 Research approach

The study adopts a mixed-methods methodology following a sequential explanatory design which is informed by a conceptual framework explained in chapter three. Investigating and understanding the use of indicators in the social process of urban planning policy and decision-making requires social science theories and methods. While understanding the nature of UHI tools, requires application of positivist approaches. The resulting quantitative and qualitative data will be interpreted together, using systems thinking, and collaborative rationality theories (described in chapter three), to provide new insights into the use of UHI tools in planning policy and decision-making.

The mixed-methods study design is shown in Figure 1-1 with an arrow indicating that each component informs the next. The first two components of the research (the systematic review Parts A and B) are the stages in which quantitative and qualitative data are sequentially collected, analysed and then combined (a mixed-methods sequential explanatory design). The results of both datasets are then used to inform the later stages of the research, which are all qualitative.

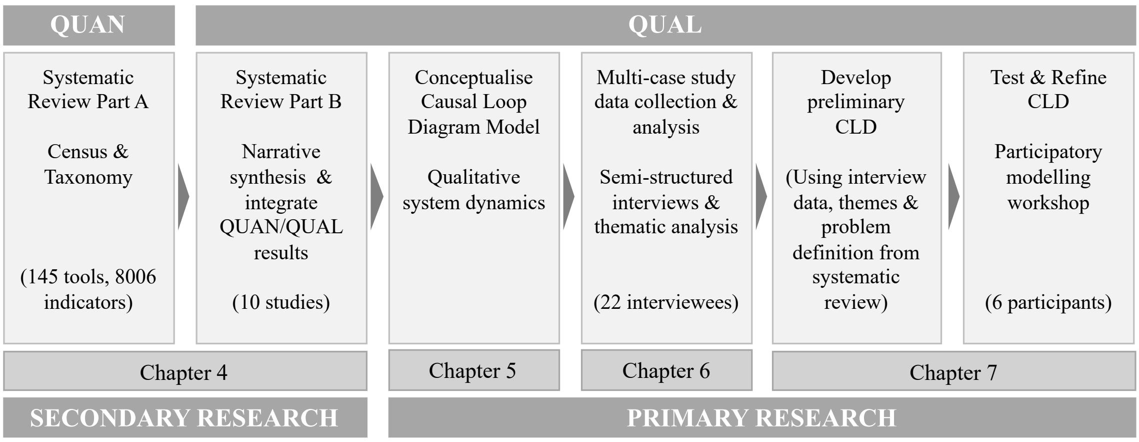

Figure 1-1 Study design indicating the relationship between study components, methods and thesis chapters (QUAN: Quantitative, QUAL: Qualitative, CLD: Causal loop diagram)

The systematic review census (Part A) involves understanding and explaining the nature of UHI tools (research question (RQ) 1) through identification, analysis and description of UHI tools. This allows for identification and review of qualitative studies on the use of such tools by built environment policy and decision-makers (RQ2&3, systematic review Part B). These are both secondary research methods which assemble and synthesise existing data to create new understanding.

The results from Part A and B of the systematic review are then used in three ways: 1) development of a theory of change (ToC) of the use of UHI tools in urban planning 2) conceptualisation of indicator users' and producers' mental models (RQ2) and 3) identification of appropriate interview participants. The ToC and model conceptualisation process informs the direction and analysis of the semi-structured interviews (RQs 2 and 3). The challenge of complexity was raised in two general areas: UHI tool representation of the urban health system (RQ1) and the value of UHI tools in the complex planning policy and decision-making process (RQ3). Investigation of these topics requires systems thinking and modelling; the former will be incorporated in all components of data analysis in Figure 1-1. Data from the semi-structured interviews will be used to develop a preliminary causal loop diagram (CLD) of indicator users' and producers' mental models using qualitative system dynamics (also called systems thinking). A participatory modelling workshop will then test the CLD in relation to participants' mental models of these systems. In summary the research design sequentially builds on the results of previous components and data from separate phases in the research are integrated together to produce additional findings.

1.6 Research methods

This section briefly outlines each of the methods used in the research project and provides a short overview of the objectives and progress for each phase of research.

1 A systematic review is conducted to gather and review literature to avoid the bias which can be found in traditional literature reviews, such as inconsistent inclusion/exclusion of studies (Petticrew and Roberts, 2006). The systematic review allows for a thorough understanding of the nature and characteristics of UHI tools and how these have changed over time through the quantitative component (Part A). The qualitative element (Part B) will help explain why a particular intervention (in this case UHI tools) is effective (or not) and which factors aided or disrupted the implementation of a particular intervention (Popay et al., 2006). This will not result in a 'meta-answer' but it will help build and test theories about the use of UHI tools (ibid). Data from both Parts A and B will be integrated to further explore the research questions, with the intention of finding additional insights that were not evident through the separate datasets (Ivankova et al., 2006; Bryman, 2007). The narrative synthesis data is supported by development of a ToC as recommended by Popay et al. (2006).

2 Findings from the systematic review will be used to conceptualise and develop mental models of how UHI tools inform urban planning policy and decision-making, particularly in relation to promoting health. System dynamics methods will be used to conceptualise the model including: defining the problem, describing emergence of the problem, outlining model boundaries, and developing dynamic hypotheses of how UHI tools influence urban policy and decision-making (Sterman, 2000).

3 Semi-structured interviews will be used to explore the use of UHI tools in San Francisco, Melbourne and Sydney (a multi-case study approach) based on the long-term nature of UHI tools in these locations. These interviews will be informed by the findings from the systematic review.

4 The transcribed interview data will be analysed using thematic analysis, a theory-neutral technique that can be applied in both essentialist and constructionist paradigms (Braun and Clarke, 2006). A hybrid approach of inductive and deductive coding will be used to ensure the themes identified in previous studies and the study's conceptual framework are considered. The codebook will build on theory and the broad themes outlined in part B of the systematic review. This will not exclude additional themes being identified through an inductive coding process. The emerging codes and themes will inform the systems thinking analysis of the data and development of causal loop diagrams.

5 The coded interview data will be used to identify participants' mental models of indicator use in the planning policy and decision-making process, using guidance from the system dynamics literature (Luna-Reyes and Andersen, 2003; Kim and Andersen, 2012; Turner et al., 2013; Eker and Zimmermann, 2016). System dynamics is a method using systems thinking and complexity theories to model and simulate problems in complex systems. It is 'fundamentally interdisciplinary' (Sterman, 2000, p.4) and integrates both positivist and interpretivist paradigms (Lane, 2001). It is therefore a useful method for approaching the use of UHI tools in policy and decision-making. The systems thinking analysis will result in the creation of a causal loop diagram representing participants' mental model.

6 Finally, the causal loop diagram will be tested and further improved in a participatory modelling workshop. Participatory modelling with problem owners can be used to co-produce models or to improve the quality of a preliminary model (Andersen and Richardson, 1997; Zimmermann et al., 2015). Both processes can have the effect of changing participants' thinking, helping them to understand a problem in a different way (Kim, 2008; Zimmermann et al., 2015). The workshop format will follow guidance from the literature (e.g. Andersen et al., 1997, 2007).

The study elements involving participants (interviews and workshops) were approved by the Bartlett School of Energy, Environment and Resources (BSEER) Low Risk Ethics process. All participants were informed and consented.

1.7 Originality and research contributions

This original research has contributed new knowledge filling research gaps and demonstrated applications of methods in new contexts. These contributions are detailed in chapter nine and summarised very briefly here.

1.7.1 Contributions to knowledge

- The first census and taxonomy of UHI tools, classifying the scope and characteristics of health and wellbeing, quality of life, liveability, wellbeing and walkability/physical activity indicator sets. *As described in chapter four and Pineo et al. (2017a, 2017b, 2018a).*
- The first narrative synthesis of studies on the use of UHI tools by built environment policy and decision-makers. *As described in chapter four.*
- A theory of change of the value of UHI tools for health-promotion developed through a narrative synthesis of ten studies. *As described in chapter four.*
- Research filling a knowledge gap about the use of UHI tools in urban planning policy and decision-making. *As described in chapters six and eight.*
- The first causal model of UHI tool influence on urban policy, implementation and health promotion. *As described in chapters seven and eight.*

- Research filling a knowledge gap about how UHI tools represent the complexity of urban health systems and how they are used in the complex urban planning process to promote health. *As described in chapters, four, six, seven and eight*.
- Application of the collaborative rationality theory (Innes and Booher, 2010) to stable UHI tool processes and considering the value of such approaches to address complexity characteristics in urban health and planning. *As described in chapter eight*.

1.7.2 Contributions to methods

- Development of the systematic review method by conducting a mixed-methods systematic review of sequential explanatory design on this topic. *As described in chapter four.*
- Development of the application of the thematic analysis method to analyse interview data in development of causal loop diagrams, where grounded theory has typically been used. *As described in chapters six and seven*.

1.8 Thesis structure

The thesis is structured as follows:

- Chapter two introduces the context of the research topic in relation to urban health challenges and governance mechanisms and specifically the role of indicators.
- Chapter three sets out the conceptual framework for the study, defining the assumptions, values and beliefs that informed the selection of research questions, a theoretical framework and methods. This chapter also describes the research methods in more detail.
- Chapter four reports the methods and findings of both the quantitative and qualitative elements of the systematic review, and development of a theory of change.
- Chapter five uses the outputs of the systematic review to conceptualise the mental models which are later developed in chapter seven.
- Chapter six reports the methods and findings of the semi-structured interview and thematic analysis.

- Chapter seven describes the methods used to develop and test the causal loop diagram. The CLD (including a high-level diagram and five detailed sections) is explained and then the participatory modelling workshop findings are discussed.
- Chapter eight brings together the findings from chapters four to seven and synthesises the main findings in four themes. These themes are considered in relation to the conceptual framework and wider literature. Chapter eight also discusses the overall strengths and weaknesses of the study.
- Finally, chapter nine summarises the research, knowledge contributions, recommendations for practice, reflections on the research process and future research directions.

CHAPTER 2

Literature review of indicators and urban health governance

2.1 Introduction

Two recent urban planning texts by Bolan (2017) and Barton (2017) begin by posing a question about the purpose of urban planning. Bolan argues that a planner balances skills and knowledge spanning engineering, architecture, sociology and more to manage change in urban environments. Both Bolan and Barton argue that the goal of such change is contested and may be economic development, quality of life, a well-functioning settlement or other objectives. Yet Barton points out that although sustainable development may be the official goal of planning according to organisations such as the United Nations, the European Union (EU) and the UK government, the reality does not match this rhetoric. In practice, he argues, economic considerations often trump the social, economic and environmental balance implied by sustainable development. How then does human health and wellbeing fit into the already contested purpose of urban planning?

This chapter provides an overview of the literature about urban planning and health. It focuses specifically on the role of indicators, which public health academics and practitioners have used to insert health and wellbeing on the urban planner's agenda. The chapter covers the background to: the nature of health in cities and the role of the built environment; complexity in urban health governance; promoting health through urban planning; using indicators to understand and improve urban health; and influencing policy and decision-making with evidence. The chapter provides the wider context in which the research is situated and highlights gaps in the current knowledge of indicator use in urban planning.

2.2 The nature of health in cities

The public health profession began with attempts to understand and prevent the spread of disease and illness in 19th century cities (Hancock and Duhl, 1986). Industrialised cities of the late 1800s are characterised by air pollution, overcrowding, open sewage and contaminated drinking water as shown in drawings from that period (Figure 2-1). The pioneering work of British sanitarians Edwin Chadwick (1842) and Sir Benjamin Ward Richardson (1876) linked health with the social and physical environment. Yet in the 20th century health pursued a bio-medical paradigm, leaving the environment behind until the seminal 'Lalonde Report' (Lalonde, 1974), which re-asserted the significant influence of environment and lifestyle (Hancock and Duhl, 1986).

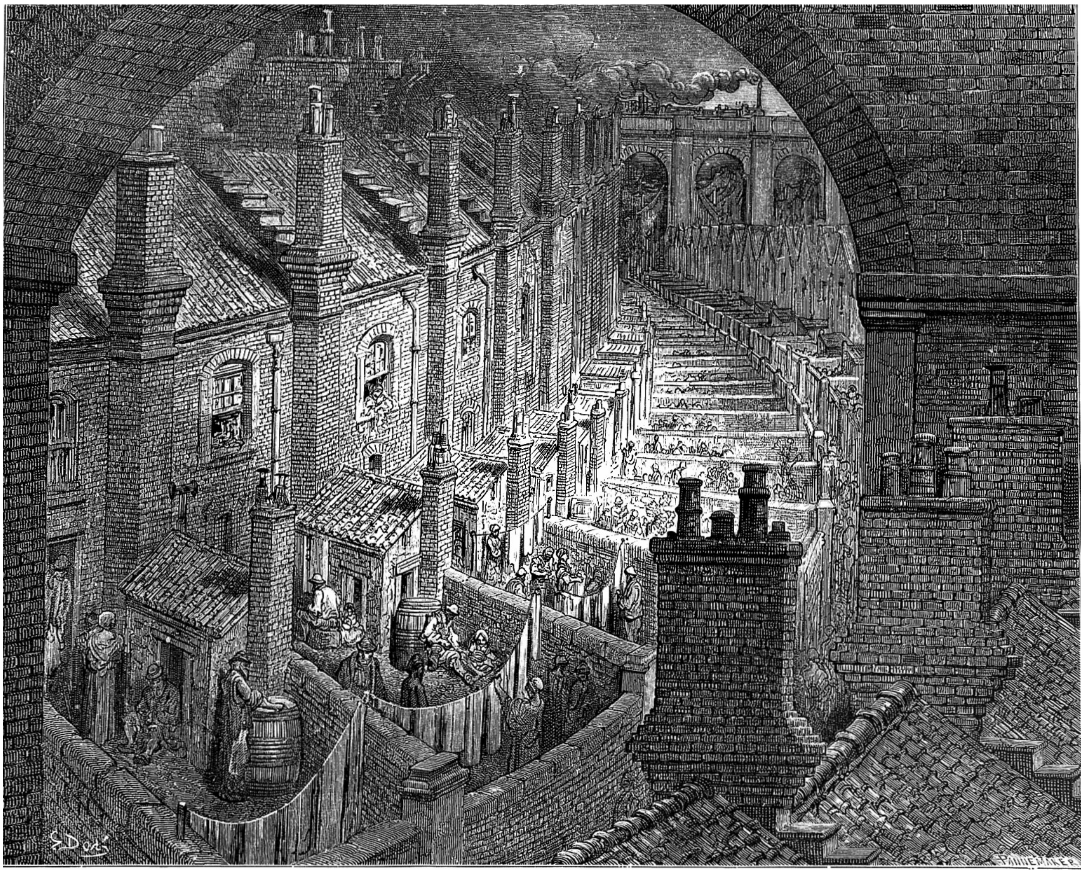

Figure 2-1 Drawing of London slums by Gustave Dore, 1872. Source: Wellcome Images

2.2.1 Defining health and its wider determinants

To examine health in cities, it is essential to first establish definitions for health and its determinants. The WHO defines health as 'a complete state of physical, mental and social well-being, and not merely the absence of disease or infirmity' (1948, p.1). This broad view of health, which encompasses wellbeing, sets the scene for health professionals to not only be concerned with curing ill-health, but also understanding and promoting the societal context in which good health flourishes.

Dahlgren and Whitehead's (1991, 2006) well-known framework (Figure 2-2) depicts the wide range of factors which are known to determine health and wellbeing. These factors are known as the 'social determinants of health' and are defined as 'the circumstances in which people are born, grow up, live, work and age, and the systems put in place to deal with illness' (WHO 2008, p. 3). These wider factors that influence health are sometimes referred to as distal or upstream determinants, where factors at the core of the Dahlgren and Whitehead framework are proximal or downstream (de Leeuw, 2011).

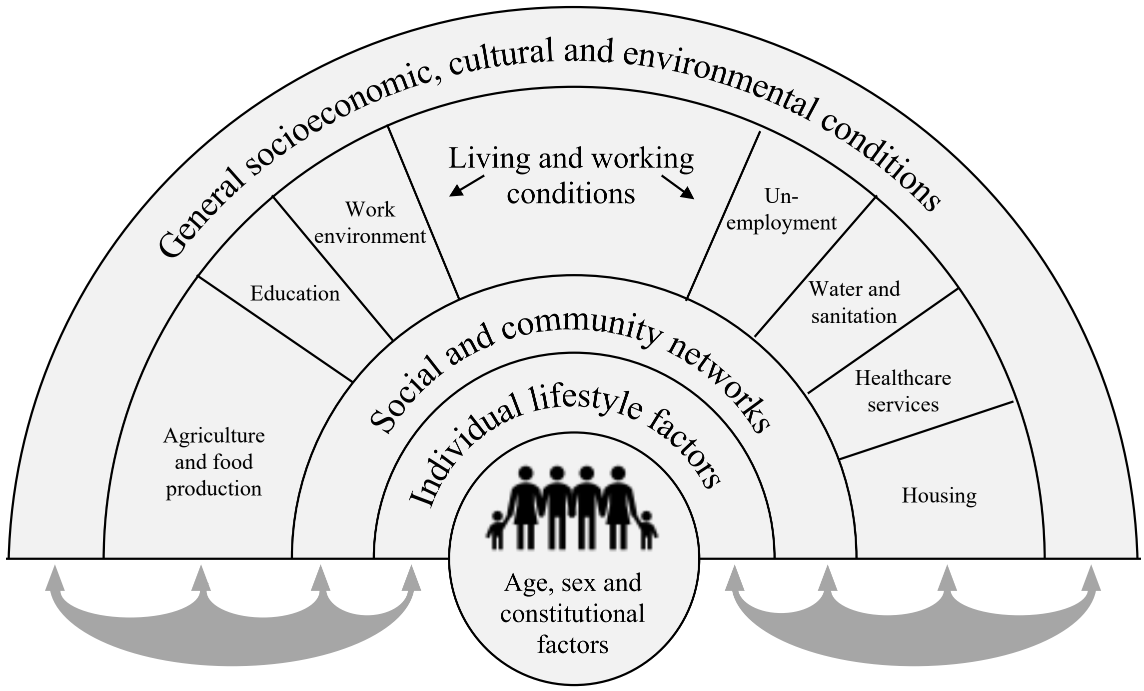

Figure 2-2 Reproduction of Dahlgren and Whitehead's (1991) 'Main Determinants of Health' framework from (2006, p.20)

Galea and Vlahov's (2005) definition of urban health builds on these concepts: '[u]rban health, then, concerns itself with the determinants of health and diseases in urban areas and with the urban context itself as the exposure of interest' (p.342). Thus urban health research, as advocated by the International Society for Urban Health, studies the determinants of health in cities, including solutions to improve residents' health and wellbeing (International Society for Urban Health, n.d.).

2.2.2 Health impact of the urban environment

A growing body of epidemiological research attempts to identify associations and causal relationships between aspects of the urban environment and health outcomes. A number of frameworks conceptualise the multiple pathways from urban environment exposures to behavioural and health outcomes (Northridge et al., 2003; Rydin et al., 2012; Badland et al., 2014; Gelormino et al., 2015). Such frameworks demonstrate that almost all parts of an urban system can impact health and wellbeing. In particular, Rydin and colleagues (2012) emphasise the complexity of urban health and interconnections between parts of this system. Building on these previous frameworks, the author developed a diagram of physical urban environment exposures and their impact on behaviour and health outcomes for the Building Research Establishment (BRE) (Figure 2-3, reported in Pineo et al. (2018b)). The framework was established by reviewing epidemiological studies, primarily using systematic reviews or other evidence reviews. Figure 2-3 highlights the wide range of built environment factors which affect health and begins to show the complexity of this system, although many interconnections are not shown. In the diagram, 'urban environment exposures' range from city-scale (top left), such as urban sprawl, to building-scale (bottom left), such as poor ventilation. Arrows connect exposures to health outcomes with indication of whether the evidence supports a causal association (solid line) or otherwise (dotted line). Some exposures lead to specific 'direct exposures' (such as toxins) or 'behavioural outcomes' (such as unhealthy diet).

Although the urban environment can cause or provide conditions for injury, death and communicable disease, non-communicable diseases, also called chronic diseases, are an outcome of growing concern (WHO, 2014). In Figure 2-3 these are shown on the top right and include cardiovascular and respiratory diseases, among others. According to the U.S. Centers for Disease Control and Prevention (CDC), these are 'among the most common, costly and preventable of all health problems' (2016). The WHO (2014) estimates that in 2012 chronic diseases were responsible for 68% of the world's deaths. They also highlight the role of the urban environment in tackling this epidemic, particularly through the creation of environments which support physical activity (ibid). This is a key opportunity for built environment professionals to positively impact health and wellbeing as physical activity has benefits beyond helping to protect against non-communicable disease, including maintaining a healthy weight and mental wellbeing (Fontaine, 2000; Butland et al., 2007; Lee et al., 2012; Sallis et al., 2016). In Figure 2-3, the pervasive impact of deprivation (introduced in the next section) is shown on the far left with a statement cutting across all urban environment exposures.

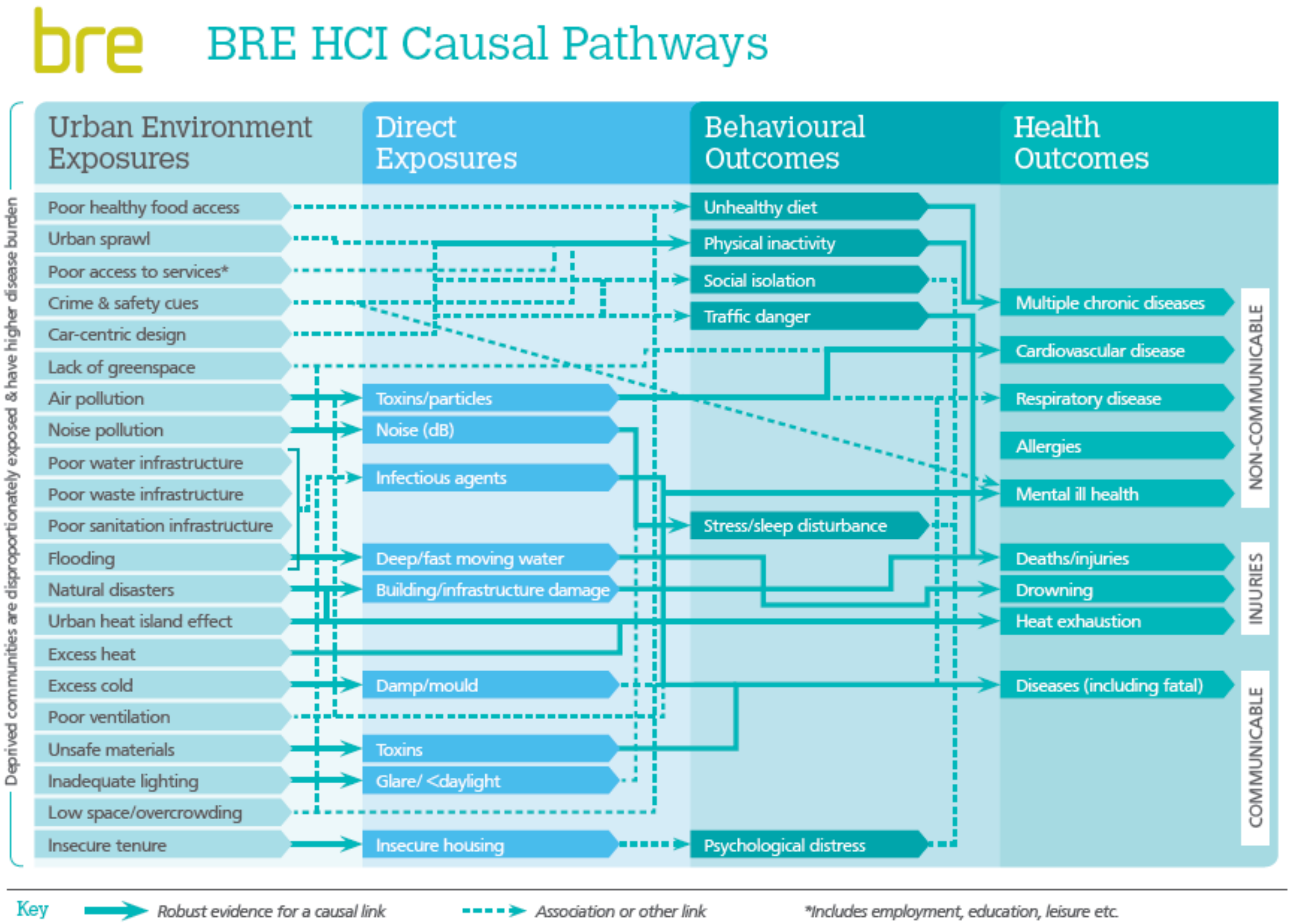

Figure 2-3 Diagram of pathways from urban environment exposures to health outcomes (Pineo et al., 2018b, p.34). Developed for the BRE Healthy Cities Index (HCI). Copyright BRE. Reproduced with permission from the BRE Trust.

2.2.3 The role of deprivation and inequities

A fundamental component of health in cities is the role that disadvantage and socio-economic inequity play in health and wellbeing. Researchers have demonstrated that there is a social gradient in health which results in poor people dying younger and living longer with disability than more affluent people (The Marmot Review Team, 2010). This phenomenon is not unique to cities but it does play out spatially within urban areas where those living in deprived neighbourhoods are more likely to be exposed to poor environments which negatively affect health and wellbeing (Commission on the Social Determinants of Health (CSDH) 2008; Geddes et al., 2011; WHO, 2012; WHO and United Nations Human Settlement Programme 2010).

Many environmental exposures have been shown to disproportionately affect socio-economically deprived communities. Research on access to food has shown that residents of low income or ethnic minority neighbourhoods have reduced access to healthy foods and greater access to unhealthy foods than more affluent neighbourhoods (Fraser et al., 2010; Black et al., 2014). In addition, deprived communities are more likely than affluent communities to be exposed to: higher levels of air pollution (WHO, 2013), poor quality housing (Braubach et al., 2011), less access to green space (Institute of Health Equity, 2014), fewer recreation facilities (Gordon-Larsen et al., 2006; Hillsdon et al., 2007), reduced availability of safe children's play areas (Curtice et al., 2005), increased rates of road traffic injuries (Cairns et al., 2015), greater levels of noise (Nega et al., 2013) and homes which are less able to withstand extreme heat, flooding, earthquakes, and other natural disasters (WHO, 2016). Conditions are particularly poor for those living in informal settlements where unsafe buildings, lack of sanitary and waste facilities and other environmental health risks cause a number of avoidable diseases, injuries and deaths (Rydin et al., 2012).

In addition to socio-economic deprived communities, other population groups can be disproportionately affected by environmental exposures and may require additional consideration for planning and designing healthy environments. For example air pollution more strongly impacts children (from the time they are in the womb), older people and people with certain existing health conditions (WHO, 2013). Researchers and practitioners are increasingly aware of the influence of gender on feelings of safety in the city (Escalante and Valdivia, 2015), which in turn may affect physical activity (Foster et al., 2004; Foster and Giles-Corti, 2008). Pineo (2017) reviewed methods to engage with residents about their perceptions of health and place. The review highlighted the importance of seeking out under-represented groups which may have experiences of the built environment which are counterintuitive for urban planners and designers. This was the case in Madison, Wisconsin, USA where researchers found that African-American children's perceptions of the neighbourhood food environment contradicted objective measures such as availability of healthy food (Dennis et al., 2009). In summary, health inequities are related to environmental inequities and built environment (and other) professionals need to consider how inequities can be improved through design and policy interventions.

2.2.4 Governing for health in cities

The role of city leaders and policy-makers in influencing urban health conditions is widely recognised and forms a key part of health promotion activities. Following the publication of the Lalonde report (1974) and the Ottawa Charter for Health Promotion (WHO, 1986), a growing movement of health professionals began using a city-wide and whole-of-government approach, moving into the 'health in all policies' (HiAP) approach, to influence other sectors to take action on the wider determinants of health (Kickbusch and Gleicher, 2012).

Governance for health is defined by Kickbusch and Gleicher (2012) as 'the attempts of governments or other actors to steer communities, countries or groups of countries in the pursuit of health as integral to well-being through both whole-of-government and whole-of-society approaches' (p.vii). Corburn and Cohen (2012) provide a more detailed definition of governance, which summarises the views of Burris et al. (2007):

> *'Governance is not just government and the decisions of formal institutions, such as ministries of health, but also includes the norms, routines, and practices that help shape which issues get onto the health research and policy agenda, what evidence base is used to underwrite decisions, and which social actors are deemed expert enough to participate in these decisions' (p.2).*

In the 21st century, the drivers influencing governance include globalisation, urbanisation, climate change, widening inequities, and other trends, and the interdependencies and complexity of these processes (Kickbusch and Gleicher, 2012). As a result, Kickbusch and Gleicher argue that health is not alone in requiring collaboration across other sectors to achieve its objectives. Effective governance in the face of 21st centrury challenges requires systems approaches across multiple levels, co-production and creating shared value (ibid).

The WHO has raised awareness of the importance of non-health policy domains for decades and this was the impetus for the WHO Healthy Cities movement. Healthy Cities is an international programme that originated in Europe in 1986 and was grounded in the understanding that local government, including built environment professionals, can play a significant role in improving population health (Hancock, 1993). A number of evaluations of the European Healthy Cities programme show that it has succeeded in: raising the importance of health on political agendas; developing local health policy across government and urban sectors; and addressing complex challenges with equity, governance and participation in healthy urban planning (de Leeuw, 2011; de Leeuw et al., 2015, 2014). Three decades after the programme started, multi-sector cooperation to improve health and wellbeing is still a key goal of the public health profession which requires ongoing advocacy (Hancock, 2011; Kickbusch and Gleicher, 2012).

2.3 Complexity and urban health

A consistent theme throughout the urban health literature relates to the complexity of urban health and governance (see Galea and Vlahov, 2005; Rydin et al., 2012). This section introduces the concepts of complex systems and systems thinking and discusses the impact of complexity on urban health research and policy-making.

2.3.1 Characteristics of complexity

Complex systems are characterised as interconnected, dynamic, non-linear, adaptive and governed by feedback, among other features; and they are often defined by a description of these many characteristics (see Sterman, 2000; Glouberman et al., 2006; Sterman, 2006; Innes and Booher, 2010; Luke and Stamatakis, 2012). Table 2-1 provides an overview of these characteristics of complex systems from the literature. Sterman (2000) emphasises the role of feedback, the mechanism that creates change (dynamics) within a system, stating that 'the most complex behaviors usually arise from the interactions (feedbacks) among the components of the system, not from the complexity of the components themselves' (p.12). Understanding complexity allows for a different way of thinking about the world, called systems thinking; in which everything is seen as connected (ibid). Systems thinking and complexity theory are described in more detail in chapter three as they are part of the conceptual framework of this thesis.

Table 2-1 Characteristics of complex systems

Characteristic	Description	Source
Dynamic	Elements within the system change over time (possibly in unpredictable ways).	(Sterman, 2000)
Number of elements	There are a high number of variables/agents within the system.	(Glouberman et al., 2006; Luke and Stamatakis, 2012)
Interconnected	There are multiple interactions within and across systems and sub-systems.	(Sterman, 2000)
Non-linear structure	There are non-linear relationships between cause and effect (effects are rarely proportional to causes).	(Sterman, 2000)
Feedback	Elements within the system interact recursively (in feedback loops) to change the behaviour of the system.	(Sterman, 2000)
Counterintuitive	Effects are distant in space and time to causes.	(Sterman, 2000)
Emergent behaviour	Effects of the whole system are greater than the sum of individual impacts within the system.	(Glouberman et al., 2006; Luke and Stamatakis, 2012)
Policy resistance	Interventions (e.g. policies) are 'delayed, diluted, or defeated by the response of the system to the intervention itself'.	(Sterman, 2000, p.5)

2.3.2 The complex urban health system

In cities, physical, social, economic and environmental structures interact and change over time to impact health and wellbeing, comprising a complex dynamic system (Glouberman et al., 2003, 2006; Rydin et al., 2012). For example, the impact of air quality on respiratory health can cause immediate exacerbation of existing conditions and lead to chronic conditions over time (WHO, 2013). This impact is modified by policies and the design of urban form, greenspace, transport systems and buildings, among other factors, which interrelate and mediate each other (Mindell and Joffe, 2004; Mindell et al., 2011; Cohen et al., 2014).

Complexity is a challenge for urban health research, particularly because it inhibits understanding of cause and effect within this system (Galea and Vlahov, 2005; Northridge et al., 2003; Rydin et al., 2012). Earlier in the chapter, a conceptual framework was introduced showing the pathway from urban health exposures to outcomes (Figure 2-3). However, this framework, and others like it, fail to show the complexity of urban health by omitting the full extent of interconnections and feedback relations among parts of the system, partly due to weaknesses in the urban health evidence base which has not established cause and effect relations in many cases (Rydin et al., 2012; Sarkar et al., 2015). In recognition of this challenge, scholars have argued for new approaches in epidemiology and public health research to account for complexity (Carey et al., 2015; Luke and Stamatakis, 2012; Rutter et al., 2017). For example, Rutter et al. (2017) argue that by incorporating systems thinking, researchers would re-evaluate the timeframes in which outcomes would be expected to arise from specific interventions. However, Naimi (2016) argues that claims regarding the limitations of epidemiological methods to address complexity (e.g. non-linearity) have suffered from important fallacies (namely they are constructed using straw-man arguments and lead to an 'irrelevant conclusion') and require further justification (p.843). Naimi contends that the incorporation of systems thinking into epidemiological research is essential, yet this is more about framing approaches than a preference for systems methods (such as system dynamics) over traditional epidemiology methods.

2.3.3 Policy-making and complexity

Complexity is not only a feature of the urban health system, but also of the system of governance which seeks to improve health in cities. As described in section 2.2.4, governance for health requires action across multiple levels, with many actors who may have competing or complementary agendas.

Cairney (2012a, 2012b) argues that policy-making systems are complex and that complexity theory can aid both policy-makers and political science researchers. He summarises four core insights about complexity for policy-making as:

- 'law-like behaviour is difficult to identify' meaning policies cannot necessarily be transferred across contexts;
- systems are difficult to control due to 'self-organising capacities' and therefore policies may result in unintended consequences or other failure;

- the context of complex systems requires agents to adapt quickly and avoid single policy strategies; and
- all actors within a system will make decisions of how to act making top-down approaches unlikely to succeed (p.349).

In relation to urban health governance, Kickbusch and Gleicher (2012) promote a systems approach which would involve 'understanding of the system as a whole, the interactions between its elements and possibilities for intervention' (p.75). Complexity theory and systems thinking has also influenced the study of urban planning governance systems (e.g. Innes and Booher, 2010). This subject is revisited in chapter three as a core element of the conceptual framework for this thesis.

2.4 Promoting health through urban planning

The beginning of this chapter posed a question about the purpose of urban planning and queried the extent to which the promotion of human health and wellbeing can be seen as one of planning's core objectives. Urban planners influence many of the social determinants of health. In the physical environment, their work covers transport systems, buildings, public open space, air quality and noise among other factors, which may have negative or positive impacts on health. Although estimates vary, recent research attributes 23% of global deaths to the environment (Prüss-Üstün et al., 2016). The process of planning and designing communities and cities also influences the location and nature of employment and education opportunities, potentially impacting health. Taking this wider social view, New York's Regional Plan Association estimated that urban planning could 'shape 80% of any community's health' (2016, p.11). Regardless of whether planners see it as a core objective, their work influences health and wellbeing. This section outlines the history and current practice of healthy planning, which segues to the role of indicators within the planning system.

2.4.1 History of urban planning for health and current state

The desire to build healthy human settlements to escape the overcrowding and pollution in 19th century urban centres is frequently referred to as the joint foundation of both public health and urban planning (Hancock and Duhl, 1986; Sarkar et al., 2014). Yet incorporation of health issues can be found in the architecture, urban planning and engineering practice of ancient cultures (Dannenberg et al., 2011; Pineo, 2012). As previously discussed, although 19th century physicians, such as Edwin Chadwick, applied a socio-ecological model of health (Hancock and Duhl, 1986), toward the end of the 19th century a bio-medical paradigm emerged in health which widely dominated until publication of the Lalonde report (1974). Nevertheless, Chadwick's work inspired early urban planning practice, such as Ebenezer Howard's (1902) Garden City Movement (Hancock and Duhl, 1986) which sought to provide respite from the smog and overcrowding of industrialised cities. Throughout the 20th century there were many other planning and architectural solutions to promote health and wellbeing such as Le Corbusier's high rise cities (Marmot, 1981) and Clarence Perry's (1929) Neighborhood Unit (Corburn, 2015). Such approaches have been criticised either in their formulation or execution, particularly for applying a one-size-fits-all solution to the varied needs of people (Corburn, 2015; Marmot, 1981).

The WHO Healthy Cities programme emerging from the Lalonde report's shift back to a socio-ecological model and created a new opportunity to unite built environment and public health practice in local government (Hancock and Duhl, 1986). The Local Agenda 21 sustainable development initiative, born from the 1992 Rio Summit, was well-aligned to the participatory approach of the Healthy Cities movement (Rydin et al., 2012) and the two agendas may have been mutually reinforcing in local government. The impact of the WHO Healthy Cities programme was highlighted previously and will be addressed later in this chapter with regard to indicators.

The 2010s mark a renewed interest in designing and planning healthy places from built environment and health professionals and the research community. There are a number of new textbooks on planning healthy cities (see Barton, 2017; Barton et al., 2015; Dannenberg et al., 2011; Sarkar et al., 2014). The development sector in the UK and USA, through its representative membership bodies, has recently published a number of reports on planning healthy buildings and places (Pineo and Rydin, 2018; Pinoncely and Hartkoorn, 2014; Town and Country Planning Association, 2015). Furthermore, there are a number of new international standards to promote healthy development at building and community scales, such as Fitwel and the WELL Building Standard, that have received widespread industry interest (Pineo and Rydin, 2018).

In the global community, the 2015 United Nation's Sustainable Development Goals (SDGs) demonstrate a renewed drive to link sustainable development, health, and city planning (United Nations General Assembly, 2015; Giles-Corti et al., 2016). In Europe, the Copenhagen Consensus of Mayors, an initiative of the European WHO Healthy Cities Network, shows leadership in improving urban health through policies that prioritise people and the planet (as do the SDGs), including through urban planning (WHO, 2018). In the UK, the National Health Service (NHS England) funded a Healthy New Towns programme to incorporate healthy design into ten new large-scale community demonstrator sites (NHS England, n.d.). Alongside these high-level initiatives there are examples of community-driven processes which involve collaboration across residents and local government to improve urban health through planning (see Bhatia, 2007, 2014; Bhatia and Corburn, 2011). Today's planners have a number of frameworks and policies to drive healthy urban planning, yet many would argue that more advocacy, training, and leadership is needed to ensure health is promoted through urban planning and related fields (Grant et al., 2017; Pineo et al., 2019).

2.4.2 Frameworks for healthy urban planning

Just as urban health is a complex system, the process of urban planning and decision-making is complex. The complexity of policy-making was introduced in section 2.3.3. Here this concept is specifically addressed for the urban planning policy process. Urban planning is described as cyclical, iterative, and contentious, involving many diverse stakeholders with overlapping and divergent agendas; all characteristics of complex systems (Innes and Booher, 2010; Tewdwr-Jones, 2012; Bolan, 2017). Pineo et al. (2019) outline several factors of urban planning policy and decision-making that create challenges for health promotion: 'competing objectives and demands (e.g. sustainability and economic growth); tensions with market-led versus public sector-led development; political decisions and priorities; short-term versus long-term considerations; and representation of community interests in land use' (p.202). To effectively influence the complex urban planning process, those who wish to promote healthy cities need to understand and work with these constraints and others. The evidence-based policy model which health professionals may be familiar with (Cairney and Oliver, 2017), does not easily transfer to urban planning (Grant and Davis, 2019).

Several frameworks and approaches are outlined below that have been proposed to influence heathy urban planning (informed by Pineo et al. (2019)). In their role as advisors to WHO Healthy Cities, Barton and Grant (2006) developed a Health Map (Figure 2-4) which builds on the Dahlgren and Whitehead social determinants of health model (Figure 2-2). The map indicates the ways in which urban planners can influence health through policy development and implementation.

Cummins et al. (2007) argue for a relational view of place and health, particularly to address health inequities. A relational approach involves more attention to how people experience place, rethinking spatial boundaries, the impact of social networks, and the dynamic nature of places. Corburn (2015) advocates this relational approach to promote health through urban planning due to the many social, political, and governance processes involved.

Corburn's approach to addressing the complexity of healthy urban planning and health equity is through an adaptive management framework (Corburn, 2015, 2013; Corburn and Cohen, 2012). This recognises and addresses complexity and uncertainty by monitoring policy interventions with indicators and making adjustments as necessary (ibid). Under this approach, a range of stakeholders would: co-create a model for change, consider and prioritise policy interventions, monitor results over time, and adjust policies as necessary (ibid).

Rydin et al. (2012) propose experimenting with policy interventions and closely monitoring impact, in line with the adaptive management approach. Furthermore, they propose that cities carry out complexity analyses to map interrelations among urban environment features and health and consider related policy interventions (ibid).

Finally, Gatzweiler et al. (2018) propose a systems approach to policy and decision-making for urban health that involves co-production of knowledge and participatory governance mechanisms. They advocate integrated urban planning that allows for spontaneous urban development and engineered approaches (for example, informal settlements that are connected to water, waste and sanitation infrastructure). Furthermore, they note the requirement of access to data resources across all urban actors (incorporating scientific and experiential knowledge) to enable integrated monitoring and feedback.

The approaches outlined above, specifically the last three, introduce a role for indicators in a healthy urban planning process, particularly in terms of monitoring. In the next section, the potential role of indicators will be broadened beyond monitoring policy impact to inform a range of other planning activities.

Figure 2-4 A Health Map (Barton and Grant, 2006, p.2). Reproduced with permission.

2.5 Indicators as a tool to improve urban health

Indicators are a way of simplifying, measuring and understanding a complex system and they have a long history linked to health. This section begins by defining indicators before describing their history, application to urban health and relation to addressing complexity. Meadows (1998) defined indicators as a ‘necessary part of the stream of information we use to understand the world, make decisions, and plan our actions' (p.1). Although Lowe et al. (2015) point out that there is no single accepted definition of indicator, several existing definitions (Table 2-2) converge on the concept of an indicator representing something more complex than a single data point.

Table 2-2 Definitions of 'indicator' across several policy fields

Definition	Policy field
'The key aspect of an indicator is the transition from "data" to "information". In this context environmental health indicators can be understood as synthesized information regarding known environment-related diseases or contaminants with known adverse health effects' (Corvalán and Kjellström, 1995, p.75).	Environmental health
'Indicators are pieces of information that summarize the characteristics of a system or highlight what is happening in a system' (Saisana and Tarantola, 2002, p.5).	Multiple
'The term *indicator* means to point out or to identify that which is not immediately visible, audible, or perceived in a precise situation' (Lawrence, 2008, p.302).	Environmental health
'A parameter, or a value … with a significance extending beyond that directly associated with a parameter value' (Science for Environment Policy and Science Communication Unit (SCU), 2015, p.8).	Sustainability

Indicators often combine multiple measures either as a 'basket of indicators' (not mathematically combined) or as an index (combined and weighted). In either case, a combination of indicators can be referred to as a 'set', 'collection' or 'tool' (Pastille Consortium, 2002; Rothenberg et al., 2015; Science for Environment Policy and SCU, 2015). This research focuses on urban health indicator tools, defined by Pineo et. al (2017a) as: 'a collection of summary measures about the physical urban environment's contribution to human health and wellbeing' (p.2). Urban health indicators are described in more detail in section 2.5.2.

Davern et al. (2017) claim that the most important benefit of indicator systems is that they 'provide a measurable way of keeping issues of societal importance on the public and political agenda' (p.568). The indicator literature provides many other proposed benefits to using indicators (Table 2-3). However, the majority of indicator research has focused on the development and validation of indicators with little attention to how these tools are used by policy and decision-makers (Innes and Booher, 2000; Pastille Consortium, 2002; Wong, 2006; Sébastien et al., 2014). Thus, it is unclear whether these benefits are realised in practice.

Table 2-3 Range of potential uses or benefits of indicators

Potential uses or benefits of indicators found in the literature (Songsore et al., 1998; Christakopoulou et al., 2001; Parnell and Poyser, 2002; Pastille Consortium, 2002; Wong, 2006; Lawrence, 2008; Corburn and Cohen, 2012; Kingsley and Pettit, 2011; Rothenberg et al., 2015; Davern et al., 2017)
● inform policies and decisions ● monitor policy impact over time ● compare performance with local, regional, national or international levels (also as part of performance management by higher tiers of government) ● determine targets for improvement ● transparently show performance to residents or government (accountability/performance management) ● support applications for funding/support decision-making in awarding funding ● serve as an 'early warning' of potential issues ● involve the public in prioritisation and definition of policy goals ● understand local strengths and weaknesses ● ensure that important issues stay on political and public agendas

There is a significant literature on best practice indicator development. Contributions from Davern et al. (2017) build on Holden (2009) and Cobb and Rixford (1998) regarding best practice for community indicators. A similar best practice literature exists for urban health, sustainability, quality of life, liveability and wellbeing indicator development (e.g. Briggs, 1999; Saisana and Tarantola, 2002; Balsas, 2004; Greenwood, 2008; Nardo et al., 2008; Pencheon, 2008).

2.5.1 History of indicators

The practice of developing urban health indicators can be traced back to Europe in the 1830s when physicians and statisticians began to use social data from the census (Gahin and Paterson, 2001). In the early to mid-twentieth century, social indicators were gradually developed through the publication of several key reports in the USA (ibid). In the late 1960s and 1970s the social indicators movement was made popular through city profiles, assessments and state-of-the-city reports about quality-of-life and economic issues (Wong, 2006). The Urban Institute undertook a review of indicator projects between 1970 and 1977 and identified 58 intra-city reports (Gahin and Paterson, 2001). This activity in the USA spurred international organisations to develop indicator schemes (Wong, 2006).

In the late 1970s indicator topics expanded beyond social and economic issues to include environmental subjects, later under the banner of sustainability. The Organization for Economic Cooperation and Development (OECD) produced its report on 'Urban Environmental Indicators' in 1978 which included housing among other environmental measures (Gahin and Paterson, 2001). The Brundtland Report (World Commission on Environment and Development, 1987) and the 1992 UN Summit in Rio de Janeiro were the impetus for sustainability indicators (Holden, 2001; Pastille Consortium, 2002). From 1992, the OECD published country-level environment reports covering topics including air and water pollution and intensity of energy use (OECD, 2000) Recent reports have gathered and compared the hundreds of sustainability indicators that have developed internationally (International Federation of Environmental Health, n.d.; Joss et al., 2015; Science for Environment Policy and SCU, 2015).

From 1990 the WHO Europe Healthy Cities programme involved the development of programme-wide Healthy City Indicators which were used by individual cities to inform City Profiles and local strategies (Breuer, 1998; Doyle et al., 1996). Other initiatives during the same time period aimed at producing environmental health indicators (Briggs, 1999; OECD, 1997). Such indicators were intended to inform policy by helping a city understand how it performed in relation to health or sustainability objectives.

From the late-1980s indicators (social, economic and environmental) were also tied to local policy and decision-making through New Public Management, with its emphasis on performance management through targets and assessment regimes (Parnell and Poyser, 2002; Pastille Consortium, 2002). Wong (2006, 2000, 1998) documents the impact of national government decision-making on the basis of indicators in the UK. She explains that local indicator data was used centrally to inform decisions about urban regeneration and regional funding, alongside monitoring the impact of local policies. Wong (2000) claims that local urban planners were under a 'bombardment' of guidance on the use of indicators and as a result, many policy-makers were sceptical about their use to inform local decision-making (p.213). In essence, Wong found that local policy actors viewed indicators as a distraction from more important matters and harboured serious doubts about their accuracy (ibid).

2.5.2 Urban health indicators

Urban health indicators are one form of indicators, often produced by public health professionals and epidemiologists to inform urban planning and other policy domains outside health. Many urban health indicators have been published globally, measuring a wide range of environmental exposures and related health outcomes (Prasad et al., 2016; Rothenberg et al., 2015). During the height of the social indicators movement in the 1970s there was little consensus about how to measure social progress: 'We really have no way of knowing if things are getting better or worse in view of the bewildering diversity of standards of measurement attached to most social problems' (Smith, 1973, page ix). Over four decades later, there is still ongoing debate about the merits of standardising indicators (Hayes and Willms, 1990; WHO, 2011a).

In relation to urban health, there are various types of indicators identified in the literature. For example, there are distinctions between objective/subjective and effect-based/exposure-based indicators (defined in Table 2-4). In addition to the 'best practice' literature on indicator development previously cited, there are also frameworks to guide environmental health indicator development to ensure measures are part of a chain from exposure to health impact, known as DPSEEA, covering Driving force, Pressure, State, Exposure, Effect and Action (Briggs et al., 1996; Corvalán and Kjellström, 1995) and Pressure-State-Response which does not necessarily involve health impacts (OECD, 2000).

Table 2-4 Types of urban health indicators

Indicator description	Definition
Objective vs. Subjective	**Objective indicators**: 'used existing or routinely collected data that measured concrete facts (such as the number of doctors or amount of public open space per capita)' (Lowe et al., 2015, p.136). **Subjective indicators:** 'measured people's behaviours, beliefs and perceptions about their local environment (such as perceptions of safety or satisfaction with public open space), and thus were usually sourced from population surveys' (ibid).
Exposure-based vs. Effect-based	**Exposure-based indicators:** 'measure environmental exposures with established health effects such as particulate matter with respiratory disease' (Rothenberg et al., 2015, p.11). **Effect-based indicators**: 'typically measure a health effect that is commonly associated with an environmental exposure: for example, diarrheal disease and drinking water quality' (ibid).

A number of international programmes (see Table 2-5) have used the DPSEEA framework and expanded the initial environmental focus to include a wider scope of the social determinants of health. The primary aims of these indicator projects include identifying problems, monitoring the progress of actions to improve urban health and informing policy-makers. As will be shown in chapter four, the projects in Table 2-5 are a selection of a much wider set of urban health indicator projects. These international projects were primarily instigated by the WHO and/or the EU; however, urban health indicator projects have been instigated elsewhere. For example, the Belo Horizonte Observatory for Urban Health was triggered by the creation of a Brazilian Healthy Cities programme, stemming from the WHO Healthy Cities programme, led by the Pan American Health Organization (PAHO) in the Americas (Dias et al., 2015).

Table 2-5 Major international and regional environmental health indicator development projects

Programme	Aim
WHO Healthy Cities Indicators	From 1990, indicators about health, health services, environment, and social and economic conditions were gathered from cities in the WHO Healthy Cities project to inform 'rational policy making and priority setting in relation to health' (Doyle et al., 1996, p.1).

Programme	Aim
Health and Environment Analysis for Decision Making (HEADLAMP), WHO	Aimed 'to provide valid and useful information on the local and national health impacts of environmental hazards to decision-makers, environmental health professionals and the community' and 'monitor progress towards sustainable development as recommended in *Agenda 21*' (Corvalán and Kjellström, 1995, p.71).
Environmental Health Indicators, WHO	Built on previous WHO environmental health indicator efforts to further develop indicator tools to support decision makers. 'It focuses on the establishment of a comprehensive, environmental health indicators system for integrated assessment and regular reporting based on comparable data and information' (WHO, 2000, p.4).
European urban health indicator system (EURO-URHIS)	This project build on previous European Union funded monitoring projects to create a 'comprehensive and integrated EU health information and knowledge system' which aimed to help with identification and prioritisation of urban health problems, monitor progress of actions to improve problems, and contribute to advocacy among other goals (Patterson et al., 2017, p.4).

Urban health indicators may also be used in urban planning to inform impact assessment, including health impact assessment (HIA), strategic environmental assessment (SEA) and environmental impact assessment (EIA). Impact assessments are prospective, evaluating the future expected impacts of current or proposed plans, policies, programmes or development projects (Cave, 2015). These assessments may be required through legislation, such as the EU's SEA Directive (European Parliament and Council of the European Union, 2001; Nowacki et al., 2010), or encouraged through local planning policy, such as Policy 3.2 of the London Plan's recommendation to use HIA on major development proposals (Mayor of London, 2016). HIA involves both quantitative and qualitative evidence, and policy-makers 'often give greater weight' to the former (Cave, 2015, p.376). The San Francisco Indicators Project initially started as an impact assessment process (referred to as HIA and EIA) of a specific neighbourhood plan that grew into a wider community-informed effort to integrate environmental health and social justice issues into planning policy and decision-making using indicators (Bhatia, 2014, 2007; Bhatia and Corburn, 2011; Bhatia and Wernham, 2008; Corburn and Bhatia, 2007; Farhang et al., 2008).

2.5.3 Maps and interactive indicator tools

Epidemiologists and geographers share an affection for John Snow's (1854) investigation of cholera in London because he employed maps in his analysis. Snow plotted the location of deaths caused by cholera (Figure 2-5) and found that the Broad Street pump-well was the source of disease (ibid). Technology advances in GIS-based (Geographic Information Systems) tools have allowed epidemiologists and other researchers to undertake sophisticated analyses of built environment exposures and health risks, behaviours and outcomes (e.g. Adams et al., 2014). Davern et al. (2017) claim that GIS is an 'extremely useful application for the creation, visualisation and analysis of indicator data' (p.575). In particular, they note the value of GIS for the development and analysis of indicators that test planning policy impact (ibid). Maps are also recognised as a valuable way to display indicators about the urban environment and health for consumption by policy and decision-makers (Pineo et al., 2018b).

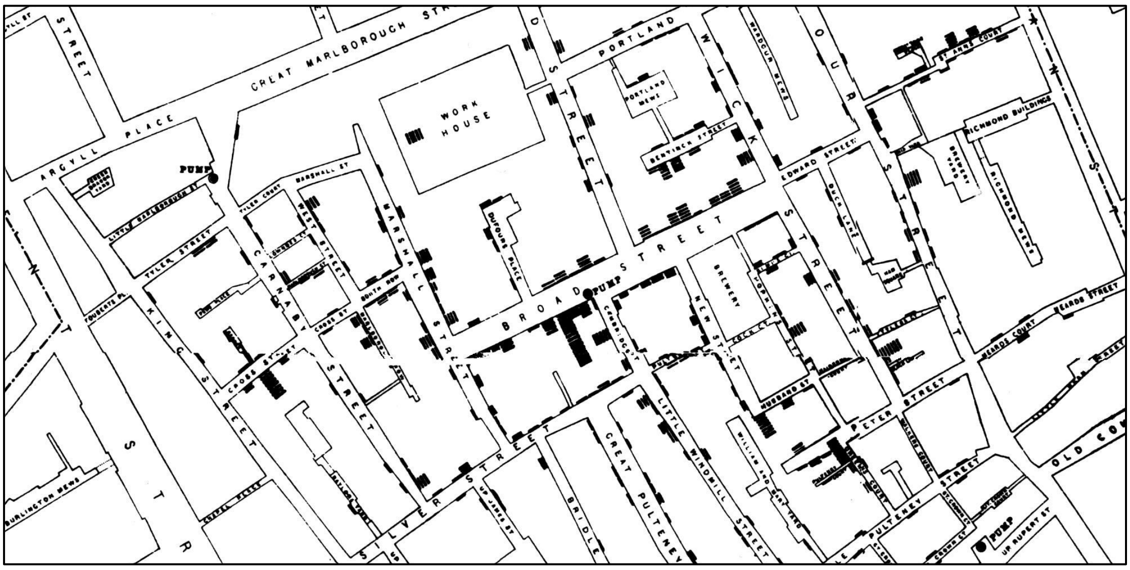

Figure 2-5 Section of the map produced by John Snow (1854) depicting cholera deaths (as black bars) at residential addresses in and around Broad Street in London

A number of interactive online tools allow users to map indicators about health and the built environment. Maps are recognised as a visual way to help non-specialists understand complex data and they are increasingly being used to share health-related data (Bell et al., 2006). There is also an important role for maps in highlighting spatial and health inequities (Rothenberg et al., 2014). For example, San Francisco's Department of Public Health provides a series of maps (e.g. Figure 2-6) about community resilience to the impacts of climate change, showing variation across the city. There is also an associated Community Resiliency Index interactive map allowing users to interrogate data on the department's website.

In summary, indicators about the environment's impact on health can be traced back nearly 200 years, however they began being used in earnest from the 1970s. There are international indicator programmes and increasingly sophisticated ways to present such metrics to the public and decision-makers via maps and online dashboards. Such presentation methods seek to simplify the detailed, and often complex, phenomena that indicators represent.

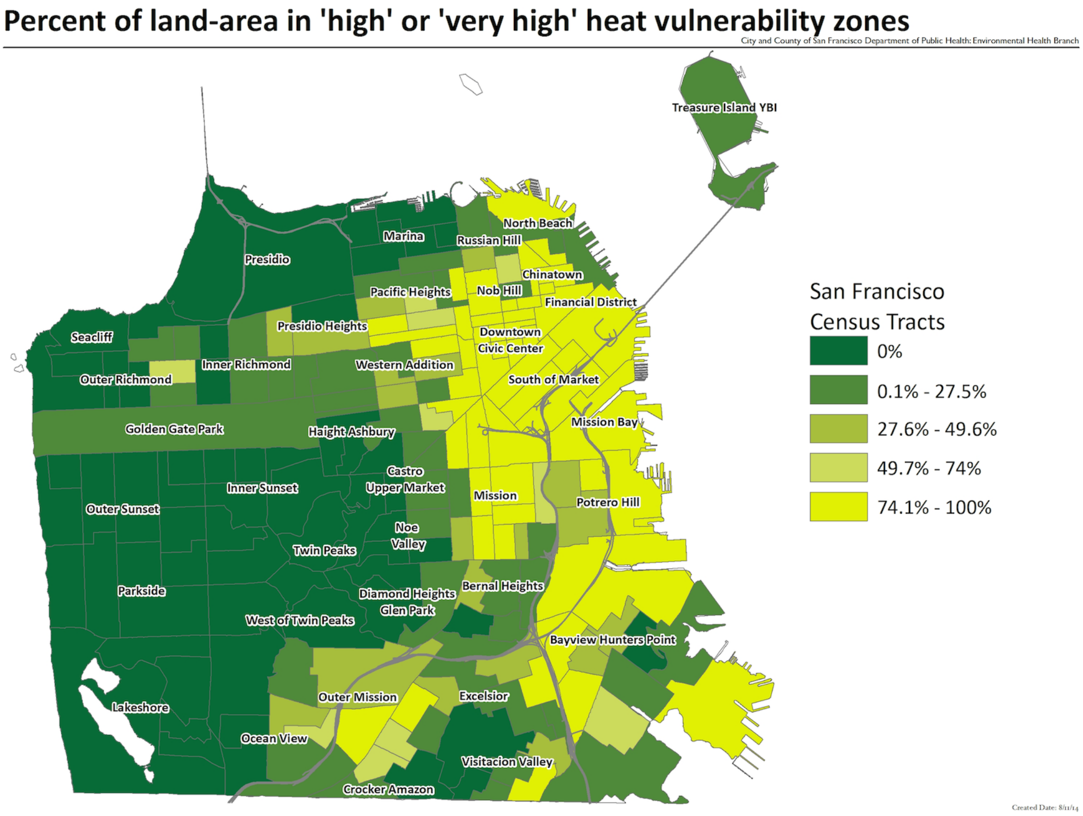

Figure 2-6 Map from San Francisco Climate & Health Program, Community Resiliency Indicator Maps, San Francisco Department of Public Health, 2018 (reproduced with permission)

2.5.4 Indicators and complexity

The level of complexity in the urban health system is a challenge for policy-makers and those attempting to create indicators which accurately measure, simplify and represent this system. Lawrence (2008) emphasises that environmental health indicators should show 'the many material and non-physical constituents [affecting health] but also the interrelations between them' (p.302). Indicators have been described as both simplifying complexity (Holden, 2001; Saisana and Tarantola, 2002) and masking complexity (Rothenberg et al., 2015; Decoville, 2018). Gatzweiler and Zhu et al. (2017) argue that improving city 'surveillance and response' systems of health outcomes and the wider determinants of health can 'harness urban complexity' (p.12). Several urban planning scholars have proposed indicators as a mechanism to help develop and monitor policy in complex systems, outlining specific characteristics of indicators to aid this task.

First, Corburn and Cohen (2012) propose urban health equity indicators to support an adaptive management framework (see section 2.4.2) to support understanding and management of both complex urban health and policy systems. Yet they warn that indicators can 'portray a too simplified picture of a complex reality and policy solutions may suffer the same defect' (2012, p.1). For Corburn and Cohen, single measure indicators are not sufficient for complex systems; instead they propose the following urban health equity indicator features (p.3):

- longitudinal
- asset driven (balancing identification of problems with further development of existing strategies)
- multi-scalar and beyond individual and biological (information regarding individual and community characteristics with policies at local, national and international levels)
- dynamic (recognising changing population and community characteristics)
- developed through collaborative and participatory processes (with experts and the community)
- linked to multiple policy domains and sectors
- highlighting political accountability and transparency.

Second, Rae and Wong (2012) advocate the use of 'strategic indicator bundles' to inform policy monitoring in the complex domain of spatial planning. These indicator bundles are an 'analytical overview' which provides an understanding of both the 'spatial relationships between places associated with individual indicators and the interindicator relationships that exist in individual locations' eschewing the reductionist approach of composite indicators (ibid; p.893).

Third, Innes and Booher (2000) suggest that the development of sustainability indicators could be informed by a complex adaptive systems approach which would require three types of indicators to support urban sustainability governance: system performance indicators; policy and programme measures; and rapid feedback indicators. These three types of indicators would inform citizens and policy-makers to enable distributed intelligence and adaptive learning so that all urban actors could contribute to sustainability as opposed to solely centrally driven initiatives. System performance indicators would be about basic agreed community values measured through a proxy indicator or subjective measure. These would provide a sense of direction at the system level. Policy and programme indicators would relate to the sub-system level and would measure specific outcomes such as public transport use or customer satisfaction. Such indicators would not require development by consensus and would allow for adjustments to policies and programmes over time. Finally, rapid feedback indicators would be for all city residents and would inform day-to-day decisions, such as travel decisions based on real-time traffic volumes.

Although such proposals for designing indicators to manage and understand complex systems exist, there is a lack of research on the effectiveness of such indicators used in practice. Furthermore, very few urban health indicator tools explicitly describe how they address complexity, which will be shown in chapter four of this thesis. One interesting exception is the Hawaii Quality of Life indicator tool (Hawaii Business et al., n.d.) which explicitly and visually attempts to address complexity. The Hawaii Quality of Life website presents a series of causal maps about the sub-systems which impact quality of life, such as the environment as well as the overall system. These interactive causal maps show the connections within the system as well as the feedback structure. This is a rare example where interconnections among indicators are clearly shown. In conclusion, indicators often seek to simplify complex processes for decision-makers through a variety of approaches. The next section explores how the effectiveness of these efforts could be evaluated within the wider context of evidence use by policy-makers.

2.6 Cultures of evidence and indicator use

Investigation of how indicators may influence the complex urban health policy and decision-making system can be informed by the literature on translating knowledge into policy. Indicators are often described as evidence which seeks to inform policy. This section defines evidence and summarises research about its use to inform the complex urban planning policy and decision-making context. Finally, the section outlines the research on the use of urban health indicators to inform planning policy and decision-making, setting out two divergent models of indicator and evidence use in the literature.

The definition of 'evidence' varies for public health and urban planning professionals, yet both would consider indicators to be included. Ingold and Monaghan describe evidence as a 'patchwork' of different types of information (2016, p.181). In relation to public health, evidence is defined as 'any useful information that serves as a basis for making decisions' including experience, scientific evidence, and local research (Banta, 2003, p.562). Policy-makers in non-health fields, including urban planning, have classified the following types of information as evidence: trials, literature reviews, needs assessments, surveys of public views or preferences, public consultation, case studies, expert opinion, routine data and statistics (Lorenc et al., 2014). Indicators report data gathered from routine data sources, resident questionnaires/surveys, sensors, geographic information systems (GIS), and field audits (Pineo et al., 2017a). Therefore the diverse definitions of what counts as evidence by public health and planning practitioners support the inclusion of indicators into this 'patchwork' of information.

2.6.1 Translation of health evidence into policy

The way in which evidence informs policy and decision-making is a large topic of study which varies in emphasis and approach across different disciplines. Evidence-based policy, policy transfer or policy translation terms (Ingold and Monaghan, 2016) seem to focus on the policy element while terms like knowledge translation, knowledge brokering and knowledge mobilisation highlight the evidence side of this equation (McKibbon et al., 2010). Although this research area often examines the use of evidence derived from scientific research, a number of studies have looked at different types of evidence and cultures of use by local government policy and decision-makers (Lorenc et al., 2014; Oliver et al., 2014a; McGill et al., 2015; Phillips and Green, 2015).

Recent research on cultures of evidence use has shown that evidence is only part of the decision-making process. Phillips and Green (2015) found that rather than basing policy and decisions on evidence, local government activities related to the social determinants of health employed 'localism, empiricism and a holistic approach' to defend decisions which met multiple aims and satisfied numerous stakeholders (p.11). This is reinforced by Oliver et al.'s (2014a) systematic review of the barriers and facilitators of evidence use by policymakers. They synthesised 145 studies and found that policy 'is determined as much by the decision-making context (and other influences) as by research evidence' (p.1).

Two studies by Lorenc et al. (2014) and McGill et al. (2015) specifically evaluated evidence use by built environment policy and decision-makers. Lorenc et al.'s (2014) systematic review found that decision-makers in planning and transport value data about local contexts and information that may predict public perceptions of policy decisions. Academic research was seen as useful when credibility and legitimacy is required, but it tended to be used to justify previously determined policies. Some studies found that built environment policy-makers perceived academic research as over-simplifying problems and not resulting in findings that could inform practice. Lorenc and colleagues found that evidence use was partly determined by constraints in built environment policy areas, such as political and legal, that were not as evident in public health policy-making. They concluded that a key area for further research is in understanding the political structures and evidence cultures that influence built environment policy-makers.

McGill et al. (2015) used focus groups to investigate how local built environment decision-makers use evidence. They found that decision-makers valued: evidence about local circumstances and case studies; quantitative data that compared the local area with neighbours or national indicators; and evidence that could be used in 'viability' arguments (as defined in planning terms, often related to the costs and benefits of policies) (p.3). They highlighted the concern that research evidence was not meeting practitioners needs and called for researchers to consider such needs when developing research questions (ibid). In summary, the existing literature on knowledge translation into local built environment policy and decision-making acknowledges that the term 'evidence' encompasses a broad range of information, with practitioners prioritising knowledge on local circumstances. Furthermore, evidence is one of many factors which influence policy and decision-makers.

Characterising urban planning as a complex policy-making process, as previously discussed, fits contemporary views of wider policy-making. Cairney and Oliver (2017) argue that the complex policy-making process should not be understood as a cycle with discrete stages in which evidence can be inserted, although this remains a popular model in health sciences. Health policy and decision-making is frequently understood as more linear and evidence-based than other social policy areas (Lorenc et al., 2014). Phillips and Green (2015) refer to public health professionals working in local government as 'evidence guardians' who can act as a 'necessary bulwark against ideologically driven decision-making' (p.2). This emphasis on positivist policy approaches clashes with a general trend toward more social constructivist or critical/communicative approaches (Healey, 1997; Innes and Booher, 2010). These debates about the role of knowledge in policy and action underpin the literature on the use of indicators.

2.6.2 Role of indicators in policy and decision-making

The existing research on the use of indicators by built environment policy-makers highlights some contradictory views on the potential value of indicators in local government policy and decision-making. The wide-ranging benefits of indicators were previously outlined with the caution that most indicator research has focused on the development and validation of indicators with little attention to how these tools are used by policy and decision-makers (Innes and Booher, 2000; Pastille Consortium, 2002; Wong, 2006; Sébastien et al., 2014). This section describes dominant models for how indicators may inform policy and decision-making, as well as research on the benefits of using UHI tools.

Researchers characterise the use of indicators in the policy and decision-making process in two ways: 1) a rational linear approach and 2) a complex process in which knowledge is seen as socially constructed and negotiated. These divergent characterisations of indicator use broadly align to Rydin et al.'s (2003) description which situates sustainability indicators as being either part of 'government' in the rational/linear approach or 'governance' in the social construct approach (p.583). They argue further that indicator use must be viewed within the second conceptualisation, as 'contextual', 'contested' and 'socially constructed' before researchers will be able to understand the difficulty of indicator application into policy (ibid).

The rational/linear approach to conceptualising urban health indicator use is best summarised by two diagrams originally associated with the work of the WHO

HEADLAMP project (previously introduced in section 2.5.2, Table 2.5) and Briggs et al. (1996). These diagrams are shown in Figure 2-7 and Figure 2-8 and have been referenced and re-interpreted by recent indicator producers (e.g. Davern et al., 2011). This conceptualisation of indicators is epitomised by Webster and Sanderson's (2013) description of Healthy City Indicators as part of a logical process of 'evidence-based, rational policy making and priority setting' in the WHO Healthy Cities programme (p.2). Both figures below move through a linear process from data to policy (or decision) with very little reference to the interpretation process. Although Figure 2-7 introduces feedback from policy action to elements of indicator development, this does not refer to the wider policy development process (or the actors involved).

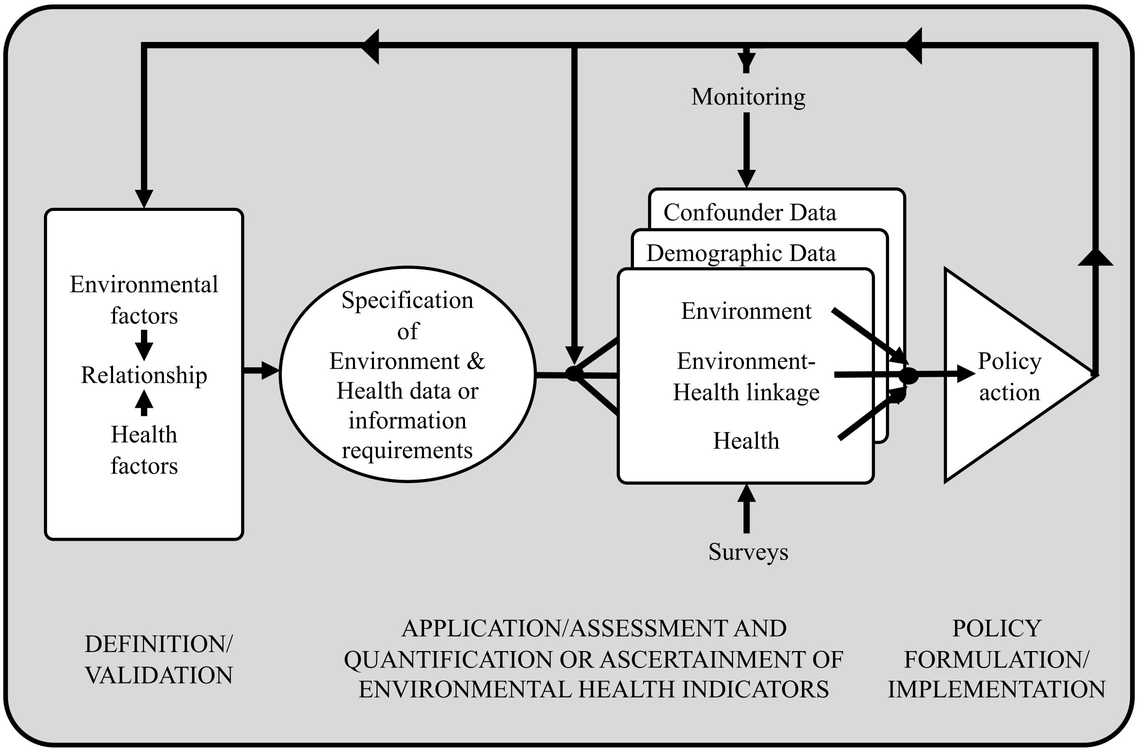

Figure 2-7 The HEADLAMP process, reproduced from Briggs et al. (1996; p.14)

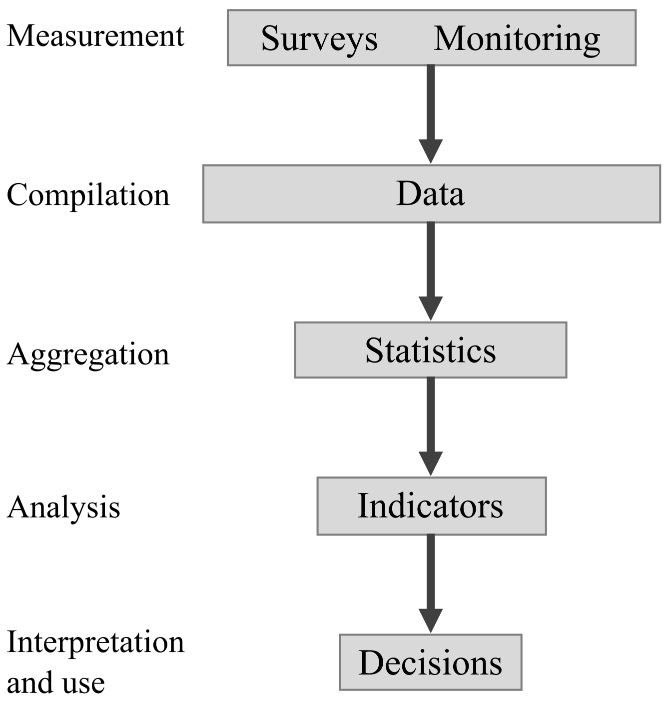

Figure 2-8 'The place of indicators in the decision-making chain' reproduced from Briggs et al. (1996: p.22)

These models contrast starkly with more recent accounts of the use of indicators in policy and decision-making and the use of evidence in policy-making more broadly. In contrast to a linear knowledge translation to policy model, Ingold and Monaghan (2016) propose the model in Figure 2-9 which highlights the importance of people, organisations and networks in determining policy agendas. The Pastille Consortium (2002) argued that the indicator research community mistakenly conceptualises indicators as an 'exogenous' entity that is inserted in a linear policy process (p.12). Furthermore, Innes and Booher (2000) claimed that most indicator reports failed to inform policy because their producers 'relied on a simplistic model of how information drives policy' (p.174).

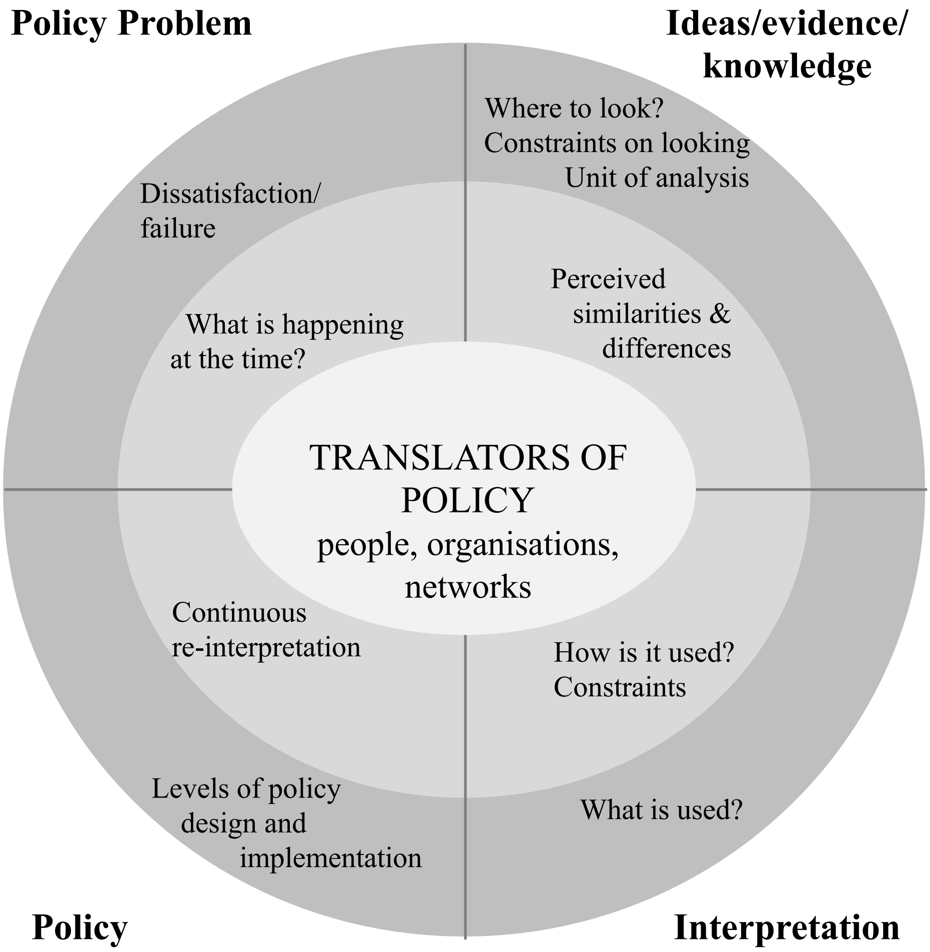

Figure 2-9 Policy translation model reproduced from Ingold and Monaghan (2016, p.177)

A number of recent studies have explored the use of indicators by urban planners, some specifically reflecting on their value to promote urban health. Such research on the use of indicators in policy focuses on co-production, complexity, interdisciplinary collaboration and other participatory approaches to governance (Innes and Booher, 2000; Pastille Consortium, 2002; Farhang et al., 2008; Corburn and Cohen, 2012; Lowe et al., 2015). These studies are discussed in further detail in the next chapter.

In relation to sustainability and community indicators, a number of authors have argued that co-production and the resulting shared learning among actors is an essential part of indicator development that is associated with policy influence. Holden (2009, 2007, 2001) argues that indicators need to be produced in collaboration with policy-makers and community stakeholders in a participatory deliberative process. She claims that indicators often fail to be effective in making change happen because they do not involve all of the stakeholders who would enact change on the ground. Similarly, Innes and Booher (2000) claim that rather than indicators themselves 'it was the learning and change among key players that took place during the course of their development and the new shared meanings and changed discourses' that was most important (p.174). Shared learning and interaction amongst practitioners may be valuable for urban health as there is a noted lack of collaboration amongst urban planners and public health professionals on the wider determinants of health (Barton, 2005; Rydin, 2012). Furthermore, shared learning may change norms, as highlighted by Innes and Booher:

> *'The [indicator] report and its findings are essential, but its influence comes through the deliberation and production process and as a consequence of the ideas becoming part of the discourse, and taken for granted by the participants. As the ideas become taken for granted they have their strongest impact on action' (2000, p.177).*

In summary, there are diverse conceptualisations of the mechanisms through which indicators may inform policy and decision-making. Traditionally, urban and environmental health indicators have been described as influencing policy in a linear manner. Although there is a lack of research on the use of urban health indicators, the existing indicator literature suggests that rather than indicators themselves, there are important processes brought about by developing indicators which influence policy such as, shared learning, changing norms and broadening participation in governance.

2.6.3 Criticisms of indicators

This section has thus far presented several significant critiques of indicators when they are presented as a technical tool produced in isolation by experts. Such indicators are seen as being ill-suited to the democratic nature of urban governance and the socially constructed nature of knowledge (e.g. Innes and Booher, 2000; Rydin et al., 2003; Holden, 2009). Furthermore the potential influence of such indicators is misunderstood by their producers due to a misconception of the policy process (Innes and Booher, 2000). Table 2-6 summarises a number of criticisms of indicators related to how they are developed and applied found in the literature. Indicator producers are often familiar with such critiques and indeed recognise that some requirements of good indicators are 'mutually incompatible' (Briggs, 1999, p.3).

Table 2-6 Major criticisms or limitations of indicators found in the literature

Critique	**Description**
Inaccurate representation of phenomena *(specifically related to composite indicators)*	Scholars have questioned whether composite indicators can be an accurate representation of reality, particularly given the arbitrary nature of weightings (Cicerchia, 1996). There are significant challenges with assigning appropriate weightings in relation to complex phenomena (Pineo et al., 2018b) and meeting the needs of diverse indicator stakeholders, including the community (Pastille Consortium, 2002; Grant and Barton, 2013). If relative weightings are not applied deliberately, then equal weightings are applied by default; which may be as undesirable as inaccurate relative weightings. Furthermore, there are a number of statistical problems with indices which affect their interpretation for policy and decision-making (Lawrence, 2008; Rothenberg et al., 2015).
Unclear conceptual basis	Indicators have no value if they are not grounded in a clear conceptual basis (Rothenberg et al., 2015). This means that the measured information relates to a conceptual or theoretical framework showing how inputs and outputs are related, such as the DPSEEA framework outlined in section 2.5.2.
Inaccurate data	Indicator data may be inaccurate or flawed in terms of factors such as: age, statistical representativeness, inadequate control of confounding factors, unreliability of modelled data, and more (Corvalán et al., 2000). Data are often gathered from routine government statistics and are likely to be several years old at best (Parnell and Poyser, 2002). Furthermore, such data may prioritise objective measurements of the urban environment from routinely collected sources, rather than subjective views gathered from the community (ibid).
Excessive cost	Collection and analysis of indicator data is expensive and does not always make use of existing data (Parnell and Poyser, 2002). Pastille Consortium (2002) highlight that focusing attention on the development of indicators and other decision-support tools can distract from more important sustainable development activities, which could be considered an opportunity cost.
Geographic non-transferability	Indicators produced in other geographic or governance contexts may not match local problems and priorities, and therefore may not be suited for local use (Lawrence, 2008; Parnell and Poyser, 2002).
Oversimplification of complex phenomena	Indicators only show part of a larger system or they try to simplify a complex system and may mislead policy-makers as a result (Lawrence, 2008; Corburn and Cohen, 2012). Decoville (2018) argued that indicators can be manipulated by politicians precisely when indicators have oversimplified a complex topic.

Critique	Description
Policy irrelevance	Many indicators are produced without consideration of which policies they could inform or monitor (Innes and Booher, 2000). Corvalán et al. (2000) argue that environmental health indicators should primarily be related to existing policy areas although some will need to help spur new policy. Holden (2001) and Cobb and Rixford (1998) argued that sustainability indicators were excessively aspirational in policy terms and for this reason they fell out of favour with policy-makers.
Underrepresentation of sub-population groups	Indicators may not represent the diverse needs of different groups within the population, such as different genders, races or physical abilities (Cicerchia, 1996; Parnell and Poyser, 2002). The gender data gap in particular has gained recent momentum in relation to the SDGs, building design and city planning (Buvinic and Levine, 2016; Criado-Perez, 2019).
Inappropriate spatial scale	Indicators at an inappropriate spatial scale (e.g. neighbourhood, city, or national scales) would mask inequities (Cicerchia, 1996; Lawrence, 2008; Prasad et al., 2016) or would not measure the impact of policy accurately (Rae and Wong, 2012), and therefore would not be useful for policy-makers. In relation to inequities, viewing the distribution of resources or problems at too large a spatial scale would not show important variations within the population. Rae and Wong (2012) point out that urban planning policies apply at multiple spatial scales and that policy impacts cannot necessarily be measured at the spatial level at which policies were made. Furthermore, aggregate-level data pose problems when seeking to translate associations from the level of populations to individuals, termed ecological fallacy (Corvalán et al., 2000).

2.7 Conclusion

This chapter has positioned urban health indicators as a form of evidence to influence urban governance, specifically through urban planning. The challenge of managing the urban environment impact on health was explained through historical efforts, including the WHO Healthy Cities programme, and contemporary urban planning frameworks to improve urban health. Complex systems and systems thinking were introduced and urban health, governance and policy-making were described as complex. Frameworks of urban environment exposures on urban health were critiqued as not fully representing the complexity of these systems, with implications for how UHI tools could address such complexity. UHI tools were described within the wider history of social, economic and environmental indicators developed throughout the 19th century. Modern examples of indicator tools which map data and allow interactive exploration of datasets and comparisons of geographic areas were introduced. The chapter concluded by reviewing the literature on how evidence informs policy, and specifically how UHI tools may influence planning policy and decision-making. Two divergent views were represented from the literature and the findings of recent studies of indicator use were described. Finally, a number of criticisms of indicators were outlined to summarise the limitations in applying indicator data for policy and decision-making.

A key point outlined in this chapter is the two divergent conceptual models of evidence use, summarised as a rational/linear model and a socially constructed/complex model. These diverse ways of understanding how evidence informs policy, and indicators in particular, are related to underlying epistemological positions. The next chapter explores philosophical assumptions and views in more detail and further interprets the literature on the use of UHI tools to set the conceptual framework for this study.

CHAPTER 3

Development of an overarching conceptual framework

3.1 Introduction

The literature review in chapter two situated the research topic of the value and use of UHI tools by urban planners within the historical and modern context of healthy urban governance, planning and indicators. This chapter *presents and interprets* literature about the philosophical underpinning of the research topics. It explains how the research topic is investigated through introduction of a conceptual framework which acts as scaffolding for the development and selection of the research questions, paradigm, theories, methods and interpretation. Conceptual frameworks have become a more central component of doctoral research in the last decade, with increased distinction between theoretical and conceptual frameworks and their role in determining the overall research approach (Berman, 2013; Grant and Osanloo, 2014). A theoretical framework 'consists of the selected theory (or theories) that undergirds your thinking… as well as the concepts and definitions from that theory that are relevant to your topic' (Grant and Osanloo, 2014, p.13). A conceptual framework includes the theoretical framework (Berman, 2013, p.2) and 'the researcher's understanding' of 'key concepts, assumptions, and beliefs that support and guide the research plan' (Grant and Osanloo, 2014, p.17) This chapter uses a visual depiction of the conceptual framework alongside a narrative description, building on Berman's (2013) approach of developing and representing her conceptual framework as a key component of her doctoral thesis.

Figure 3-1 shows the full conceptual framework diagram which is systematically built throughout this chapter as a map of the overall research approach. In the first section of this chapter, the conceptual framework is introduced, building on the literature review to synthesise key 'concepts, assumptions and beliefs' underpinning the 'epistemological and ontological worldview and approach' which are applied in this research (Grant and Osanloo, 2014, p.17) (Figure 3-1, boxes one to four). These underlying concepts informed the research goals (boxes five and six) and selection of the paradigm and specific theories (boxes seven and eight). The final section outlines the methodological approach and methods (box nine) used to investigate the research questions and justifies their selection on the basis of the conceptual and theoretical frameworks. Section headings (or sub-headings) remind the reader of the relevant box (B) in the conceptual framework throughout this chapter.

Assumptions, Beliefs & Values

(B1) Complexity as a Golden Thread impacting: measurement and representation of urban health through indicators, use of UHI tools to promote health in the complex planning policy and decision-making context.

(B2) Indicator producers: Public health professionals

- Aim to reduce suffering and improve health for population and individuals.
- Involves prevention programmes, surveillance, policy-making, evaluation, research, etc.
- Work informed by shared values: action and solution-oriented approach, evidence-based decisions, justice, equity, community engagement, participatory process, transparency, functioning government processes, public trust, collective action, respect for human research participants (Lee and Zarowsky, 2015).
- Philosophical basis: Positivist, pragmatic

(B3) Indicator users: Urban planners

- Aim to manage urban change to balance social, economic and environmental objectives.
- Involves policy-making, masterplanning of neighbourhoods/cities, evaluation of trends/needs, and decision-making via planning proposals.
- Work informed by diverse (sometimes conflicting values): decisions taken for long-term public interest, transparency and fairness, efficiency v. quality of environment, technical v. participatory approach, balancing social justice, environmental protection and prosperity of local economy (Campbell and Marshall, 2002)
- Philosophical basis: Positivist, social constructivist, pragmatic

(B4) Type of evidence: Urban Health Indictor (UHI) Tools

- Based on diverse epistemological conceptualisations (rational v social construct).
- Constructed using diverse approaches to knowledge and expert/community participation.
- Promoted for a range of uses (assess, monitor, inform, etc.) and topics (health, liveability, quality of life, etc.)

Research Goals

(B5) Research Questions

1) How do UHI tools present and measure the impact of the urban environment on health, especially in relation to complexity?

2) What mental model(s) do indicator producers and users have regarding the use of UHI tools in urban planning policy and decision-making?

3) What is the potential value of UHI tools for health promotion in the planning policy and decision-making process, particularly in relation to the complexity of this process?

(B6) Summary Research Objectives

- Create a census & taxonomy of UHI tools (RQ1)
- Understand how indicator users perceive the use and impact of UHI tools in the policy and decision-making process and represent via a Theory of Change and causal loop diagrams (RQ2, RQ3)
- Investigate the value of UHI tools in relation to simplifying, representing and addressing complex systems (RQ1, RQ3)
- Explore indicator users and producers' perceptions of the value of UHI tools for health promotion in the complex planning policy & decision-making process (RQ3)

Theoretical framework

(B7) Research Paradigm: Pragmatic

Accommodates diverse epistemological positions across public health and urban planning professions and theories, policy translation/transfer theories, complexity and systems thinking approaches and conceptualisations of UHI tools.

(B8) Theories

Complexity and systems thinking theories: bounded rationality; structure and behaviour of complex systems; move beyond traditional linear models of policy-making; interdisciplinary.

DIAD (diversity, interdependence and authentic dialogue) theory of collaborative rationality: moves beyond linear policy approaches reliant on technical expertise; values many kinds of knowledge; builds capacity for self-management; improves knowledge of policy; develops new strategies for particular situations and contexts; results in new learning, values and goals; builds social, political and intellectual capital; moves forward complex problems; empowers hidden voices; key part of governance.

Methodology

(B9) Methodology and methods: mixed-methods explanatory sequential design

Systematic Review
Census & Taxonomy (Part A)
Narrative synthesis and theory of change (Part B)

Conceptualise mental models

Semi-Structured Interviews
UHI tool producers & users

Thematic Analysis & develop preliminary mental models

Test and refine models via participatory workshop

Figure 3-1 Conceptual framework building underlying assumptions to research goals, the theoretical framework and finally the research methodology and methods (B: Box)

3.2 Underlying concepts and research goals (B1-B6)

This section reviews relevant literature on the philosophical bases and assumptions behind three core elements of the research topic: 1) indicator producers, typically public health professionals, 2) indicator users, specifically urban planning professions and 3) the use of urban health indicators. All of these topics introduce issues related to complexity, which is a cross-cutting concept intersecting multiple aspects of the conceptual framework. The section is organised in relation to boxes one to four in the conceptual framework (although box one is cross-cutting).

This section requires a short preface on terminology. Terms related to the philosophical underpinnings of research are interpreted and used differently across fields. In this research, postmodernism refers to approaches which encompass interpretivism, phenomenology, constructivism and social constructionism, the latter two being used interchangeably, as used by Allmendinger (2002), Creswell and Plano Clark (2011) and Innes and Booher (2010). Rationalist and positivist approaches are used interchangeably. Post-positivism relates to Allmendinger's (2002) definition as 'a rejection of positivist understandings and methodologies' (p.7). Systems theory encompasses complex systems theory, complexity science (as used by Innes and Booher, 2010) and systems thinking (as used by Sterman, 2006).

Although there are shared roots between urban planning and public health, these fields have progressed along different philosophical paths, underpinned by some overlapping concepts, assumptions and beliefs. Public health professionals advocate HiAP and whole-of-government/-society/-city approaches, which seek to influence policy and decision-makers across silos and sectors, including urban planning (Kickbusch and Gleicher, 2012). Urban planners seek to manage urban change by integrating many considerations about people, the economy and the environment into a framework of public policy and land-use regulations. To understand how these two professions operate and relate conceptually, it is necessary to reflect briefly on their philosophical underpinnings as these inform wider values and norms in both fields.

3.2.1 Public health (B2)

Research on the philosophical basis of public health practice describes diverse ideological standpoints among professionals with a set of shared values (Lee and Zarowsky, 2015).

Weed (1999) claimed that public health practitioners employed ontological, ethical and epistemological considerations in their policy and decision-making, balancing empiricist evaluations of evidence alongside philosophical concerns of health, the individual and the population. He recognised the complexity of this context and the importance of 'real life' considerations such as economics (ibid, p.99), and others might add community participation (Martin, 2009), in addition to the philosophical issues. Notwithstanding these practical components or constraints to decision-making, Banta (2003) argued that 'public health cannot be a matter merely of belief or… fundamentalist ideology' and professionals have an 'ethical responsibility' to use evidence in their practice (p.560). Interpreting Banta's (2003) full account, health research prioritises positivist epidemiological evidence, through a hierarchy topped by the gold standard of randomised controlled trials. Grill and Dawson (2017) proposed an ethical framework for public health decision-making that promotes the use of empirical evidence for distinguishing between and ranking policy alternatives. Despite the significant advocacy for such evidence-based policy models, researchers argue that public health policy is often not informed by research, highlighting the importance of epistemological and political boundaries in public health policy and decision-making (Oliver et al., 2014b; Smith and Joyce, 2012) and other barriers and facilitators to evidence use (Oliver et al., 2014a). Smith and Joyce (2012) argue that 'research-based ideas or technologies' inform networks of policy-makers when they fit with the 'shared value systems (or political interests)' of that group, rather than an automatic application of evidence (p.58).

Thus policy and decision-making in public health is informed by philosophical, ethical, and value-based considerations, which vary among practitioners. Lee and Zarowsky (2015) explain that although there is not a consensus about modern public health ethics, it is understood to differ from clinical medicine in its consideration of the whole community and the individual. Lee and Zarowsky also point to historical issues of 'power, politics and governance – especially the role of the state and relationships between state, citizens and science' which are still important influences on the profession today (ibid, p.6). Table 3-1 provides a summary of public health values summarised from Lee and Zarowsky. As will be demonstrated in the remainder of this section, these values align well with some, but not all, values in contemporary urban planning practice. There is a particular clash with the role of evidence-based decisions and what constitutes 'evidence' in these fields may vary considerably.

Table 3-1 Comparison of public health and urban planning professional goals, philosophies and values

Public health (Lee and Zarowsky, 2015)	**Urban planning** (Bolan, 2017; Campbell and Marshall, 2002)
Overarching goal To reduce suffering and improve health.	 To move from knowledge to action for the benefit of society (debated).
Values • action and a solution-oriented approach • evidence-based decisions • justice and equity • community engagement and participatory practice • transparency and functioning governance processes • public trust • collective action • respect for human research participants	 • regulatory (technical/legal) or efficiency or quality (debated) • technical competence and professional judgement • decisions for the long-term public interest: varying prioritisation of what this means (e.g. social, environmental, economic priorities) • using expert knowledge and community engagement to improve decision-making (debated) • transparency and accountability in decision-making • fair procedure
Shared themes of importance underpinning theory Power, politics, governance, equity, consideration of community and individual interests	

3.2.2 Urban planning (B3)

Healey (1997) provides a concise history of the philosophical underpinning of urban planning which she claims was 'built up through a mixture of evangelism, formal institutional practice, scientific knowledge and, increasingly, academic development' (p.7). She explains that at its origins, planning emerged as a response to the complex social, economic, environmental and political challenges brought on by the industrial revolution, within the intellectual movement of modernity (ibid). Planning was meant to counter these challenges and their 'dynamic and contradictory forces' using 'scientific knowledge and instrumental rationality' (ibid, p.9). As Innes (1998) clarifies, instrumental rationality as applied to planning is the 'use of objective information to produce desired outcomes' supported by 'public choice theory, which assumes specifiable rules for decisions by individuals' (p.52). The emergence of what was later called the 'rational planning process' (Healey, 1997, p.23) stemmed from the adoption of the 'policy analysis' approach (building on Herbert Simon's 'management by objectives' method) in the 1960s to address the perceived challenges of political corruption and short-term policy/decision-making to maximise electoral advantage (ibid). Rydin (2007) emphasises the central role of knowledge in planning under modernist planning theory: '[i]ndeed the very rationale for planning within modernism is that knowledge can be harnessed through planning to achieve positive change' (p.53).

In the 1960s and 1970s, planning theorists began to question the emphasis on science and rational decision-making, raising the issue of values (Healey, 1997). This coincided with a broader move in the social sciences away from positivist epistemologies toward a position where social reality is seen as being socially constructed (Allmendinger, 2002). Theorists began suggesting that planners had a 'moral responsibility to argue in favour of improving conditions for the disadvantaged' which led to the emergence of community participation in the planning process, alongside consideration of the unequal distribution of power (Healey, 1997, p.25). This back-drop led Healey to develop her perspective of communicative planning theory, called collaborative planning, which responded to the broader conceptual shift away from positivism and viewed public policy and planning as 'social processes through which ways of thinking, ways of valuing and ways of acting are actively constructed by participants' (ibid, p.29). Rydin (2007) claimed that a 'new orthodoxy' was emerging in the fragmented planning theory landscape that centred on 'the idea that the core of planning should be an engagement with a range of stakeholders, giving them voice and seeking to achieve a planning consensus' (p.54). This was variously represented through theorists and practitioners including Healey (1997), Innes (2004), and Sandercock (1998) who adopted diverse theoretical positions within the post-positivist planning theory landscape (Allmendinger, 2002).

The 'communicative turn in planning' (Healey, 1992) has been the dominant influence on planning practice and theory since the 1980s (Tewdwr-Jones and Allmendinger, 2002; Bolan, 2017). Communicative planning theory stems from Jürgen Habermas's work on communicative action and communicative rationality (Habermas, 1987, 1984; Healey, 1997), which has been diversely interpreted in planning theory and practice (Allmendinger, 2002). Habermas presented an alternative notion of reason to rationality which allowed planning theorists to move on from the classical view of planning (Harris, 2002). As part of the Frankfurt School, Habermas argued that truth can be found beneath 'socially constructed understandings, theories, assumptions and language' (Innes and Booher, 2010, p.23). Communicative planning covers a diversity of theoretical positions with a set of shared perspectives, summarised by Healey (1997):

- knowledge is socially constructed
- knowledge is developed and communicated in many ways
- individuals arrive at 'preferences' in social contexts through interaction
- power relations may 'oppress and dominate' different interests
- public policies need to draw on a 'range of knowledge and reasoning' from all those who have a ''stake' in a place'
- this approach transitions from a state of competition to 'collaborative consensus building' with the potential to 'endure' and 'build cultures'
- through this work planning is both 'embedded' in its social context and has the 'capacity to challenge' such relations (pp.29–30).

In essence, communicative planning is about participatory, deliberative and consensus building approaches with many actors. In practice, the involvement of the public in urban planning policy and decision-making has often been reduced to a tightly managed community engagement activity with pre-determined outcomes (Innes and Booher, 2010; Pineo, 2018).

Communicative planning recognises the complex social and political processes in urban policy, which planners are asked to lead, managing relationships and knowledge claims from a multitude of actors across civic society and the private sector 'many of whom are hostile and contentious' (Bolan, 2017, p.4). Rydin (2007) defines knowledge claims as 'a claim to understanding certain causal relationships' (p.56) which has clear links to Simon's (1976) definition of knowledge as 'the means of discovering which of all the possible consequences of a behaviour will actually follow it' (p.77). Much of contemporary planning theory aligns with themes in the literature on the use of urban health indicators, such as the challenges of diverse knowledge claims, power relations and consensus building. Rydin (2007) explains that in contemporary planning theory, 'the purpose of planning is to handle multiple knowledges' as opposed to the modernist view which positions planners as the experts and knowledge holders (p.55). She goes on to argue that contemporary planning approaches for handling multiple knowledges rely on deliberation and collaboration, yet these are not sufficient to 'distinguish knowledge from other bases for involvement' such as values (ibid).

The task in this section was to understand the values, beliefs and assumptions in planning practice. Thus far, this has been reviewed through theory, which cannot be taken as representative of practitioners' perspectives. In fact, Allmendinger (2002) highlights that 'shifts in [planning] theory may be and often are unrelated to the practice of planning' (p.4). Campbell and Marshall (2002) researched planners' values and professional identities and found considerable lack of consensus and reluctance to discuss values normatively. Furthermore, they identified a lack of clarity from planning academics about the 'purpose and ends' of good planning, with a preference for focusing on 'procedure and means' (ibid, p.108). Bolan (2017) notes that although many planners would recognise Friedmann's (1987) description of planning as the process of going from knowledge to action, they would also see the complexity of this process in terms of their knowledge base, potential actions and working with stakeholders in this process. The knowledge to action process involves contradictory knowledge even within individual planners and certainly among wider stakeholders, requiring planners to adopt communication and mediation skills (Bolan, 2017). Given the interdisciplinary, social and political nature of planning, it is not surprising that there are diverse views among planners about the ultimate goal of planning and how it should be achieved. As previously introduced, Table 3-1 attempts a summary of the overarching goals and underlying philosophy and values of both public health and urban planning professions and describes shared themes of importance underpinning theory and practice in both professions, informed by relevant sources (Campbell and Marshall, 2002; Lee and Zarowsky, 2015; Bolan, 2017). There was significantly less consensus in the planning literature about its purpose and means than the public health literature.

3.2.3 UHI tool use (B4)

Building on the assumptions, beliefs, values and philosophical underpinnings of both public health and urban planning, the next portion of the conceptual framework turns to urban health indicators and their use in complex policy and decision-making contexts. Indicators have been critiqued regarding their potential to influence policy and decision-making, labelled as a technical rational tool which does not fit with the complex and social urban planning context (Innes and Booher, 2000; Rydin et al., 2003). However, there are contradictory accounts that 1) support indicator use in local government urban planning (Parnell and Poyser, 2002; Wong, 2006, 2000) and 2) provide examples where this has been achieved (Corburn and Cohen, 2012; Bhatia, 2014). The conceptual framework for this study recognises two significant challenges for investigating the use and value of UHI tools by city planners: 1) opposing conceptualisations of urban health indicators and their use and 2) the complexity of urban health and the policy/decision-making process. These challenges inform the concepts, assumptions and beliefs that are addressed through the study's conceptual and theoretical frameworks and research methodology.

The thesis has previously described two divergent views of indicators and their role in the policy process. In this chapter an alternative conceptualisation of indicators is proposed which combines elements from the oppositional views. Traditionally indicators have been described as either A) rational technical tools in a linear policy and decision-making process (e.g. Briggs et al., 1996) or B) a social construct which is defined and interpreted according to local negotiation and context (e.g. Rydin et al., 2003).

The typical opposing views of indicator use are related to the nature of indicators themselves, but also represent different understandings of how policy-makers use evidence, including indicators. Chapter two introduced two models of evidence (or indicator) use in the policy and decision-making process, demonstrating the diverse nature of how indicator producers and users may conceptualise the use and value of indicators. The rational/linear view by Briggs et al. (1996) could be seen as undervaluing the complex process of policy and decision-making and the multiple actors, pressures and constraints that characterise this system. The social construct view could be seen as undervaluing the role of expert knowledge in relation to environmental health exposures.

Figure 3-2 presents an alternative view to the dichotomous rational/technical versus social construct conceptualisations of indicators and their use in policy and decision-making. The content in Figure 3-2 summarises terms and concepts identified in the literature review (presented in chapters two and three). The diagram interprets the existing literature on indicator use to highlight key concepts that are represented in the conceptual framework. The remainder of this section describes Figure 3-2 in detail.

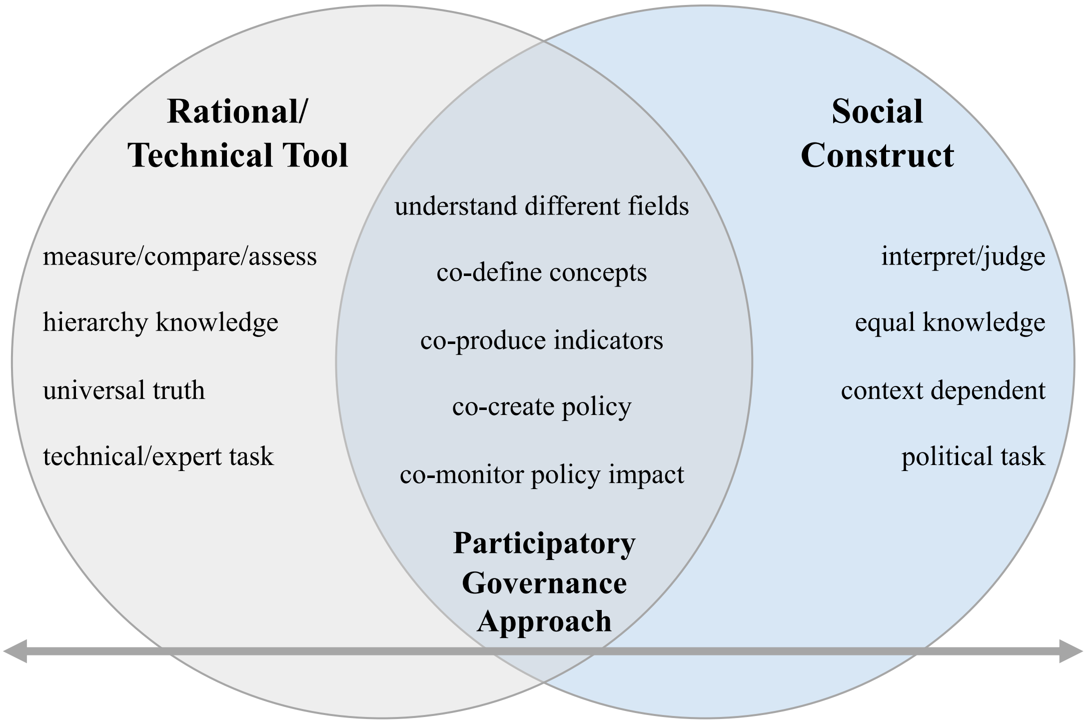

Figure 3-2 Spectrum of opposing views of indicators with a potential middle ground of a participatory governance approach to indicator development and use

The two ends of the spectrum in Figure 3-2 depict indicators as either rational/technical tools (left) or social constructs (right), with a middle alternative to these extremes where indicators are developed and used in a process of participatory governance characterised by co-production of knowledge and adaptive management principles. This alternative approach is exemplified by Corburn and Cohen (2012) and employed in varying formats by others (Hunt and Lewin, 2000; Van Assche et al., 2010; Verbeek and Boelens, 2016). This alternative view of indicators accommodates aspects of either extreme of the spectrum, such as the desirability of using research evidence to underpin indicators and the importance of using local community knowledge. This approach to developing and applying indicators may address two requirements. First, the participatory nature of this process may be suitable for the diverse professional philosophies and norms of public health and urban planning which both value research-based knowledge and community knowledge as described above. Second, this approach may also address the challenges associated with complexity and urban health. Both of these requirements are elaborated below.

Governance, participation of multiple actors and shared learning were key themes discussed in studies on the use of indicators, supporting the new conceptualisation of indicators. Three studies demonstrate the value of participatory processes in urban health indicators. The themes emerging from these studies are summarised in Figure 3-2 as understanding different fields, co-defining concepts, co-producing indicators, co-creating policy and co-monitoring policy impact. First, Lowe et al. (2015) explored the role of liveability indicators in policy-making and found that they 'can be useful for monitoring progress towards achieving policy reform, engaging government in conversations with the private and community sectors, and enhancing the connection between urban planning and public health' (p.133). Second, Corburn and Cohen (2012) focused on the governance benefits from the process of developing and using indicators through urban health equity indicators. They noted that '[t]he drafting, measuring, tracking, and reporting of indicators can be viewed not as a technical process for experts alone, but rather as an opportunity to develop new participatory science policy making, or what we call governance' (ibid, p.2). Finally, in their description of the San Francisco Indicators Project, Farhang et al. (2008) emphasised the important role of the community in developing indicators to inform land-use planning. They listed a range of outcomes from the use of indicators, including increased understanding among those who produced indicators of the health impacts of development and new collaborations between constituent groups in the city (ibid).

The 'Participatory Governance Approach' in Figure 3-2 may help address the challenge of complexity, which impacts both indicator developers and users and is manifest in multiple interrelated ways. In chapter two the following complexity challenges were raised:

- developing indicators which accurately represent the complex urban health system (particularly with regard to limitations of epidemiological methods);
- evaluating the effectiveness of specific policy options or interventions (before and after application);
- investigating when and how indicators can improve health through the complex process of urban policy and decision-making.

The use of urban health indicators in a process of participatory governance responds to Verkbeek and Boelens' (2016) argument that the complexity of urban health requires two strategies: 1) co-production of knowledge between experts and lay community members and 2) an adaptive management approach. First, co-production of knowledge aligns well with contemporary health practice and policy-making generally (Badland *et al.*, 2014; Gelormino *et al.*, 2015; Northridge, Sclar and Biswas, 2003; Rydin *et al.*, 2012) which promotes public participation (Martin, 2009). It is also promoted by Corburn and Cohen

(2012) and Innes and Booher (2010) as part of a wider strategy to address complex urban planning challenges, such as urban health equity. Second, Corburn and Cohen (2012) referred to adaptive management as an iterative governance process which responds to 'the failures of linear processes where narrow disciplinary scientists have aimed to develop complex models, predict long-term outcomes, and suggest one-time policy standards' (p.2). They proposed that urban health equity indicators could be used in a process of adaptive management which involves collaboratively developing, monitoring and adjusting policy (ibid). Adaptive management is also suitable for urban health issues because it emphasises setting policy even when there is not a clear relationship between cause and effect (ibid). Elements of these strategies were found in the wider literature about urban health indicators; however, they are relatively underexplored in indicator research.

3.2.4 Research goals (B5 and B6)

Under the 'Assumptions, beliefs and values' heading in Figure 3-1 boxes one to four contextualise the existing dominant and emerging representations of indicators in the policy and decision-making process from the current literature and highlight the assumptions, beliefs and concepts that must be addressed through the research goals, theoretical framework and research methodology. The research questions (box five) specifically investigate the complexity challenges highlighted in the previous section (research questions one and three). Research question two recognises that there may be different mental models between indicator producers and users partly as a result of the diverse philosophical underpinnings of public health and urban planning. Finally, research question three allows for a broad investigation of the potential health promotion value of indicators in response to the diverse conceptualisations of indicator use in the literature. The research objectives (box six) are a summarised version of those presented in chapter one (Table 1-1) and each objective is linked to at least one research question.

3.3 Pragmatic research approach (B7)

This research project spans the fields of health, urban planning, policy science and complexity theory, encountering multiple ontological and epistemological views including positivism and postmodernism. To conduct research in this area, it is necessary to understand and accommodate these diverse views through selection of an appropriate research paradigm and theoretical framework. This section builds on the previous description of assumptions, beliefs and values to summarise the epistemological basis of existing research in the fields of study and outlines an approach for this project.

3.3.1 Overview of paradigms in existing research

Urban health indicators originated from health and public health science which have been described as ‘pragmatic sciences’ (Banta, 2003, p.559) combining diverse epistemological views. Banta (2003) reported the views of a WHO European Advisory Committee on Health Research which argued that evidence should be generated from either positivist or interpretivist approaches depending on the research question. However, their conclusion privileged quantitative positivist research as ‘highly important and very valuable’ while qualitative research ‘should usually be used in a complementary manner with quantitative research’ (ibid. p.569). This is indicative of the dominant role of positivism in health sciences, although other views are accommodated in the overarching pragmatist approach.

Indicators have been described as being derived from positivist approaches but functioning in policy and decision-making as a relative social construct (e.g. Parnell and Poyser, 2002; Rydin et al., 2003). Wong (2006) argued that indicators are ‘seen’ to be developed in the positivist tradition and this has ‘elevated indicators to a darling position in the policy world’ (p.3). However, in her review of indicator literature Wong identified three epistemological bases (empiricism, rationalism and relativism) which are described in Table 3-2 showing how the underlying epistemology characterise the development and use of indicators. Not all of these epistemological bases are compatible with positivism. The view of indicators as relativist, involving interpretation by users, moves toward Rydin et al.’s (2003) claim that indicators are a social construct and can no longer be seen as technical policy tools.

Table 3-2 Three epistemological bases for indicators, summarised from Wong (2006, pp. 3–4)

Epistemological basis	Characteristics of indicators
Empiricism	Indicators are used to measure abstract concepts and problems and show how a problem is structured or changing.

Rationalism	Indicators are used for goal setting and monitoring achievement, requiring a 'presupposition of certain innate knowledge' regarding the benchmark to be achieved (p.3).
Relativism	Indicators require interpretation by users who apply value judgements and therefore the 'norm of assessment is susceptible to change and interpretation' (pp.3-4).

While urban planning theory was historically grounded in positivist epistemologies, it has since moved to post-positivist, postmodern and pragmatic theories (Allmendinger, 2002). Understanding how indicators, as a form of 'evidence', are used in policy and decision-making sits in policy transfer, policy translation and evidence-based policy research fields which have been approached from both positivist and pragmatist perspectives (Ingold and Monaghan, 2016). Complex systems theory spans multiple research paradigms. Complexity theory has been described as 'functionalist/structuralist', while systems thinking can be seen as either 'hard', embodying a 'functionalist/positivist' character, or 'soft', taking on an interpretive approach (Jackson, 2006, p.653). Lane (2001) argued that system dynamics does not fit 'in any one paradigm with any certainty' and summarises its application in positivist and interpretivist approaches (p.97).

These diverse ways of understanding truth, reality and knowledge are not always compatible and have to be unpicked to determine which assumptions underpin the methodologies and methods for the research topic. Kuhn's (1962, 2012) incommensurability thesis argued that researchers in different paradigms were working in 'different world[s]' (2012, p.134) and inherent assumptions would not permit objective judgement of knowledge claims across paradigms (Phillips, 1987). There is agreement that researchers work within a framework of assumptions and theories, however critics of Kuhn's incommensurability thesis proposed that it is possible to accept and understand multiple paradigms simultaneously (Phillips, 1987). The interdisciplinary research topic addressed here requires an accommodation of multiple paradigms and diverse methods.

3.3.2 Justification for adoption of a pragmatic approach

The philosophical position of pragmatism appealed to planning theorists because pragmatists eschewed *a priori* theorising and required that knowledge was gained through practical research of concrete problems (Allmendinger, 2002; Innes and Booher, 2010). According to Innes and Booher (2010) pragmatists combined diverse epistemologies:

> *'They were empiricists in the sense that they believed in the importance of searching out facts and data, while at the same time they were social constructionists who saw knowledge as an evolving social product' (p.26).*

Creswell and Plano Clark (2011) compared diverse paradigms and explained their implications for research methodologies. They summarised the pragmatic paradigm as follows (p.42):

- Nature of reality (ontology): allows both singular realities and multiple realities to be explored through research, thus accommodating multiple epistemologies.
- Values in research (axiology): accommodates both biased and unbiased perspectives
- Methodology: can include deductive, inductive and participatory approaches which can also be mixed.
- Language of research (rhetoric): can employ either a formal style familiar to positivists or a more informal literary style.

The pragmatic perspective fits the investigation of indicators as technical tools and/or social constructs and how they inform planning policy. It accommodates exploration of the nature of indicators as tools, with their diverse characteristics, through a quantitative census. It also allows for an in-depth exploration of indicator use in the policy and decision-making process which requires an understanding of actors who are informed by diverse experiences and work in diverse contexts. Finally, pragmatism allows for multiple theories to be used within this worldview to frame the research questions. As described previously, there are multiple models of indicator use and the policy process which span positivist and postmodernist perspectives. This research uses systems theory and collaborative rationality to investigate urban health indicator tools and their use in policy and decision-making.

3.4 Theoretical lens (B8)

3.4.1.1 *Systems theory*

Complexity and systems thinking approaches were introduced in chapter two. The reasons for adopting these approaches are threefold and include: 1) the ability to take a systems perspective of indicators and policy-making, exploring interconnections and feedback relations; 2) investigation of indicator use and policy-making within the perspective of bounded rationality and 3) these approaches are well-suited to interdisciplinary research approaches. Each of these points is elaborated below.

First, approaching urban health and planning policy-making as being characterised by complexity allows for the exploration of multiple interacting phenomena. This could provide a more realistic account of the use of indicators than the rational linear model which has typically been used. Systems thinking refocuses attention from detailed analysis of constituent parts to examination of the behaviour of the whole system of policy and decision-making. Sterman (2006) stated that systems thinking is about examining problems from different viewpoints and 'expand[ing] the boundaries of our mental models' (Sterman, 2006, p.511). A systems approach allows for a departure from the traditional focus on the barriers and facilitators of evidence use to a more holistic understanding of where improvements or interventions are possible in policy-making.

Second, systems thinking and its underpinning theories provide principles to approach the cognitive process of policy and decision-making which move beyond the rational model. In other words, we do not choose to ignore certain evidence or perspectives, rather we cannot process all data equally. Herbert Simon's (1976) bounded rationality principle is a way of understanding how a decision is reached given limits to time, knowledge and processing power in the human brain. Bounded rationality recognises that our cognitive systems are not able to process all stimuli in a given situation. Shortcut tools, or heuristics, are used to understand stimuli and make decisions. The rational model of decision-making is particularly problematic in complex dynamic systems (Sterman, 2006). Therefore approaching indicator use by policy and decision-makers within a bounded rationality and systems thinking framework can provide new insights into this process.

Third, systems theory and bounded rationality are interdisciplinary theories which can be applied across many research fields (Sterman, 2006; Zimmermann et al., 2015). Planning theories and public policy theories are informed by bounded rationality (Cairney, 2012a; Healey, 1997). For example, in policy studies, bounded rationality is used to explain how people have a limited ability to consider all of the relevant facts for policy-making, thus they focus on factors which they evaluate as most relevant and important (Cairney, 2012a). In relation to the complexity of policy-making, Cairney (2012b) discusses how punctuated equilibrium theory uses bounded rationality and complexity language (in terms of positive and negative feedback) to describe how policy-makers determine which information to regard. Systems thinking approaches use bounded rationality to explain bias and limitations in thinking (Sterman, 2006). Using cross-disciplinary approaches such as complexity theory and bounded rationality will provide additional explanatory power to the topic of evidence-based policy and decision-making. This is also a goal of system dynamics, a key method in this research.

3.4.1.2 *The DIAD theory of collaborative rationality*

Innes and Booher (2003, 2010) combined components of Habermas's communicative rationality and emancipatory knowledge, negotiation theory and complexity theory with planning practice knowledge in their DIAD (diversity, interdependence and authentic dialogue) theory of collaborative rationality. This descriptive ('of successful collaborative processes') and normative (in providing 'a model for the design and implementation of collaborative processes that can produce significant outcomes') theory is well-suited to the research goals of this study (Innes and Booher, 2010, p.35). The underlying basis and articulation of this theory (outlined in Figure 3-3) is closely related to the concepts outlined in the first section of this chapter regarding the potential role of participatory governance processes in the development and use of indicators. Furthermore, this theory provides a contemporary interpretation of principles from Habermas (1987, 1984) and Healey (1997) and integrates complexity theories, particularly regarding complex adaptive systems, building on previous work (Innes and Booher, 1999, 2000; Booher and Innes, 2002). Therefore, this theory is applied alongside complexity theory and systems thinking approaches as the theoretical framework for the study.

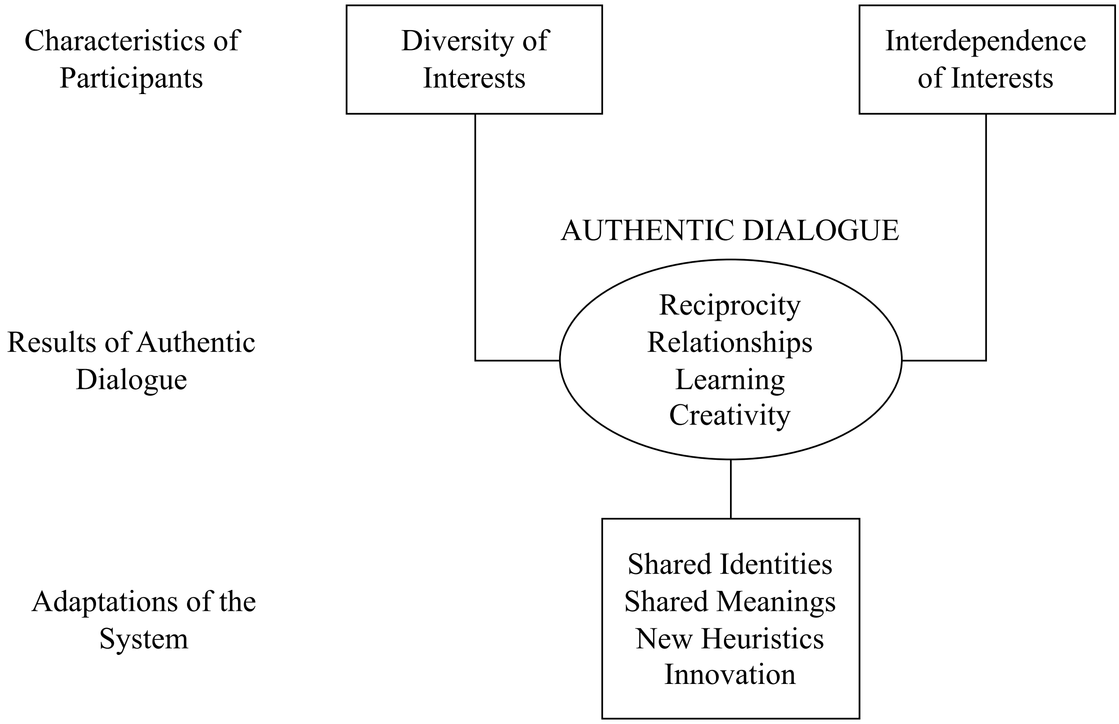

Figure 3-3 Visual diagram of network dynamics in Innes and Booher's (2010) DIAD theory of collaborative rationality, reproduced from p.35

Innes and Booher's DIAD approach recognises the failure of traditional linear models of policy-making and implementation, which rely on technical expertise. They highlight the increasing importance of 'lay knowledge' for complex problems and the inclusion of diverse knowledge claims in collaborative policy-making processes (Innes and Booher, 2000, p.5). In essence, collaborative rationality means that multiple stakeholders 'jointly engage in face to face dialogue, bring their various perspectives to the table to deliberate on the problems they face together' with the ultimate goal of seeking consensus about appropriate policy solutions (Innes and Booher, 2010, p.6). They relate collaborative policy processes to complex adaptive systems and claim that such processes will result in 'new knowledge and unanticipated policies and practices' alongside systematic 'changes in the values, goals, shared understandings, and the underlying attitudes of the participants' (ibid, p.34). These systemic changes will help with complexity by bringing about new relationships, capabilities and attitudes which are dispersed and linked across networks and diverse actors.

Analysis of the function of UHI tools in the planning policy and decision-making process must acknowledge and seek to understand power relations, collaboration, social context and diverse understandings of knowledge. The DIAD theory of collaborative rationality for public policy is thus a useful theory to inform the investigation, analysis and interpretation of the use of indicators in planning practice. However, there are criticisms of the approaches in this theory.

Rydin (2007) reviews and presents a number of critiques about the potential for planners to evaluate and build consensus around diverse knowledge claims, using deliberative and collaborative approaches, as advocated by communicative planning and collaborative rationality. She summarises general concerns regarding these theories presented in the literature as: lack of clarity about how to translate the theory into practice; concerns that planners do not have the skills to undertake such processes; risk of powerful interests derailing activities; and risk that such processes cannot achieve consensus in the face of conflicts among interests (Flyvbjerg, 1998; Rydin, 2003; Tewdwr-Jones and Allmendinger, 1998). She then specifically turns to the concern that deliberative and collaborative approaches are not suitable to handle multiple knowledge claims. First, there are concerns that translating different knowledge claims is problematic when groups approach knowledge from a background of different experiences (and epistemological bases). Against this critique, Innes (2004) clarified that consensus-building through collaborative rationality occurs through 'collaborative storytelling' which is effective when there is 'no dispute over knowledge or there is no certain knowledge' both of which Rydin sees as rare (2007, p.56). Second, Rydin argues that it is important to distinguish between knowledge claims and other claims that actors make, such as ethical claims (ibid). She provides a typology of planning knowledge claims and argues that planners should be involved in 'opening-up' and 'closing-down' knowledge claims through debate and testing, which may involve supporting actors who are less powerful to express their knowledge (p.58).

In summary, this section has justified the selection of systems theory and the DIAD theory of collaborative rationality for the conceptual framework and described some criticisms of the latter. These two theories are complementary and well-suited to the research question of the use and value of UHI tools in urban planning.

3.5 Mixed-methods methodology (B9)

This section describes the overall research methodology and methods as they relate to the conceptual framework. Each of the methods is briefly justified for this study, with some discussion of criticisms or limitations. A more detailed description of the application of these methods is contained in chapters four to seven.

Methodology refers to the way in which a researcher gathers knowledge and the assumptions underlying a researcher's activities (Taylor et al., 2016; Travers, 2004). Under a pragmatic research paradigm, the research questions (Figure 3-1, box five) inform the methodology and methods using a 'what works' approach (Creswell and Plano Clark, 2011). Investigating and understanding how social/professional norms and context shape the use of indicators in the planning policy and decision-making process requires social science theories and methods. While understanding the nature of UHI tools, requires application of positivist approaches. The resulting quantitative and qualitative data will be interpreted together, using systems theory and collaborative rationality, to provide new insights into the use of UHI tools in planning policy and decision-making. Thus a mixed-methods approach is adopted, following an explanatory sequential design (introduced in Chapter 1, Figure 1-1) comprising collection and analysis of both secondary and primary data.

A mixed-methods approach of explanatory sequential design involves collecting first quantitative and then qualitative data and then integrating the two datasets (Creswell and Plano Clark, 2011). The qualitative data collection is used to further elaborate trends and findings from the quantitative component (Ivankova et al., 2006). Although combining such data can be challenging, there is potential to find additional insights that were not evident through the separate datasets (Bryman, 2007). The systematic review follows the sequential explanatory design method. The results from the review (which includes both quantitative and qualitative data) are then used to inform further stages of the PhD study, further extending the sequential explanatory design as the analysis of secondary quantitative data informs the collection of primary qualitative data.

Figure 3-4 provides a visual of how each component of the study builds on previous components to develop: 1) theory of change, 2) model conceptualisation, 3) thematic analysis themes and 4) a causal explanation of UHI tool use.

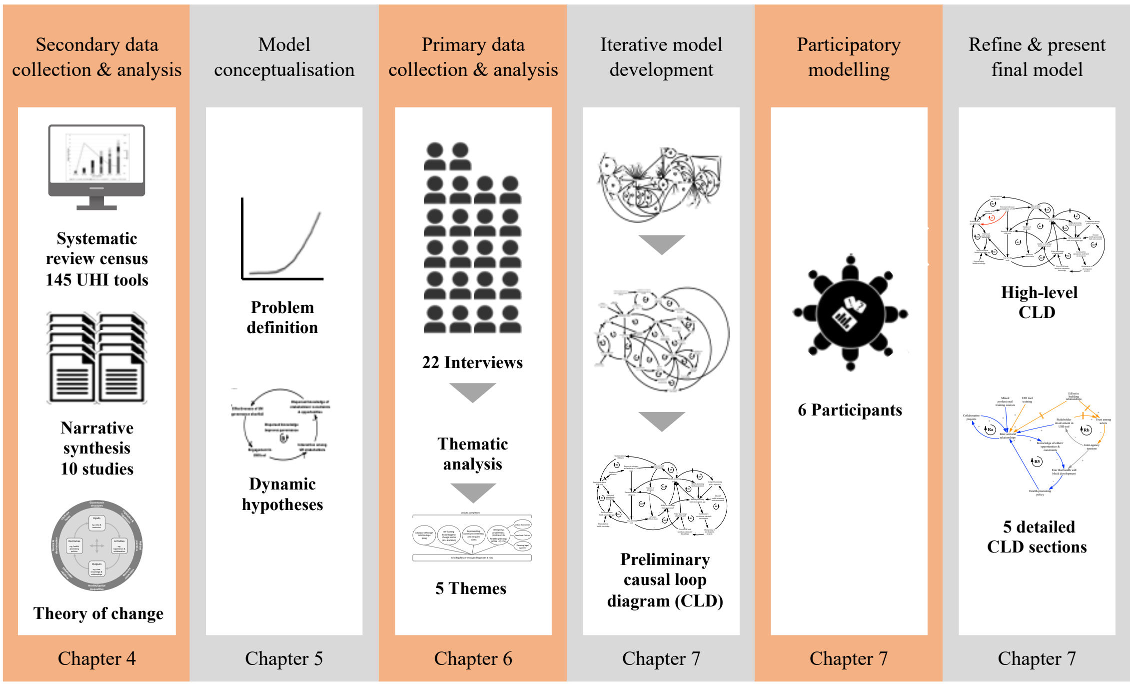

Figure 3-4 Visual depiction of study methods and outputs

3.5.1 Systematic review

A systematic review follows a set method to gather and analyse literature to avoid the bias which can be found in traditional literature reviews (Petticrew and Roberts, 2006). Bias is introduced in literature reviews in several ways, including: limited and unsystematic searches of studies; inconsistent inclusion/exclusion of studies (which could result in cherry-picking); and inconsistent extraction, analysis and synthesis of study findings. Originally developed to understand the effectiveness of interventions in the medical field, systematic reviews are now used more widely in the social sciences (ibid). Although a review of qualitative studies may not result in a 'meta-answer' it can help build and test theories about why a particular intervention is effective (or not) and which factors aided or disrupted the implementation of a particular intervention (Popay et al., 2006).

The detailed methods for the systematic review in this study were outlined in a review protocol and published in *Systematic Reviews* in January 2017 (Appendix A1.1). Publishing a detailed protocol creates transparency and allows peer review (Petticrew and Roberts, 2006). Pineo et al. (2017a) followed best practice guidelines and included a completed PRISMA-P checklist (Preferred Reporting Items for Systematic review and Meta-Analysis Protocols), sample search terms, and data extraction templates in the appendices (Moher, 2009; Shamseer et al., 2015). The outputs of the systematic review include a census and taxonomy of UHI tools and a narrative synthesis of studies describing their use in municipal built environment policy and decision-making. The latter is used to develop a theory of change, as recommended by Popay et al. (2006) (Chapter 4) and both outputs are used to conceptualise mental models of UHI tools (Chapter 5).

3.5.2 Theory of change

A theory of change (ToC) is a guiding framework for evaluation which makes explicit underlying beliefs about how a policy or programme achieves its objectives (Morra Imas and Rist, 2009; Weiss, 1998). The methods and benefits of developing a ToC were popularised through Carol Weiss's (1998) work in evaluation research. The ToC approach seeks to understand if and how programmes or policy interventions have achieved anticipated goals (Bryman, 2004). The approach has since been used to evaluate public health initiatives, among many other policy areas (Connell and Kubisch, 1998; Weiss, 1998; Breuer et al., 2016).

There are many definitions for a theory of change. Weiss (1998) explains that a ToC 'is a set of hypotheses' that explain 'the causal links that tie program inputs to expected program outputs' (ibid, p.55). Morra Imas and Rist (2009) describe a ToC as visually conveying beliefs about how a policy or programme works. Specifically, they argue that such theories 'open the "black box" to show how an intervention expects to convert inputs, activities and outputs into results' (ibid, p.152). A ToC must explain the wider context in which an initiative will be applied and any underlying assumptions that are conditions of the programme's success. In other words, a ToC seeks to make explicit actors' mental models of how a programme works.

There are multiple purposes of developing a theory of change. In addition to providing clarity about programme goals and the means to achieve these, Weiss (1998) argued that a ToC can identify and explore 'unintended consequences, unplanned and unwanted chains of events that the program may set in motion' (p.60). Furthermore, evaluators and programme managers can expose diverse understandings among programme staff who may have been working at cross-purposes and develop an overall explanation of 'stories of means and ends' that resonate with policy-makers and the public (ibid, p.68).

The literature provides guidance on the visual depictions of ToCs and emphasises the utility of such diagrams for programme stakeholders (Weiss, 1998; Morra Imas and Rist, 2009). Although ToC diagrams are often represented in a linear manner (Morra Imas and Rist, 2009), Weiss (1998) was clear that such theories evaluate 'complex undertakings' and thus provided methods for addressing such complexity (p.48). For example, Weiss recognised that evaluators may not be able to pursue all 'causal pathways' and therefore provided criteria for selecting pathways, including: uncertainty, volume, centrality and purpose (ibid, pp.65–66). In relation to ToC diagrams, Morra Imas and Rist (2009) explain that a 'good theory of change does not assume simple linear cause-and-effect relationships' and should include arrows linking elements of the theory back and forward to other elements within the theory (p.157). However, examples of ToC in the literature, particularly logic models, are usually presented in a linear format without explanation of cause and effect relations (Breuer et al., 2016).

Allen et al.'s (2017) development of a ToC was analogous to this study on the use and value of UHI tools. Allen et al. created a ToC for decision support systems for rabbit management, a complex environmental challenge in Australia. Similarly to UHI tools, they argued that decision support systems aim to support practitioners with complex decision-making, yet they remain underutilised and stakeholder participation has been advocated to increase their use (ibid). They proposed ToC as a process to inform the design, use and evaluation of two decision support systems. Their study demonstrated the value of a ToC approach to describe how UHI tools influence complex policy and decision-making contexts where multiple stakeholders are involved.

In this study, ToC is used to explore and summarise secondary data on indicator producers' and users' mental models of how UHI tools support health promotion through urban planning. ToC is familiar to the public health research community (Breuer et al., 2016) and it is recommended in narrative synthesis (Popay et al., 2006). Furthermore, it supports consideration of interconnections which can inform the conceptualisation of mental models using systems thinking approaches. The ToC methods are elaborated in chapter four. The next section describes thematic analysis, which is one of the techniques used to synthesis data for the ToC.

3.5.3 Thematic analysis

Qualitative data from the systematic review (Chapter 4) and semi-structured interviews (Chapter 6) are analysed using thematic analysis at two separate stages in the study. The narrative synthesis in chapter four uses thematic analysis techniques, but it is not a full thematic analysis, as done in chapter six. Chapter six adopts Braun and Clarke's (2006) six phase thematic analysis process, which has been further developed by Nowell et al. (2017) in relation to Lincoln and Guba's (1985) trustworthiness criteria. The detailed thematic analysis methods for the systematic review and semi-structured interview data analysis are explained in those chapters, including explanation of the six phases. The justification for selecting the thematic analysis technique is described below and it is threefold: 1) it accommodates diverse theoretical lenses to interpret data, 2) it allows a hybrid inductive and deductive analysis and 3) it allows coding at semantic and latent levels (Braun and Clarke, 2006).

First, thematic analysis is theory-neutral and can be applied in both essentialist and constructionist paradigms (Braun and Clarke, 2006) and 'can assist in communication between positivistic science and interpretive science' (Boyatzis, 1998, p.6). In other words, researchers can choose appropriate theories to analyse and interpret the data for the social processes being investigated in line with this study's pragmatic approach. Second, when coding data, researchers can apply an inductive approach, where themes emerge from the data itself, or a deductive 'theoretical' approach, where coding is based on the research question or theory-based interests (Braun and Clarke, 2006, p.84), such as those set out in the conceptual framework. As previously described, this study crosses positivist and interpretivist paradigms. Thematic analysis is well-suited to accommodate the diversity of epistemological positions in this study and it also allows emerging themes to inform subsequent analysis through application of a hybrid inductive and deductive coding approach informed by the conceptual framework.

Finally, within thematic analysis approaches, coding can take place at either 'semantic' (what Boyatzis called 'manifest') or 'latent' levels (Braun and Clarke, 2006). The semantic level involves coding data based on what is explicitly written or said, and then interpreting patterns and broader implications. In contrast, a latent level analysis looks for '*underlying* ideas, assumptions, and conceptualizations – and ideologies' thereby interpreting meaning when developing themes from the data (ibid, p.84). For this study, analysis at the semantic level is adopted for the narrative synthesis of studies about the use of UHI tools (part B of the systematic review). The analysis of interview data (Chapter 6) is done with a codebook based on the conceptual framework and the results of the systematic review. The specific thematic analysis process is described in more detail in the methods section for the relevant chapters.

There are some disadvantages and criticisms of thematic analysis. First, the use of thematic analysis is unusual among system dynamics practitioners where Strauss and Corbin's (1998) grounded theory approach is commonly used to analyse qualitative data to inform modelling (e.g. Luna-Reyes and Andersen, 2003; Kim and Andersen, 2012; Yearworth and White, 2013; Eker and Zimmermann, 2016). However, there are recent examples of thematic analysis in system dynamics modelling, particularly in the creation of causal loop diagrams (e.g. Comrie, 2015; Ibrahim Shire et al., 2018; Sharma et al., 2017). The prevalence of grounded theory among system dynamics literature may correspond to the theory's general popularity rather than a reflection that other approaches are not suitable for system dynamics analyses. Furthermore, there are criticisms related to grounded theory's inductive data driven nature. Braun and Clarke (2006) argue that 'researchers cannot free themselves of their theoretical and epistemological commitments, and data are not coded in an epistemological vacuum' (ibid, p.84). Bryman (2004) states that contrary to the position of grounded theory, many researchers 'would take the view that it is desirable that researchers are sensitive to existing conceptualizations, so that their investigations are focused and can build upon the work of others' (p.407). In this study, thematic analysis was therefore selected as a more flexible approach allowing for the analysis of data based on a particular lens informed by the conceptual framework.

A second criticism of thematic analysis is the lack of significant literature about the method, particularly in comparison with grounded theory, which could lead to inconsistency and lack of coherence when developing themes (Holloway and Todres, 2003; Nowell et al., 2017). To counter this claim, Braun and Clarke (2006) and Nowell et al. (2017) emphasise the importance of making decisions explicit when reporting results. The methods sections in chapter four and six provide detail commensurate with the application of thematic analysis, where the latter chapter provides significantly more detail on the process.

3.5.4 Semi-structured interviews

The semi-structured interviews are informed by the findings from the systematic review both in terms of selecting interview participants and creating interview questions. This research phase investigates the use of UHI tools in the planning policy and decision-making process (RQ 2) and the value of UHI tools for health promotion in the complex policy process (RQ 3). Semi-structured interviews are a flexible way to gather data from participants using pre-set interview questions as a starting point and allowing participants to guide and divert the discussion toward issues they feel are important (Bryman, 2004). Data from the semi-structured interviews are analysed using thematic analysis through the lens of the conceptual framework (as described above). Interview participants are informed and consented following an approved process through the BSEER Low Risk Ethics process. The selection of cases and participants for the semi-structured interviews is described in chapter six. The semi-structured interviews inform the development of mental models of UHI tool use, described below.

3.5.5 Systems thinking – or qualitative system dynamics modelling

According to Lane (2016) systems dynamics is ‘a method of enquiry that concerns itself with behaviour over time and the causal mechanisms that can usefully be seen as generating that behaviour’ (p.527). The method allows for testing of causal hypotheses which are modelled as closed causal systems, fully formulated and parameterised (ibid). In contrast, systems thinking can be defined as ‘a specific mapping approach derived from System Dynamics Modelling’ which helps modellers and their audience to ‘understand long chains of consequence, unanticipated consequences, feedback effects and the source of observed behaviour’ (pp.527–528). The term ‘systems thinking’ is used by a broad set of systems science approaches that use qualitative and quantitative methods to analyse systems (Sterman, 2000; Lane, 2016). In this study, qualitative system dynamics, defined as ‘systems thinking’ by Lane (ibid), is used to explore and map mental models of the use and value of UHI tools using causal loop diagrams (CLDs).

The purpose of system dynamics modelling is akin to scientific enquiry generally, ‘to build shared understanding that provides insight into the world and helps solve important problems’ (Sterman, 2000; p.850). The system dynamics field originated in management science (Forrester, 1961) and was later applied more broadly, such as in Forrester’s (1969) *Urban Dynamics*. Early models, such as *Urban Dynamics*, received much criticism from urban planning practitioners and scholars due to the resulting insights contradicting ‘received wisdom’ of the time (Lane, 1997). Recent applications have spanned the fields of service management, health, sustainable buildings, and the health impacts of energy efficient housing (Kim, 2008; Hoffer, 2015; Newell and Siri, 2016; Eker et al., 2018). Gatzweiler and Zhu et al. (2017) advocate system dynamics as one tool for understanding ‘the functioning of the integrated urban and health system’ (p.25). Sterman (2000) argues that system dynamics is ‘fundamentally interdisciplinary’ (p.4) and integrates both positivist and interpretivist paradigms (Lane, 2001). It is therefore a useful method for approaching the use of UHI tools in policy and decision-making.

Group model building, or participatory modelling, using system dynamics is widely described in the literature with detailed methods for conducting modelling workshops (Andersen and Richardson, 1997; Dwyer and Stave, 2008; Ford and Sterman, 1998; Richardson and Andersen, 1995; Vennix, 1996; Vennix et al., 1990, 1988). Participatory modelling with problem owners can be used to co-produce models or to improve the quality of a preliminary model (Andersen and Richardson, 1997; Zimmermann et al., 2015). Both processes can have the effect of changing participants’ thinking and this is often the goal of participatory modelling (Kim, 2008; Zimmermann et al., 2015). Group modelling with policy-makers has also been used to bring together diverse perspectives (of problems and solutions), make progress on contentious policy areas, and integrate different values and knowledge bases into the policy-making process (Cockerill et al., 2009; Rouwette et al., 2016). In this study, group modelling is used to bring together diverse perspectives to improve the model. The methods are fully described in chapter seven.

Ford and Sterman (1998) note that knowledge of mental models is ‘complex and tacit in nature’ and therefore it must be elicited through multi-format and multi-step processes (p.330). A causal loop diagram will be developed using data from three parts of the PhD (Figure 3-4). The systematic review will provide data to conceptualise the model. Knowledge of participants’ mental models will be elicited in semi-structured interviews. Then a preliminary model will be tested and further improved through a participatory modelling workshop. The methods for these steps are outlined in the relevant chapters.

3.6 Conclusions

This chapter began by introducing the relatively new practice of making conceptual frameworks a central component of PhD theses. The full conceptual framework was presented at the beginning of the chapter and then each section of the framework was described in detail. First, the framework highlighted the basic assumptions, beliefs and values underpinning the professional work of public health and urban planning and highlighted similarities and differences. The chapter resumed the discussion of divergent models of urban health indicator use (as either rational/technical tools or socially constructed) and proposed a middle ground characterised by a participatory governance approach. Complexity was identified as a feature of urban health and policy-making which affects the development and use of urban health indicators. The first components of the conceptual framework were therefore outlined as underlying assumptions, beliefs and values that informed the selection of research goals (questions and objectives). Second, the discussion turned to the theoretical framework (research paradigms and theories) that is used to investigate the study's research questions, involving a pragmatic research approach with collaborative rationality and systems theories. The chapter explicitly made links between the theoretical framework and earlier sections of the conceptual framework. Third, the last elements of the conceptual framework were described through an overview of the methodological approach and specific research methods, which were also informed by the earlier components of the framework. Each of the methods were introduced and justified for use in the study. The chapter presented some critiques of some of the selected theory and methods. The next chapter presents how secondary data were gathered and analysed through a systematic review to inform primary data collection and the conceptualisation of mental models of indicator producers and users.

CHAPTER 4

Characteristics and use of UHI tools: a systematic review

4.1 Introduction

The previous chapters provided an overview of the history and current research knowledge on the characteristics and use of urban health indicators, particularly by urban planning policy and decision-makers. This chapter reports the methods and results of a two-part systematic review that was conducted to obtain comprehensive understanding of the research topic in relation to the three research questions. The chapter includes slightly modified text that has been published in peer-reviewed journal articles by the author (Pineo et al., 2017a, 2017b, 2018a). A scoping review was conducted in preparation for this systematic review, the results of which were presented orally at the International Conference of Urban Health, San Francisco, April 2016. The results of the first part of the systematic review were presented in a poster session at the UK Lancet Public Health Science Conference, London, November 2017, including a published abstract in a supplement of The Lancet (Pineo et al., 2017b).

4.2 Background

There is a paucity of research addressing how indicators are used and how they can be standardised. A scoping review was conducted to identify existing reviews and develop appropriate objectives and search criteria for the systematic review.

The scoping review identified three recent reviews of relevant indicators. Prasad et al.'s (2016) systematic review of urban health metrics highlighted the lack of available data for metrics in low- and middle-income countries and questioned the translation of evidence gained through using such metrics into policy and decision-making. Rothenberg et al. (2015) conducted a review of urban health metrics and found that indicator sets focus on large-area comparisons (nations, states) and that small-area comparisons (cities, neighbourhoods) are relatively underdeveloped. They also observed similarity in the domains measured across compilations. Badland et al.'s (2014) review of urban liveability indicators for the Australian urban planning policy context found:

inconsistency in how domains were measured; a relative lack of validated indicators; and a lack of information on how to apply indicators to inform urban policy and practice.

The scoping review identified the following key discussions in the UHI tool literature that helped to guide the research protocol, summarised here and then discussed in turn below:

- Existing UHI tools cover a broad range of environmental exposures, including those which affect health-related behaviours (such as physical activity).
- UHI tools may also use terms such as quality of life, wellbeing, or liveability.
- The complexity of urban health is commonly discussed and there is lack of clarity on how complexity is, or could be, addressed through UHI tools.
- There is widespread duplication of effort during the creation of new UHI tools, but there is also lack of agreement on how to measure urban health exposures, pointing to a conflict over the potential for standardisation.

First, there are a wide range of environmental exposures measured in UHI tools. Urban and environmental health indicators have traditionally focused on health outcomes and environmental risks such as pollution (Briggs, 1999). Over time, the rise of non-communicable diseases and growing understanding of its links to urban form and development patterns has broadened the scope and purpose of urban health indicators (Northridge et al., 2003). Therefore, the review should include a broad range of environmental exposures linked to health and wellbeing, including features that affect health indirectly, for example by influencing health-related behaviours such as physical activity and healthy eating.

Second, there are recent conceptual contributions regarding the interconnections and complex relationships between the environmental determinants of health and other related policy objectives such as liveability, quality of life, wellbeing and sustainability (Rydin et al., 2012; Badland et al., 2014; Verbeek and Boelens, 2016). Several indicator tools seek to make these relations more explicit with the intention of informing and shaping policies and decisions that meet these aligned objectives (e.g. McCaughey Centre et al., n.d.; "The San Francisco Indicator Project," n.d.). Such UHI tools provide indicators on multiple aspects of the urban environment simultaneously, therefore recognising and highlighting the complexity of the system. And crucially, it is these tools which could be of most use to urban planners and other municipal built environment policy and decision-makers who need to balance multiple sustainability objectives and competing interests. The review should therefore seek to understand how UHI tools address complexity through both the review of existing UHI tools and studies on their use. Furthermore, this review needs to include investigation of UHI tools which address topics related to health such as liveability, quality of life, and wellbeing. Sustainability is considered too broad a concept for the purposes of this review.

Third, the intended use of indicator tools is likely to inform their composition and characteristics, elements which are often represented in a taxonomy (Rothenberg et al., 2015). Taxonomies have been developed for mental health and ecological indicators by identifying and classifying user requirements such as spatial scale and decision-making context (Wardrop et al., 2007; Salvador-Carulla et al., 2010). Yet, prior to this review, there were no existing taxonomies of urban health indicator tools. This review should therefore produce a taxonomy of UHI tools.

There are two main motivations for improving understanding of UHI tool characteristics and creating an associated taxonomy to support indicator producers and users. Principally, the production of new indicator tools often involves duplication of previous research efforts with little knowledge of whether and how UHI tools may be used by policy and decision-makers. There is recognition that locally developed tools may increase acceptability and allow for tailoring of indicators to local needs (Innes and Booher, 2000; WHO, 2011a; Rothenberg et al., 2015). Furthermore, some have argued that the process of indicator development is at least as important in achieving change as the eventual use of indicators (Innes and Booher, 2000; Corburn and Cohen, 2012). Increased understanding of the characteristics of UHI tools which meet the needs of policy and decision-makers could reduce wasted efforts by indicator producers and increase usability for indicator users.

Second, despite the large amount of research on indicator development, there is still a lack of consensus on how to measure the urban environment's impact on health and related concepts. Standardising the development of urban health indicators is a topic of ongoing debate (von Schirnding, 2002; WHO, 2011a). Despite the large number of UHI tools already available, researchers continue to contribute new international indicator sets whilst implicitly supporting greater standardisation (e.g. Dora et al., 2015; Giles-Corti et al., 2016). Salvador-Carulla et al. (2010) claim that there is a lack of international consensus on indicators and that they 'lack adequate semantic interoperability' (p.1). Aguilar-Gaxiola et al. (2014) created a three-level hierarchical and nested taxonomy of community health indicators with (1) determinants of health, (2) categories of community health indicators and (3) quantifiable measurements. The purpose of the taxonomy was to unify approaches to monitoring community health progress, with the added benefits of supporting aligned research and indicator selection by local authorities. Thus a taxonomy which describes the general characteristics of UHI tools would provide a useful step toward standardisation, reducing duplicated efforts and supporting identification of appropriate UHI tools.

4.3 Aims and objectives

This study aimed to investigate the nature and characteristics of urban health indicator tools and synthesise studies on their use by municipal built environment policy and decision-makers. The specific objectives are:

1. To create a census and taxonomy of urban health indicator tools.
2. To understand how UHI tools are being used in the policy and decision-making process and their perceived value in this process.
3. To explore the perceived impact of UHI tools on policy and decision-making.
4. To investigate the value of UHI tools in relation to simplifying, representing or addressing complex systems.

This systematic review examined a specific type of indicator compilation which could inform municipal built environment policy and decision-makers about the social determinants of health, defined as 'urban health indicator tools' (see 4.4.1). The review has two distinct parts. Part A is a census of UHI tools resulting in a description of their characteristics over time and development of a taxonomy. Part B explored the perceptions and use of UHI tools by built environment policy and decision-makers. Both parts examined how UHI tools address the complexity of urban health and how this complexity affects policy and decision-making.

4.4 Methods

The methods are outlined in the protocol and published results for part A (Pineo et al., 2018a, 2017a). The search strategy and review of papers was conducted simultaneously and thus the methods for parts A and B are reported together. The review methods diverge at the points of eligibility criteria, quality appraisal, data extraction and synthesis. PRISMA-P guidelines (Shamseer et al., 2015) were followed and reported in Appendix A1.2. The protocol was informed by the scoping review and the methods of similar social sciences systematic review regarding the relevant population of policy-makers (e.g. (Lorenc et al., 2014; Oliver et al., 2014a).

This review can be described as a mixed-methods systematic review of sequential explanatory design (Ivankova et al., 2006). This was not reported in the protocol as the decision to merge data from both portions of the review was taken during the data synthesis stage. The studies included in Part B described the use or perceptions of a subset of the UHI tools that were analysed in Part A. Quantitative data about the characteristics of UHI tools from Part A were combined with qualitative data about policy and decision-makers' views of these tools and the conditions in which they were used from Part B. This allowed the review to uncover additional insights than could have been derived from the constituent parts alone.

4.4.1 Definitions

Galea and Vlahov (2005) define urban health as 'the determinants of health and diseases in urban areas and with the urban context itself as the exposure of interest' (p.342). There are numerous definitions for indicator. Balsas (2004) paraphrased Kotval's (2001) definition of indicator as 'a measure or a set of measures that describes a complex social, economic or physical reality' (p.104). While Pencheon (2008) defined them as 'succinct measures that aim to describe as much about a system as possible in as few points as possible' (p.5). These definitions have been combined to form a new definition for UHI tools: 'a collection of summary measures about the physical urban environment's contribution to human health and wellbeing' (Pineo et al., 2017a, p.2). The definition broadens the scope of 'health' to include related concepts of quality of life (QOL), liveability and wellbeing. The definition also allows UHI tools regarding walkability/physical activity (PA) as this is an important contribution of the built environment toward promoting good health (Lee et al., 2012; Sallis et al., 2016). A combination of indicators can be referred to as a set, compilation, collection or tool (Pastille Consortium, 2002; Rothenberg et al., 2015; Science for Environment Policy and SCU, 2015). The term 'tool' was selected because it reflects a utility or intention to support policy and decision-making.

4.4.2 Search strategy

The search was conducted from Jan 27, 2016 to Feb 24, 2016, using seven bibliographic databases (Table 4-1), grey literature searches and key journal hand-searches. Google Advanced searches were conducted on six practitioner websites and the internet using specified search terms in line with the search strategy for databases. There was no date restriction on database searches. Four key journals were hand-searched with date restrictions of one to five years depending on the relevance of articles found and the number of volumes per year. Two University College London (UCL) librarians specialising in systematic reviews helped identify the search strategy and appropriate bibliographic databases for the review.

The search terms and Medical Subject Headings (MeSH) were identified through the scoping review. Search terms and indicators identified in similar reviews were examined and trialled to identify key terms (Lawrence, 2008; Badland et al., 2014; Rothenberg et al., 2015). The key terms were the urban environment (e.g. urban, metropolitan, city, environment, neighbourhood, community); health and related concepts (e.g. determinant, public, health, wellbeing, wellness, quality, liveability), and indicator (e.g. benchmark, tool, indicator, index, indices, measure, metric, profile, assessment, score, standard). In Scopus, Web of Science and Ovid (Embase and Medline), subject areas were limited to refine results (e.g. subjects such as pharmacology and dentistry were excluded). Boolean and adjacency operators were also used to construct the search and refine results. An example of the Ovid Medline search is included in the PRISMA-P checklist in Appendix A1.2.

Table 4-1 Databases, websites and journals searched for the review, including years hand-searched for journals

Source type	Source
Bibliographic Databases	Applied Social Sciences Index and Abstracts (ASSIA) Campbell Library Embase Medline Scopus Social Policy and Practice Web of Science Core Collection (includes the Social Sciences Citation Index)

Source type	Source
Websites	Town and Country Planning Association (UK) Royal Town Planning Institute (UK) Planning Institute of Australia American Planning Association Built Environment and Public Health Clearinghouse (USA) World Health Organization Europe, Urban Health, Healthy Cities
Hand-searched Journals	Annual Review of Public Health (5 years) Social Science and Medicine (3 years) BMC Public Health (1 year) Social Indicators Research (3 years)

4.4.3 Eligibility criteria

There were two parts to the systematic review with separate eligibility criteria. Part A identified and investigated any UHI tools. Part A eligibility criteria were:

- Includes any reference to UHI tools in peer-reviewed or grey literature documents or websites
- UHI tools meet the definition tool outlined in 4.4.1 above and regard more than one aspect of the physical urban environment (e.g. air quality and housing)
- Published in English.

Part B synthesised studies about the use of UHI tools. Part B studies were a sub-set of those identified in Part A. Part B eligibility criteria were:

- Reports substantive qualitative or quantitative data on views, attitudes or knowledge about the use of an urban health indicator tool in the policy-making or decision-making process, or about the implementation of specific policies, interventions or programmes informed by these (modified from Lorenc et al., 2014).
- Includes policy and/or decision-makers from one of the following policy fields in local government: housing; transport; urban planning and regeneration.

Studies reported in any country were included. There were no date restrictions.

All documents were screened by the researcher (HP) and a random sample of 10% of documents were screened by a second reviewer (Ketevan Glonti) at the title and abstract and full paper screening stages. Differences were resolved through discussion. A key point of discussion was whether studies reported substantive data, as required by the eligibility criteria. This was interpreted on a case-by-case basis. The researchers looked for information that could be extracted and analysed beyond a single sentence or paragraph. Eppi-Reviewer software was used to manage all documents and screening. At the end of the screening stage there were two separate sets of documents for data extraction and analysis: 1) documents (or websites) pertaining to UHI tools and 2) studies about the use of UHI tools.

4.4.4 Quality appraisal

Studies included in Part B were appraised using the quality appraisal tool for qualitative studies produced by the UK National Institute for Health and Care Excellence (NICE) (NICE, 2012). There was only one study reporting mixed quantitative and qualitative data from a survey and therefore the qualitative study appraisal tool was applied. The NICE quality appraisal checklist includes the following: theoretical approach, study design, data collection, trustworthiness, analysis and ethics. Included studies were heterogeneous regarding study design and reporting of methods and results. None of the studies were rejected on the basis of study quality, nor was the analysis differentiated on this basis. Study quality is addressed as a limitation in the discussion section. Appendix A1.5 contains the completed quality appraisal checklists.

4.4.5 Data extraction

The census of UHI tools involved several steps of data extraction. First, a Google search of the UHI tool was conducted to identify a website and/or further documentation about the tool and its methodology. Next, these documents were reviewed and then data were extracted from the most authoritative source regarding the UHI tool's methodology (including peer-reviewed papers, published grey literature, and text on UHI tool websites). Data from indicator producers was preferred over third-party summaries or evaluations. A data extraction form (in Excel) was developed iteratively during the scoping review. Data were extracted using the categories described in Table 4-2, as reported in Pineo et al. (2017a). The last four categories were added after the protocol was published.

Table 4-2 Categories of data extracted from studies or UHI too methodology reports

Category	**Description**
Scale	Scales at which the system can be applied or measured (e.g. neighbourhood or city)
Geography	Areas in which this system can be applied (e.g. specific cities or nations)
Scope	Aspects that are analysed (e.g. built environment, health outcomes, demographics)
Producer	Organisation that developed the system (name and type)
Funders	Organisations that funded the system
Purpose	Stated purpose (e.g. research or informing policy)
Methodology	Existence of an accessible published methodology
Evidence-base	Whether the methodology refers to evidence that was used to inform the system and the nature of this evidence
Weighting	Existence of a weighting system and description of its characteristics
Complexity	Whether the methodology refers to complexity and, if so, in what context
Uncertainty	Whether the methodology refer to uncertainty and, if so, in what context
Maps	Existence of an option to view the data on maps
Publication date	Year of publication
Source	Publisher or source (e.g. website name)
Indicators	Reported indicators
Topic	Concept that the UHI tool measured (e.g. health or liveability)
Main source of data	Source(s) of data used in the system (e.g. municipal datasets or resident surveys)
Indicator type	Subjective or objective, as defined in Lowe et al. (2015, p.136)
Used beyond research	Whether the UHI tool has been used beyond research, based on the Google search of each indicator tool. If this search produced evidence of case studies, policy documents or other uses beyond the original research paper, this was marked as 'used beyond research'. The others were marked as 'unknown'.

Studies that met the inclusion criteria for Part B were included in a narrative synthesis. The following data were also extracted for each study, informed by Lorenc et al., (2014) and Oliver et al., (2014), as shown in the protocol (Pineo et al., 2017a):

- author, year
- country
- year that study was carried out
- UHI tool being evaluated
- policy field
- research parameters
- data collection methods
- population and sample selection
- outcomes
- analysis methods
- limitations
- funding source
- theoretical background
- conflicts of interest

These data were contextual and did not form part of the narrative synthesis (apart from the UHI tool). The qualitative data reported as outcomes were synthesised using NVivo qualitative data analysis software (QSR International Pty Ltd., version 11.4.3, 2017), see 4.4.7.

4.4.6 Data analysis for part A

The taxonomy was developed using modified approaches from Salvador-Carulla et al. (2010) and Wardrop et al. (2007). Salvador-Carulla et al. developed key topics for their taxonomy by reviewing published literature and indicator lists. Then they discussed these topics with expert groups. Wardrop et al. developed their taxonomy by selecting characteristics of environmental indicators that would be useful for environmental managers from a survey of government officials. These approaches were combined and modified in this study. Key characteristics of UHI tools for built environment professionals were identified from relevant literature (Badland et al., 2014; Rothenberg et al., 2015; Prasad et al., 2016) and the data gathered in the review, and included: spatial scale, purpose, topic, scope, and format. These became the highest-level category within the taxonomy, denoted as ‘class’. Data were extracted on each of the five classes. The second order in the taxonomy, ‘sub-class’, was developed during the analysis of data extracted in the review, noting differences within each class and categorising these in an iterative process. UHI tools may have characteristics from multiple sub-classes (they are not mutually exclusive). Indicator domains (listed as sub-classes under 'scope') were selected using a set of domains identified from previous reviews (Badland et al., 2014; Rothenberg et al., 2015). For analysis purposes, all 8006 indicators identified in the review were standardised to this list of domains. It is possible to divide these domains into smaller groups (e.g. chronic diseases and injuries could be sub-domains under the domain of health outcomes).

During data analysis the term neighbourhood was grouped with other sub-city spatial scales including ward and district. Lower than neighbourhood scales were also grouped together, representing street or household scale for example. Given variation in the meaning of terms like 'district' or 'post-code', scales were allocated on the basis of authors' descriptions.

UHI tools report data and are available for use at different spatial scales. These were reported using three terms: spatial scale, general geography and specific geography. Spatial scale referred to the level of data aggregation for which the tool reported indicator data. General geography referred to the geographical scales in which a particular UHI tool could be accessed (such as a city, county or state). Specific geography added a place name to that general term. For example, the CDC's 'Environmental Public Health Tracking Network' covered the whole country and allowed users to select indicator data at the county and zip code scales (with comparison of state averages as well) (CDC, n.d.). The data for this UHI tool was thus extracted as:

- spatial scale: multiple (county, zip code)
- general geography: country
- specific geography: USA.

4.4.7 Data synthesis for part B

The narrative synthesis of qualitative data sought to identify recurrent themes across the studies regarding the perceptions and value of UHI tools by policy and decision-makers. The approach was informed by Popay et al.'s (2006) guidance on the conduct of narrative synthesis in systematic review. The synthesis was developed using textual descriptions, tabulation, semantic coding thematic analysis, vote-counting as a descriptive tool, subgroup analysis and development of a theory of change (ToC).

The synthesis process was iterative. It began with familiarisation with the included studies and producing a written descriptive summary of the studies. Then semantic coding and interpretation were conducted using thematic analysis. A sub-group analysis was then undertaken using data about UHI tool characteristics from part A of the systematic review, for example scale of data in UHI tools. Data about the UHI tool characteristics were sourced from the Part A systematic review studies and an additional study identified after the full search about Community Indicators Victoria by Davern et al. (2017). Based on Popay et al.'s guidance, data coding sought to inform, and was informed by, a 'theory of change' about what worked, for whom and in what circumstances.

The ToC informed the conduct of the narrative synthesis and supports the description of findings in a summary format. In addition to Popay et al. (2006), wider literature on developing theory of change was reviewed, including Weiss (1998), Morra Ima and Rist (2009), and Breuer et al. (2016). A ToC can be developed through a range of methods, including: a participatory process with stakeholders, document review, and interviews (Morra Imas and Rist, 2009). The ToC in this study was developed iteratively and helped to clarify and explore the impact and value of UHI tools for different urban actors. The ToC methods are fully described in Appendix A1.6. The remainder of this section explains how the thematic analysis was conducted to inform the narrative synthesis.

Chapter three (section 3.5.3) introduced thematic analysis and described how it is applied differently in two parts of the PhD study. For the systematic review, the thematic analysis used a hybrid inductive and deductive coding approach based on Fereday and Muir-Cochrane's (2006) approach. Deductive coding used an *a priori* codebook, while inductive coding involved identification of 'an important moment' in the data and 'encoding it prior to interpretation' (ibid, p.83). Data were coded at the semantic level, in other words the 'explicit or surface meanings of the data' rather than looking '*beyond* what a participant has said or what has been written' (Braun and Clarke, 2006) (p.84). Data were coded in NVivo qualitative data analysis software. A 'good' code in thematic analysis 'captures the qualitative richness of the phenomena' and includes five elements: a label (or name), a definition, a description of how to know when to use the code, a description of any qualifications or exclusions, examples of included and excluded data to remove confusion when coding (Boyatzis, 1998, p.31).

The codebook consisted of five code categories based on the study's objectives and the guidance by Popay et al. (2006). The full code set was updated iteratively as new factors were identified. The codebook categories allowed for the inductive development of additional codes to describe more detail within the categories, which included:

1. Theory of change: short descriptions of what worked, for whom and in what circumstances
2. Facilitators: factors that aided the use of UHI tools
3. Barriers: factors that hindered the use of UHI tools
4. Uses or benefits: built environment policy and decision-makers' perceptions of the uses and benefits of developing and applying UHI tools
5. Complexity: the complex nature of indicator development, urban health issues and application of indicators in policy and decision-making.

The coded text was iteratively grouped and explored through tabulation and concept mapping to produce the narrative synthesis of studies. For example, text which were deductively coded as 'facilitators' were inductively coded with more detail such as 'presentation of information' and 'data quality'. All of the data coded as 'facilitators' were tabulated and re-grouped under types of facilitators based on descriptions from the studies. The same process was followed for other categories such as 'barriers' and 'uses or benefits'. The interpretation of qualitative data was aided by the background literature from the scoping review, the wider literature review in chapter two and the theoretical lenses of collaborative rationality (Innes and Booher, 2010) and complexity theory/systems thinking (Sterman, 2000).

4.5 Results of UHI tool census

This section is reported in Pineo et al. (2018a) with very minor adjustments to some text and figures. The flow of documents through the review is shown in the PRISMA diagram (Figure 4-1). There were 9097 records identified in the database, internet and journal searches. After duplicates were removed, 6510 titles and abstracts were screened. Of these, 370 were included in a full-text review. Finally, 198 documents were included in the Part A census of UHI Tools. These documents referred to 145 separate urban health indicator tools (Appendix A1.3) which comprised 8006 indicators.

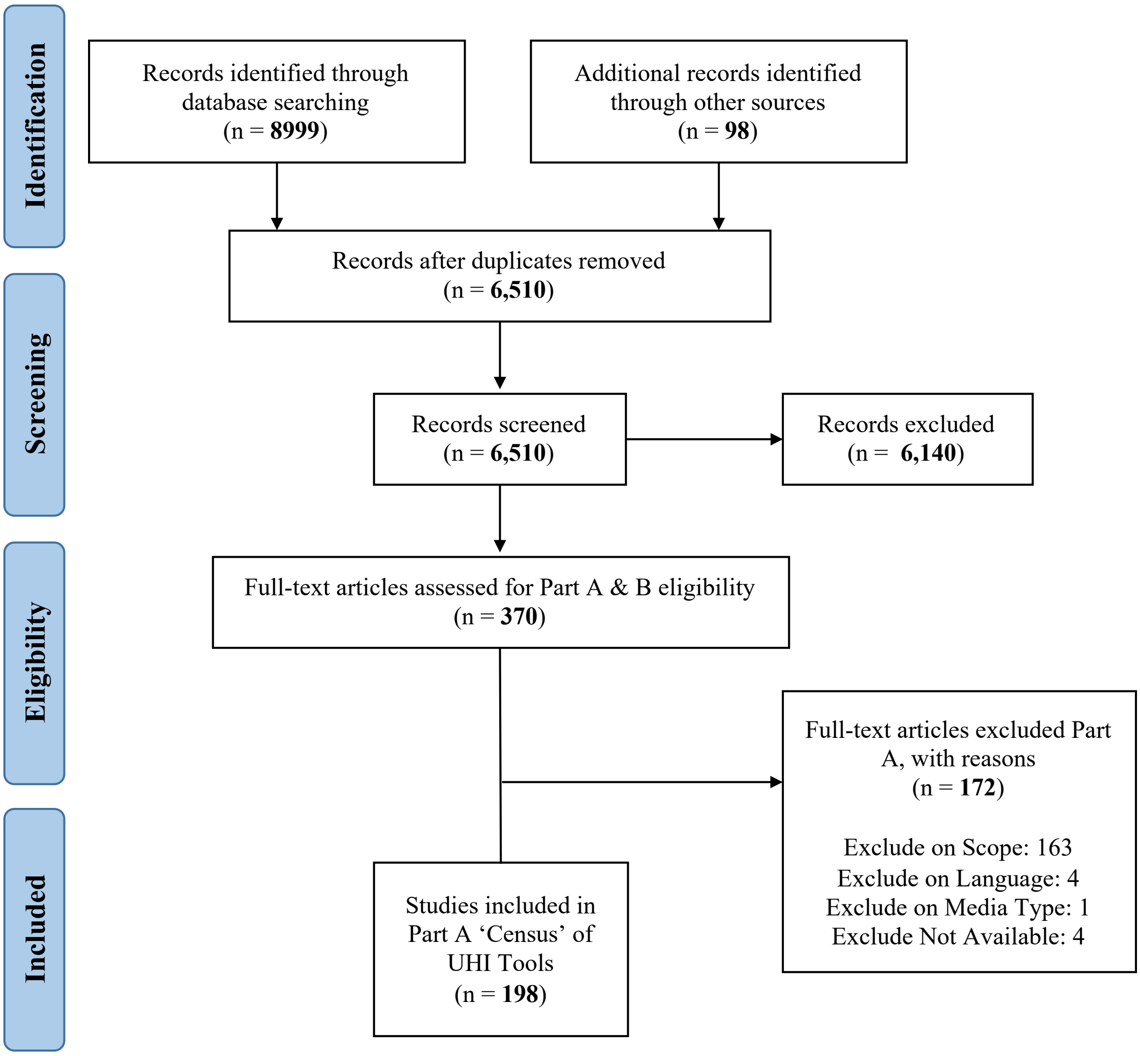

Figure 4-1 Flow of documents through the review for Part A, following PRISMA reporting style (Moher, 2009)

4.5.1 Taxonomy

Figure 4-2 shows the taxonomy with five classes: spatial scale, purpose, topic, scope, and format. In this section each of the classes in the taxonomy is reviewed, including data on the sub-classes.

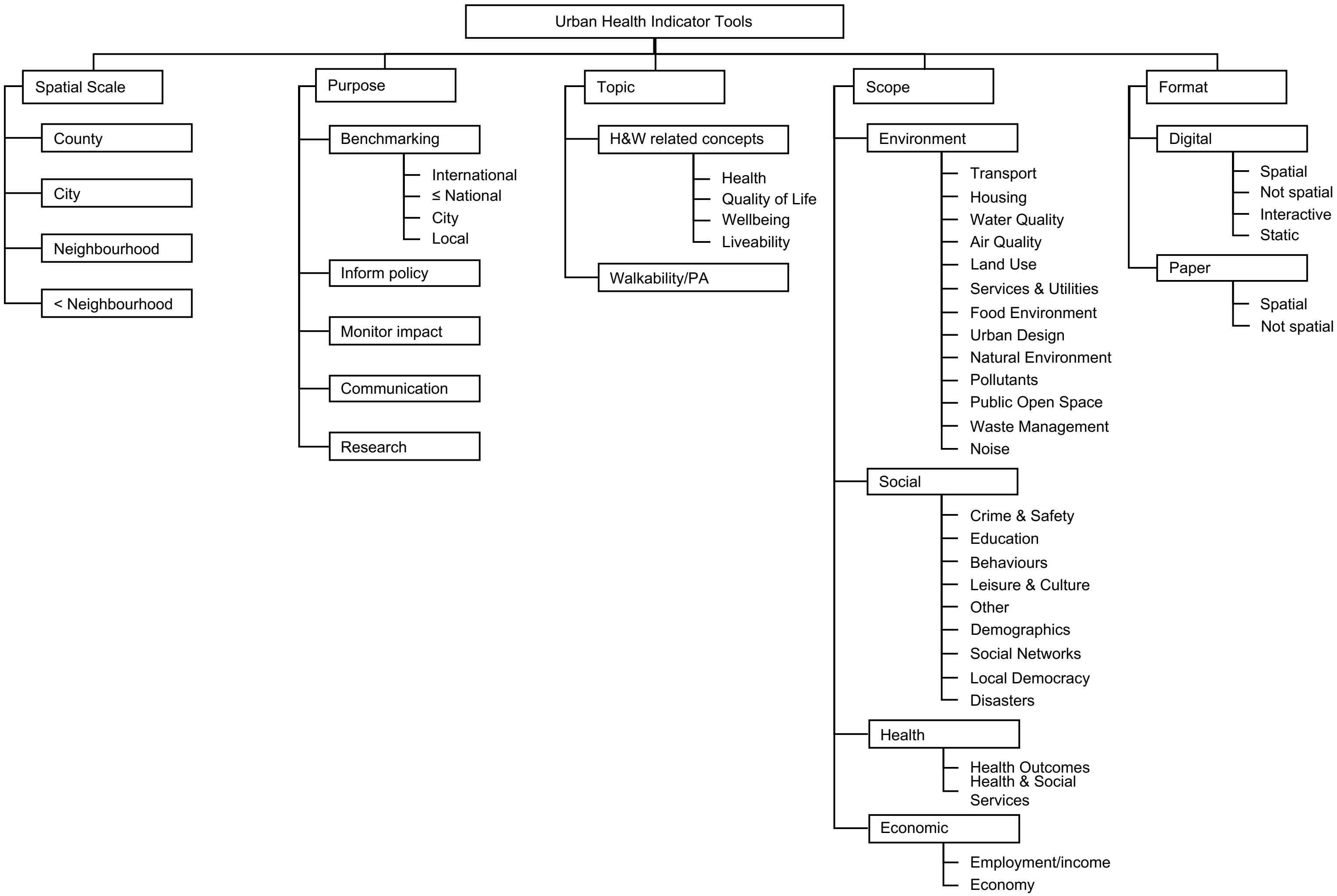

Figure 4-2 Taxonomy of urban health indicator tools (H&W: health and wellbeing, PA: physical activity)

4.5.2 UHI tool characteristics

4.5.2.1 *Spatial scale*

Of the UHI tools included in this review, 59.3% (86/145) measured data at the neighbourhood scale or lower. Over time, the proportion and number of UHI tools which present data at the neighbourhood scale and lower has increased (Figure 4-3 and Figure 4-4).

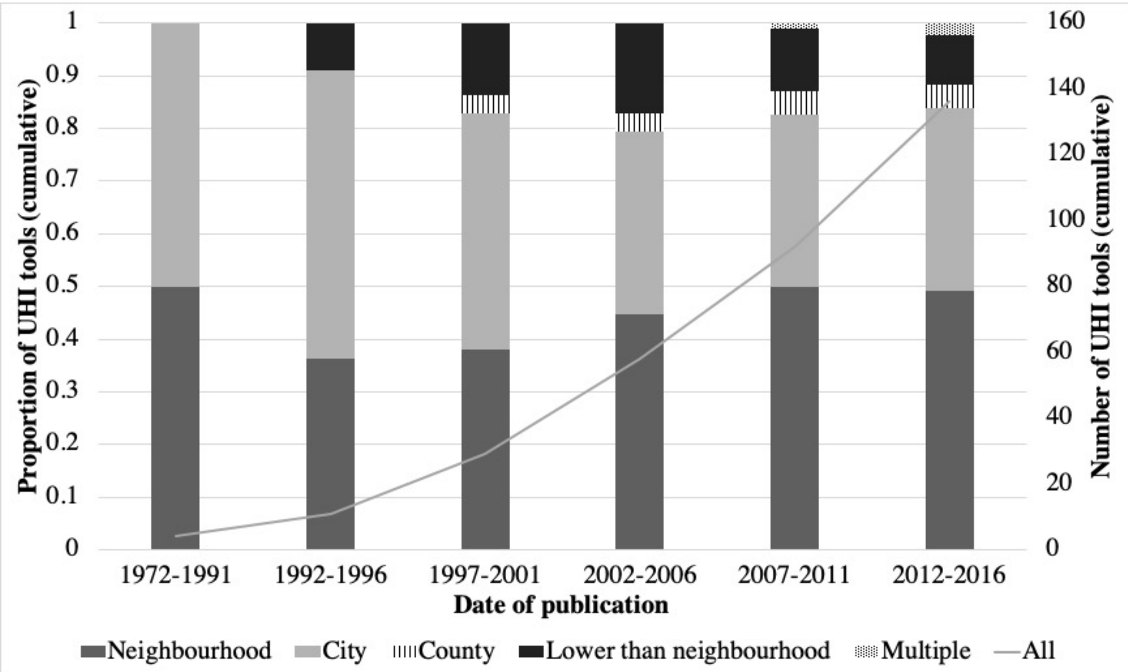

Figure 4-3 Change over time of proportion of UHI tools by spatial scale compared with cumulative growth of UHI tools. N.B. Missing data for 9/145 UHI tools: 7 did not report a date of publication and 2 did not report spatial scale

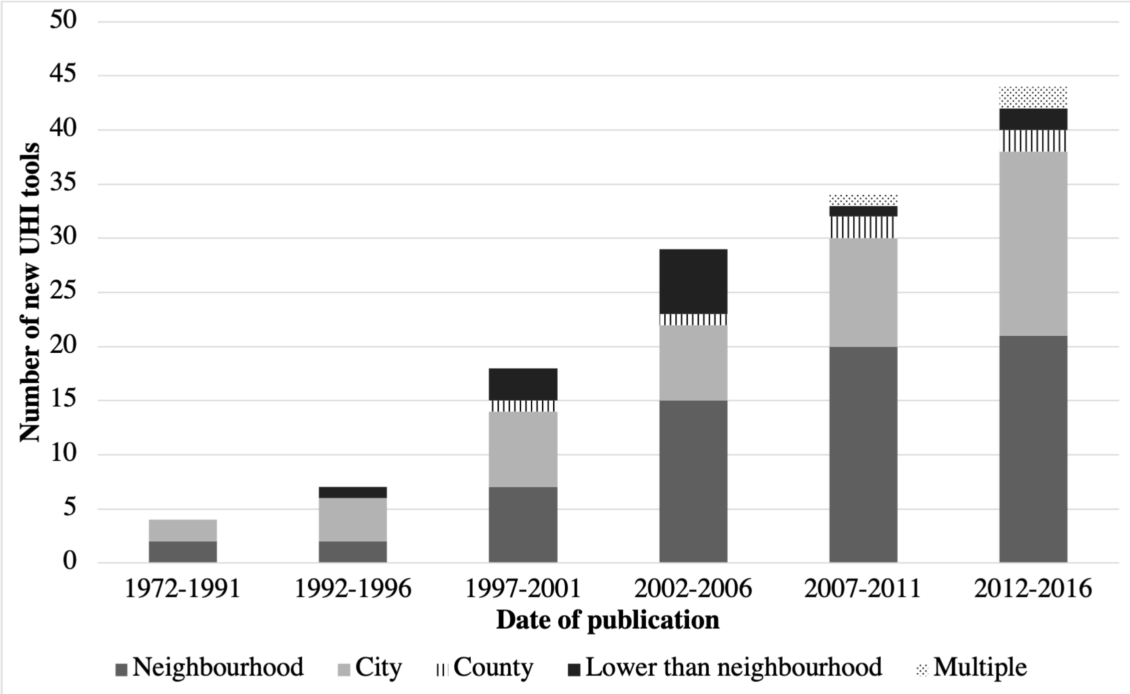

Figure 4-4 Number of new UHI tools by spatial scale. N.B. Missing data for 9/145 UHI tools: 7 did not report a date of publication and 2 did not report spatial scale

4.5.2.2 *Purpose*

82.8% (120/145) of UHI tools stated that part of their purpose was to inform policy and decision-making (Figure 4-5). Monitoring & evaluation (45.5%, 66/145), research (41.4%, 60/145), local comparison/benchmarking (40.0%, 58/145), and communicating with non-specialists (35.9%, 52/145) were also commonly stated goals of UHI tools. The majority of tools (54.5%, 79/145) were found to be used beyond research.

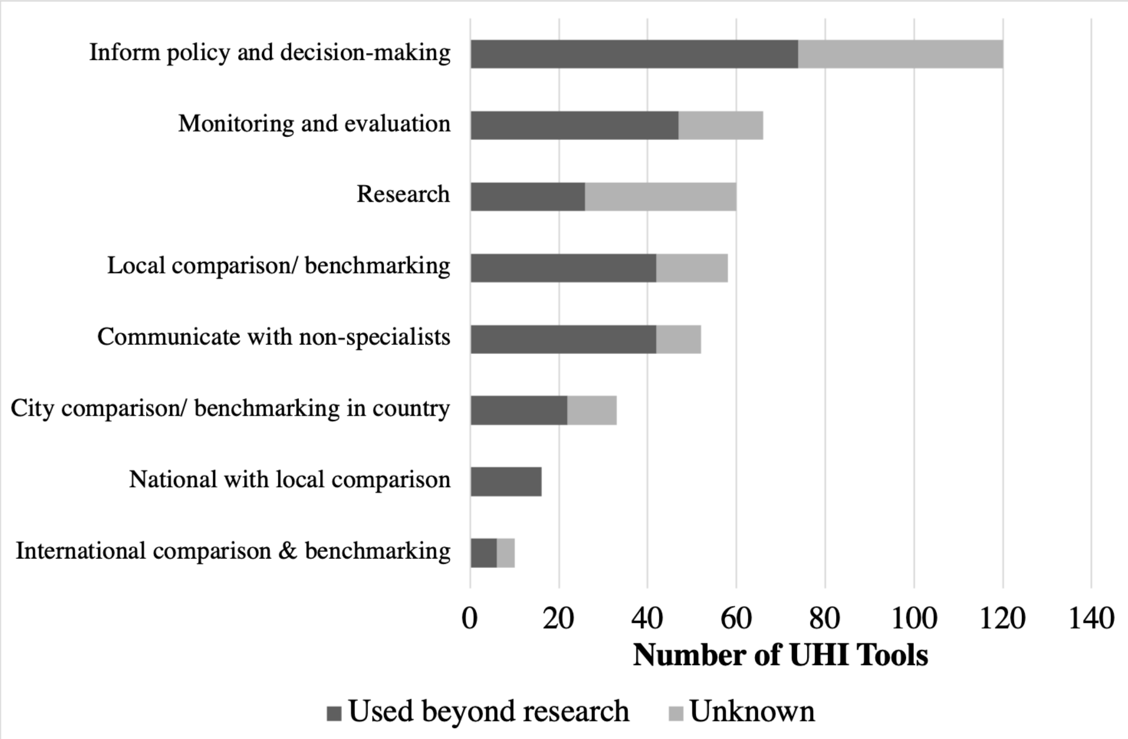

Figure 4-5 Number of UHI tools in each stated purpose categorised by those which were used beyond research and 'unknown'

4.5.2.3 *Topic*

The concepts of QOL, wellbeing and liveability are closely related to human health and their definitions overlap significantly. Table 4-3 lists a selection of definitions or explanations of these concepts which were identified in the systematic review (or citations found therein), and demonstrates overlaps between the ways in which these concepts were defined.

Table 4-3 Definitions and explanations of quality of life, liveability, and wellbeing concepts from selected papers included in the systematic review or citations found therein

Concept	Definition
Quality of Life	'the well-being of individuals within the context of their environment' (Lee and Guhathakurta, 2013, p.208)
	'an individual's happiness or satisfaction with life and environment including needs and desires and other tangible and intangible factors which determine overall well being' (Cutter, 1985 in Fahy and Ó Cinnéide, 2006, p.695)

Concept	Definition
Liveability	‘closely aligned with the social determinants of health’ (Badland et al., 2014, p.65)
	‘the human requirement for social amenity, health and wellbeing and it includes both individual and community wellbeing’ (Zanella et al., 2014, p.698)
Wellbeing	‘associated with concepts such as happiness, life satisfaction and social capital, all of which fall under the rubric of a 'social quality of life'’ (Miles et al., 2008, p.75)
Community Wellbeing	‘reflect a community's health status and its basic quality of life’ (Miles et al., 2008, p.77)

Analysis of the indicator domains showed that there is some homogeneity of scope across tools which measure different health-related concepts, with the exception of walkability/PA tools (Figure 4-6). Each topic area (excluding walkability/PA) measured a similar proportion of environmental (18.2% – 44.1%), social (23.2% – 41.8%), health (7.6% – 27.7%) and economic indicators (7.9% – 13.5%). Given the significant difference of scope in the walkability/PA tools (75.1% environmental indicators), this topic area was noted as a separate sub-class in the taxonomy to the more similar health-related concepts.

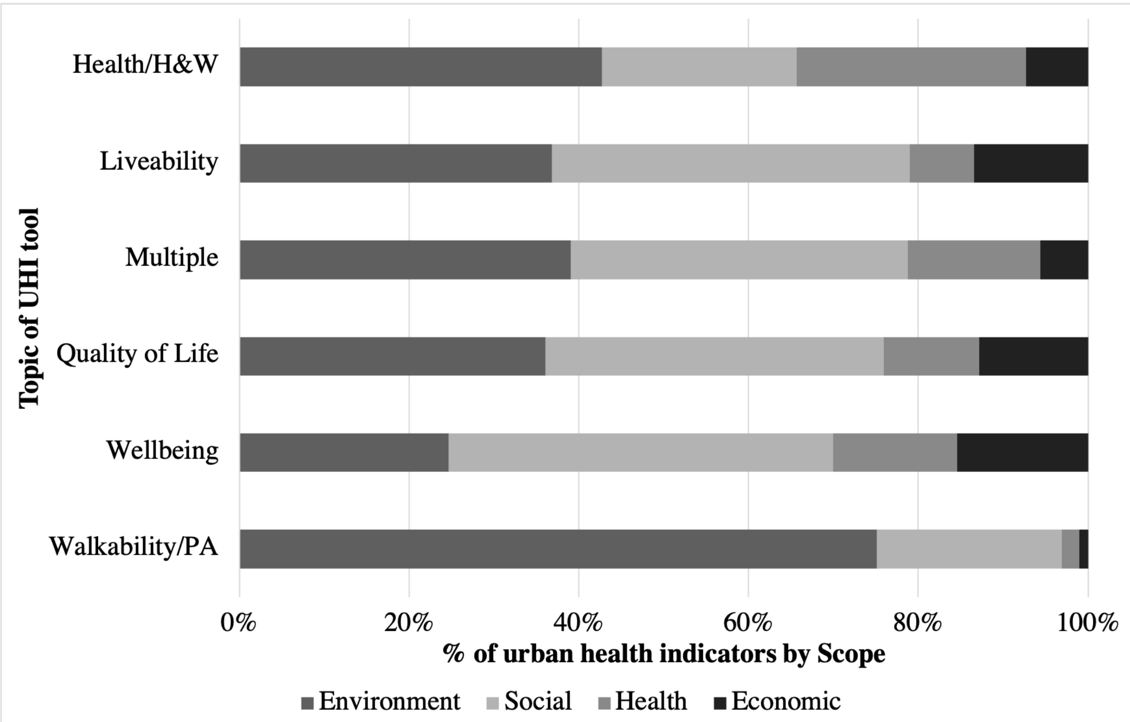

Figure 4-6 Scope of indicators across UHI tool topics (PA: physical activity. H&W: health and wellbeing)

Health and wellbeing (H&W) (45.5%, 66/145) and QOL (22.1%, 32/145) were the most common topic areas across the tools. Walkability/PA tools (13.8%, 20/145) are a relatively recent addition in urban health metrics (Figure 4-7). Bradshaw's Walkability Index from 1993 (Bradshaw, 1993) was the first example, with the remainder produced from 2002. There were only four UHI tools found between 1972 and 1991, with the number of new tools increasing 14 times by the end of 2006. The rate of growth was between 100% and 125% between 1972 and 2006 (Figure 4-7). In the last decade the growth rate has slowed to between 13.3% and 29.4%.

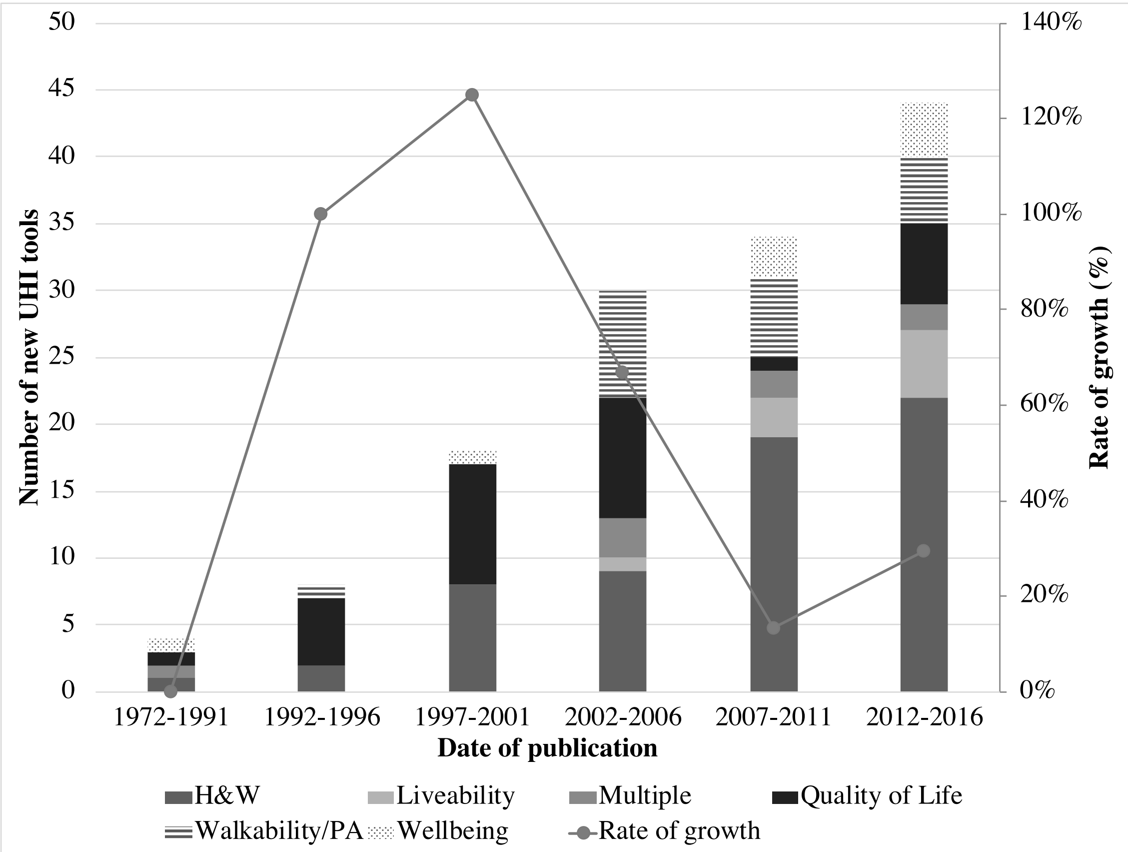

Figure 4-7 Date of publication of UHI tools by topic area and rate of growth. N.B Missing data for 7/145 UHI tools which did not report a date of publication

Table 4-4 shows a breakdown of domains across topic areas. Between four to seven of the top ten domains for health and wellbeing appear in the top ten for the other topic areas, illustrating the overlap of domains across each topic. The least similar topic is walkability/PA which only shares four domains with the H&W topic.

Table 4-4 Number of indicators in each domain across UHI tool topic areas, sorted by H&W. Top 10 domains are highlighted in green for each UHI topic area (H&W: health & wellbeing, PA: physical activity)

Domains	Topics						Total
	H&W	Liveability	Multiple	Quality of Life	Walkability /PA	Wellbeing	
health outcomes	862	15	33	139	11	60	1120
transport	394	81	18	163	293	35	984
employment and income	254	60	11	159	7	63	554
behaviours	229	29	41	43	15	28	385
water quality	211	6	1	20	1	1	240
housing	197	52	21	147	19	33	469
air quality	195	11	1	39	1	10	257
education	178	69	16	158	8	43	472
health and social services	177	41	17	69	3	19	326
crime and safety	155	54	30	157	53	58	507
land use	146	6	4	27	55	1	239
pollutants	105	5	4	6		3	123
food environment	103	7	37	11	38	3	199
demographics	100	22	7	71	19	19	238
services & utilities	93	29	7	83	2	7	221
leisure and culture	72	62	18	97	35	34	318
natural environment	65	21	13	38	13	6	156
public open space	62	30	6	46	13	10	167
social networks	62	12	6	37	2	37	156
economy	42	39	7	76		22	186
other	42	26	4	121	14	45	252
urban design	37	9	8	37	71	7	169
waste management	33	5	4	38		7	87
local democracy	29	29	2	44	1	20	125
noise	14	11	1	11	1	2	40
disasters	4	5	3	4			16
Grand Total	3861	736	320	1841	675	573	8006

4.5.2.4 *Scope*

Indicators under the scope of environment made up the largest portion (41.9%, 3351/8006). Table 4-5 shows the four scopes with each of their composite domains and the number of indicators in each. UHI tools measured between 3 and 286 individual indicators (average 56). Across the 145 UHI tools, 3 did not report the full list of indicators.

Table 4-5 Indicator domains grouped by scope across all UHI tools (total of 8006 indicators)

Scope	Domains	No. of indicators
Environment		
	transport	984
	housing	469
	air quality	257
	water quality	240
	land use	239
	services & utilities	221
	food environment	199
	urban design	169
	public open space	167
	natural environment	156
	pollutants	123
	waste management	87
	noise	40
	Category total	**3351**
Social		
	crime and safety	507
	education	472
	behaviours	385
	leisure and culture	318
	other	252
	demographics	238
	social networks	156
	local democracy	125
	disasters	16
	Category total	**2469**
Health		
	health outcomes	1120
	health and social services	326
	Category total	**1446**
Economic		
	employment and income	554
	economy	186
	Category total	**740**

4.5.2.5 *Format*

44.1% (64/145) of UHI tools displayed data on static or interactive maps, and from 1997 the number and proportion of these tools has grown (Figure 4-8). Interactive maps allowed users to select indicators and/or locations to be mapped through an online dashboard. Nearly all (96.0%, 24/25) of the UHI tools which had an interactive mapping function intended to inform policy and decision-making. Examples include 'Peg Well-being Indicators' and the health profiles on 'Plan for a Healthy Los Angeles' website (City of Los Angeles et al., n.d.; United Way Winnipeg and International Institute for Sustainable Development, n.d.). Three-quarters of these interactive UHI tools (76.0%, 19/25) displayed data at the neighbourhood scale. Most of these tools (92.0%, 23/25) also allowed local comparison and benchmarking across other neighbourhoods and counties.

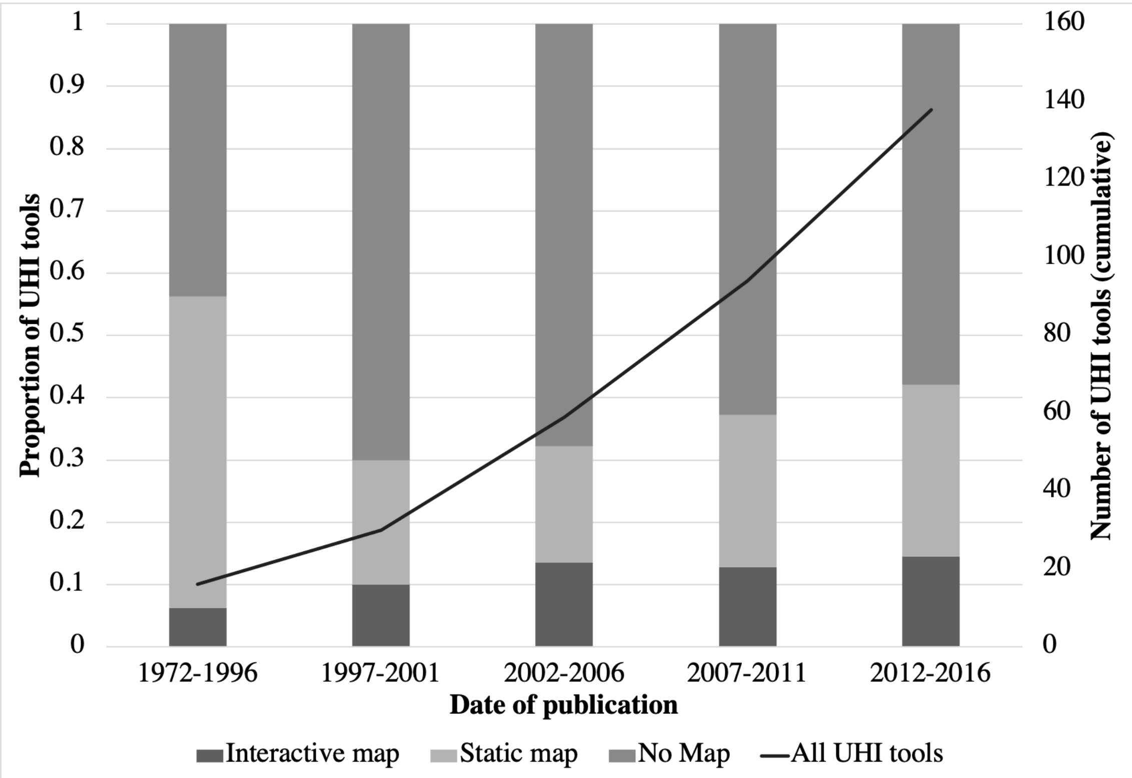

Figure 4-8 Proportion of UHI tools which display data on static and interactive maps over time, compared with the cumulative growth of all UHI tools. N.B Missing data for 7/145 UHI tools which did not report a date of publication

4.5.2.6 *Other characteristics of UHI tools*

This portion of the results section presents additional characteristics of UHI tools which were not used to form the taxonomy. Appendix A1.4 contains additional data that was extracted and analysed for the review.

37.9% (55/145) of the tools were available at the city-scale with national systems following closely behind (31.0%, 45/145). Many tools were available internationally (19.3%, 28/145). Tools were found for 28 individual countries (Figure 4-9). In addition, there were 28 international tools (i.e. could be used in any country) and 4 European tools.

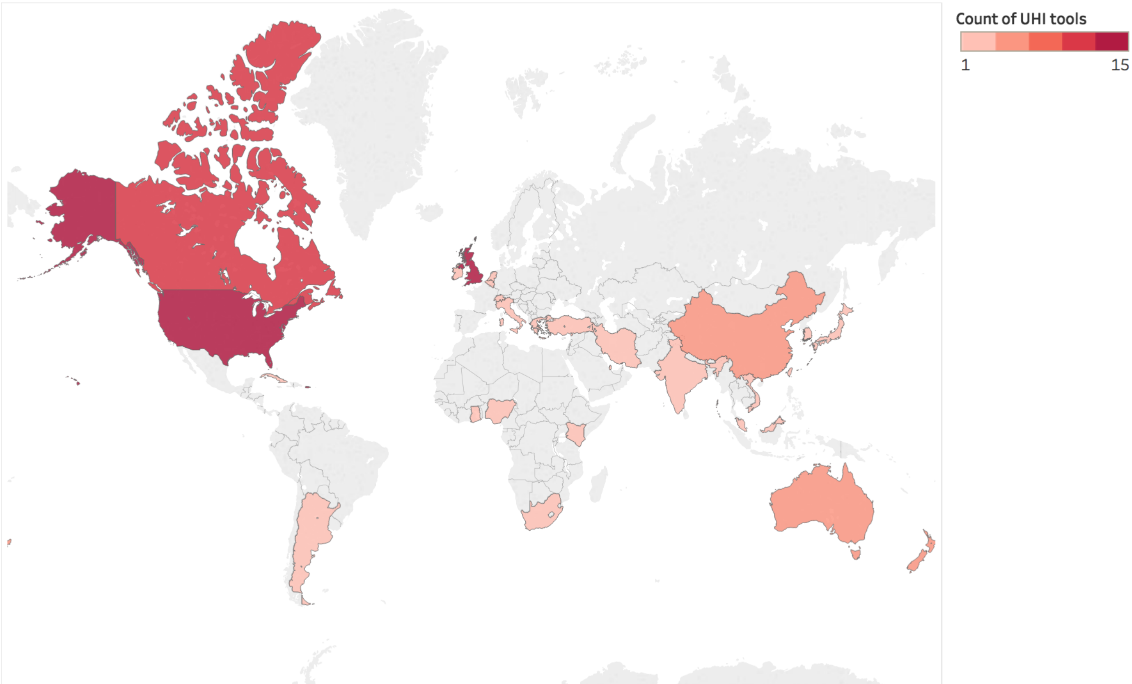

Figure 4-9 Location of UHI tools internationally. N.B. Tools which apply in more than one country are not shaded

Research institutions were the largest producer of UHI tools (54.5%, 79/145). Many of the tools produced by research institutions were not found to have been used beyond research (62.7%, 37/59). The funding source was often not stated (46%, 67/145). Where reported, the largest funder of UHI tools was government (17.9%, 26/145). 86.9% (126/145) of the UHI tools reported some information about the methodology. Evidence which informed the methodology or indicator selection was reported in 99/145 cases (68.3%). Peer-reviewed literature was the largest primary source of evidence used in 52.4% (76/145) of tools, followed by a small number of tools which used reviews of existing metrics/indicators (6/145), expert input (6/145), community input (5/145), and a combination of community and expert input (6/145). The majority of tools (57.9%, 84/145) used existing datasets from multiple organisations to measure the indicators.

4.6 Results of narrative synthesis

The flow of records through the review is presented in Figure 4-10. As in part A, 9097 records were identified from the bibliographic database, internet and journal searches. After duplicates were removed, 6510 titles and abstracts were screened, of which 370 were included in the full-text review. Finally, 10 studies were included in the Part B narrative synthesis. 360 studies were excluded on the basis of scope, policy field, language, media type, availability or not reporting substantive data.

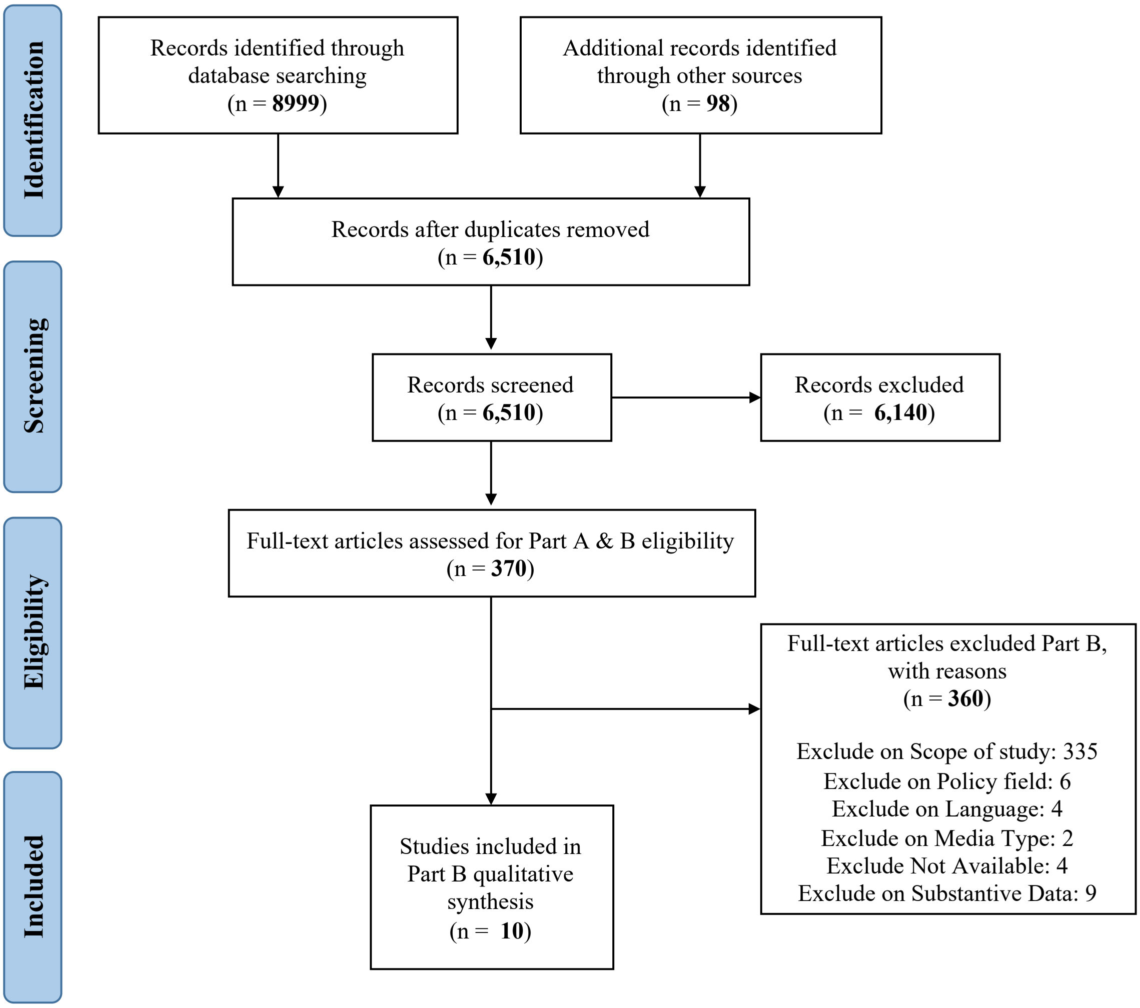

Figure 4-10 Flow of documents through the review for Part B, following PRISMA reporting style (Moher, 2009)

4.6.1 Characteristics of included studies and UHI tools

Table 4-6 shows the characteristics of the 10 included studies reporting: author, year of publication, country where the study was conducted, UHI tool(s) investigated, study design, policy field(s) of the participants and whether the authors were involved in developing the UHI tool.

Most of the studies (7/10) were case study designs using a range of qualitative data collection methods including participant observation, interviews, document analysis and group discussions. With two exceptions, all of the studies were written by individuals involved in developing the UHI tool being investigated (Table 4-6). For one of these exceptions it was unknown whether the authors had contributed to the UHI tool.

The majority of the UHI tools being investigated (8/10) were used in high income countries: the USA, Australia, England and Belgium. Two of the tools were applied in three cities in lower-middle income countries, India and Kenya. Most of the studies were conducted relatively recently (eight between 2008 and 2015, and two between 1988 and 2000). One study gathered perceptions on the use of UHI tools in South Africa.

The policy fields from which these studies reported perceptions or use of UHI tools include: urban planning (and neighbourhood planning or community development), regeneration, transport, neighbourhood safety, public works (or environmental services), sustainable development, and other non-specified local government departments. All of the studies addressed the urban planning policy field.

Table 4-7 describes the 10 UHI tools described in these studies reporting: UHI tool, lead organisation type, development process, whether evidence informed the UHI tool and which type, whether it had a mapping function and the spatial scale at which the UHI tool applied.

Table 4-6 Description of studies included in narrative synthesis

Authors and year	Country	UHI tools investigated	Study type and data collection methods	Policy field(s)	Authors developed UHI tool?
Bhatia (2014)	USA	San Francisco Indicators Project	Case study: Author's experience and observations	Urban planning, transport, community development	Yes
Corburn & Cohen (2012)	USA & Kenya	Richmond Health and Wellness Element Indicators and Urban Health Equity Indicators for Mathare Informal Settlement	Case studies (2): Authors' experiences working collaboratively with communities and local agencies to develop the UHI tools	Urban planning	Yes
Corburn et al. (2014)	USA	Richmond Health Equity Indicators (aka Healthy City Diamonds)	Case study: Participant observation, interviews, and document analysis	Urban planning, neighbourhood safety, public works	Yes
Farhang et al. (2008	USA	San Francisco Indicators Project	Case study: Not stated	Urban planning (and other 'city agencies')	Yes
Hunt and Lewin (2000)	India & South Africa	Core Environmental Health Indicators in Lucknow and Calcutta	Case studies (2): Interviews, observation, and group discussions	Urban planning and environmental services	Yes
Landis & Sawicki (1988)	USA	Places Rated Almanac	Mixed methods: Interviews and surveys	Urban planning	No

Authors and year	**Country**	**UHI tools investigated**	**Study type and data collection methods**	**Policy field(s)**	**Authors developed UHI tool?**
Lerman (2011)	USA	(Seattle) Healthy Living Assessment	Project report: Not stated	Urban planning (specifically neighbourhood planning)	Yes
Lowe et al. (2015)	Australia	Community Indicators Victoria (and other non-specified indicators)	Workshops	Urban planning (and other non-specified government policy-makers)	Yes
Shepherd & McMahon (2009)	England	(Bristol) Quality of Life Indicators	Case study: Interviews	Urban planning, transport, regeneration, officers working with Local Strategic Partnership, sustainable development	Unknown
Van Assche et al. (2010)	Belgium	Flemish City Monitor	Case study: Authors' experience working with 13 Flemish cities in developing and reporting the UHI tool	Urban planning (and other non-specified government policy-makers)	Yes

Table 4-7 Development process and characteristics of the UHI tools investigated by included studies (NBHD: neighbourhood)

Tool/Index	DEVELOPMENT OF UHI TOOL			CHARACTERISTICS	
	Lead organisation type	**Development process**	**Evidence informed UHI tool**	**Mapping function**	**Spatial Scale**
(Bristol) Quality of Life Indicators	City Government	Expert led	Unknown	Yes	City & NBHD
Community Indicators Victoria	Research Institution		Peer-reviewed literature	Yes	City & larger
Places Rated Almanac	Private Sector		Unknown	Static map	City
(Seattle) Healthy Living Assessment	City Planning Dept.		Peer-reviewed literature	No	NBHD
Core Environmental Health Indicators in Lucknow and Calcutta	Research Institution	Participatory	Unknown (Community derived)	No	NBHD
Flemish City Monitor	Research Institution		Peer-reviewed literature	No	City
Richmond Health and Wellness Element Indicators	City Government		Peer-reviewed literature	No	City & NBHD
Richmond Health Equity Indicators (aka Healthy City Diamonds)	Not-for-Profit Collaboration		Community and expert input	No	City
San Francisco Indicator Project	City Public Health Dept.		Peer-reviewed literature	Yes	City & NBHD
Urban Health Equity Indicators for Mathare Informal Settlement	Research Institution		Peer-reviewed literature	No	NBHD

4.6.2 UHI tool development

During the narrative synthesis it became clear that the approach to developing and applying UHI tools, either expert-led or participatory, influenced the value and use of UHI tools. Therefore, a distinction is made between these two approaches when analysing data and reporting results. However, there was variation across UHI tools regarding the following characterisations of these approaches.

Expert-led UHI tools (4/10) generally followed a technical approach to indicator development, with a focus on environmental health exposures and outcomes (Table 4-7). Such UHI tools were developed to measure, compare and assess the urban environment impact on health through translation of research evidence, with recognition of a hierarchy of evidence. The community was not central to the development of such tools, although their views may have been incorporated in some way, such as to inform UHI tool domains. Expert-led approaches sometimes involved an iterative process informed by engagement with local government (and other) stakeholders.

In contrast, participatory UHI tools (6/10) were described as emerging from a process of co-production with the community which placed less importance on the hierarchy of evidence defining or validating indicators (Table 4-7). These participatory processes encouraged a wide range of city stakeholders, including citizens, local government officials and academic experts, to co-define concepts and co-produce indicators through an iterative process of local negotiation, determined by context. Some of these projects involved co-creation of policy and co-monitoring of policy impacts.

The expert-led and participatory characterisations are not absolute and variations among UHI tool processes are recognised. For example, experts technically led the Flemish City Monitor and the San Francisco Indicators Project (SFIP) development, yet multiple stakeholders, including the community, were significantly involved and made fundamental decisions about the process and indicators. As a result, these projects would be viewed as participatory. In contrast, there was engagement with community organisations and government stakeholders to establish indicator domains for Community Indicators Victoria (CIV), but the majority of indicator selection and application was expert-led.

4.6.3 Uses and benefits of using UHI tools

The processes of developing and applying UHI tools resulted in a number of benefits that had the potential to improve the built environment to promote health and wellbeing. Table 4-8 describes the uses and benefits identified in the studies and how many studies reported such benefits. The table provides a breakdown of reported outcomes on the basis of the approach to developing UHI tools (participatory or expert-led) and spatial scale (neighbourhood or city). The analysis by development approach did not show remarkably different outcomes, particularly considering the overall numbers in each category. The analysis by spatial scale of data is reported in section 4.7. This section reports three of the most frequently reported uses and benefits: 1) informing policy development, 2) increasing awareness and knowledge of urban health issues and 3) supporting monitoring. The third benefit of UHI tools in Table 4-8 on facilitating collaboration is discussed in section 4.6.4 in relation to community involvement.

Table 4-8 Reported uses and benefits from developing or applying UHI tools by development approach and spatial scale of indicator data. NBHD: Neighbourhood

Uses and benefits of developing or applying UHI tools	**PROPORTION OF UHI TOOLS WITH THIS OUTCOME**									
	All UHI tools		**Expert-led**		**Participatory**		**NBHD scale**		**City scale**	
	n/10	**%**	**n/4**	**%**	**n/6**	**%**	**n/6**	**%**	**n/4**	**%**
Informed policy development	8/10	80	4/4	100	4/6	67	4/6	67	4/4	100
Created awareness and knowledge of urban health issues	8/10	80	2/4	50	6/6	100	6/6	100	2/4	50
Facilitated collaboration across stakeholders	7/10	70	4/4	100	3/6	50	4/6	67	3/4	75
Supported monitoring	7/10	70	3/4	75	4/6	67	5/6	83	2/4	50
Provided evidence of health or spatial inequalities	6/10	60	3/4	75	3/6	50	5/6	83	1/4	25
Identified local issues	5/10	50	3/4	75	2/6	33	4/6	67	1/4	25
Supported policy area prioritisation	5/10	50	3/4	75	2/6	33	4/6	67	1/4	25
Defined urban health concept	5/10	50	3/4	75	2/6	33	4/6	67	1/4	25
Enabled public accountability through transparency of data	5/10	50	1/4	25	4/6	67	4/6	67	1/4	25
Supported lobbying for policy, action or funding	4/10	40	1/4	25	3/6	50	3/6	50	1/4	25
Resulted in policies/programmes which improve or protect the environment	4/10	40	2/4	50	2/6	33	4/6	67	0/4	0
Engaged the public or changed the public's behaviour	4/10	40	3/4	75	1/6	17	3/6	50	1/4	25
Promoted ownership of health issues by planning and other city departments	4/10	40	2/4	50	2/6	33	4/6	67	0/4	0
Highlighted community needs to local government	3/10	30	1/4	25	2/6	33	3/6	50	0/4	0

Uses and benefits of developing or applying UHI tools	PROPORTION OF UHI TOOLS WITH THIS OUTCOME									
	All UHI tools		Expert-led		Participatory		NBHD scale		City scale	
	n/10	%	n/4	%	n/6	%	n/6	%	n/4	%
Supported performance management of city policy and decisions over time	3/10	30	1/4	25	2/6	33	2/6	33	1/4	25
Engaged politicians	3/10	30	2/4	50	1/6	17	2/6	33	1/4	25
Aided communication	3/10	30	1/4	25	2/6	33	2/6	33	1/4	25
Justified policies or decisions being taken by local government	2/10	20	1/4	25	1/6	17	2/6	33	0/4	0
Informed planning decisions or development proposals	2/10	20	1/4	25	1/6	17	2/6	33	0/4	0
Informed decisions about funding allocation	2/10	20	1/4	25	1/6	17	2/6	33	0/4	0
Facilitated benchmarking across communities or time	2/10	20	2/4	50	0/6	0	1/6	17	1/4	25
Improved capacity (knowledge/ability) in local government	1/10	10	1/4	25	0/6	0	1/6	17	0/4	0
Supported site selection for development	1/10	10	0/4	0	1/6	17	1/6	17	0/4	0

Informing policy development was the most widely noted output of developing and applying UHI tools. For example, in San Francisco the UHI tool improved understanding of air quality issues in certain neighbourhoods within the city, which then led to specific policies to reduce ingress of polluted air into new housing (Bhatia, 2014). Through dialogue between the city's planning and public health departments, the public health team were able to understand the planners' constraints and make appropriate recommendations to reduce the impact of air pollution in new housing.

> *'Because restricting the location of housing was in conflict with the city's growth objectives, the Department of Public Health proposed that developers install mechanical ventilation and filtration in locations with significant outdoor air pollution. In 2008 the city formalized this approach through an ordinance that used the neighborhood air pollution indicators to trigger higher building ventilation standards' (ibid; p.5).*

Thus, the UHI tool informed specific policies and was used to indicate the requirement for specific ventilation standards on a case-by-case basis.

UHI tools increased community and local government knowledge and capacity to improve urban health through built environment policies and decisions. In Cape Town, Lucknow and Calcutta study participants identified a virtuous cycle of community involvement in indicators to raise awareness and thereby improve city services (Hunt and Lewin, 2000). In Bristol, knowledge gained by the community was 'one of the most important outcomes' although it was 'more of an unintended consequence' (Shepherd and McMahon, 2009, p.117). In San Francisco, 'indicators enable[d] citizens to participate more knowledgeably in decisions' (Bhatia, 2014, p.2) and 'unequivocally increased Council member understanding of how human health is impacted by development' (Farhang et al., 2008, p.263).

Monitoring was consistently described as a valuable output of UHI tools, either as a task for local government officials alone or a participatory governance process. The latter was promoted by Corburn and Cohen (2012) as part of a process they described as adaptive management. Where UHI tools included longitudinal data, local officials observed trends and acted early when problems arose. For example, monitoring through Bristol's Quality of Life Indicators 'improved the targeting of investment in graffiti removal to prioritise Neighbourhood Renewal Areas which then quickly saw positive impacts on public perception' (Shepherd and McMahon, 2009, p.113).

4.6.4 Benefits of community involvement in UHI tools

Involving communities in developing or using UHI tools resulted in additional outcomes than could be achieved without their involvement. This could be achieved through expert-led or participatory processes, although the latter were likely to have greater community involvement. There were four key benefits of community involvement in UHI tool development: 1) increased participation and sense of power in governance, 2) increased balancing of expert and lay knowledge, 3) increased negotiation and consensus building among actors and 4) promotion of a 'health in all policies' and 'whole-of-society' approach.

First, community involvement led to increased participation and sense of power in urban governance. Corburn et al. (2014) described the outcome of participatory workshops with the community and city staff as being 'crucial for generating policy solutions and transforming the governance relationships between the city and its residents' (p.633). The authors went on to say that the UHI tool development and co-production of policy had far-reaching results in terms of increasing community spirit and participation in city meetings and events. Farhang et al. (2008) stated that the indicator process in San Francisco 'promote[d] meaningful public involvement in land use policy making by making explicit competing interests and facilitating consensus' (p.256). Expert-led UHI tools also facilitated community involvement in planning processes. Lerman (2011) noted that through using Seattle's Healthy Living Assessment '[c]ommunity members were engaged in the planning process in a genuine and productive way' (p.3).

Second, community input in UHI tools increased balancing of expert and lay knowledge claims and representation of community needs to policy-makers. Diverse stakeholders brought their own knowledge and priorities to UHI tool development. Project leaders determined how different perspectives and knowledge claims should be elicited and treated when developing indicators. For example, in San Francisco 'the quality of participation likely enhanced the interpretability, meaning, and relevance of indicators for stakeholders and contributed to the indicators' usefulness in supporting stakeholders' demands in the process of policy making' (Bhatia, 2014, p.6). A wide range of stakeholders were consulted, contributed views and made decisions (as part of a Community Council), with the public health department acting as a final arbiter to interpret this range of information and apply indicator results with the city's planning department.

Third, participatory development of UHI tools created or exposed tensions between stakeholders which opened opportunities to discuss and negotiate solutions. Tensions were related to conflicting views on how environment, land-use and health issues should be addressed through urban planning and development. They were also related to power imbalances among actors and differing views on how the indicators would be used to redress a perceived lack of power. In Lucknow and Calcutta, the indicator development process created a positive opportunity to discuss issues and gain new perspectives about pre-existing tensions between residents, planners and service providers. The process of developing indicators created opportunities for residents and government representatives to move beyond their 'stereotypic views' and 'discuss common concerns… to improve the understanding of each other's needs and constraints' (Hunt and Lewin, 2000, p.198). This new shared understanding was found to have improved dialogue and thereby improve service delivery. Similarly, in San Francisco the UHI tool faced opposition from various stakeholders. Developers, were suspicious that the UHI tool was '"stacked" against development interests' and would be used in an attempt to stop development (Farhang et al., 2008, p.264). The UHI tool was purposefully developed in the context of existing conflict to 'foster dialogue among diverse stakeholders to help bridge the multiple and often competing interests placing demands on development' (Farhang et al., 2008, p.257).

Finally, the development and use of UHI tools with community members improved the knowledge of residents and city agencies about the varied environmental causes of health impacts, leading to examples of health in all policies (HiAP) and whole-of-society approaches, as defined by Kickbusch and Gleicher (2012). Farhang et al. (2008) reported that developing the UHI tool increased knowledge and led some participants 'to apply public health arguments and evidence in public policy dialogues on housing, economic, and environmental issues' (p.263). This could be seen as an HiAP approach. In one example, a community group used data about parks and affordable housing to argue for community impact fees from a new luxury residential development in their neighbourhood. Similarly, the focus on residents' views provided through application of the UHI tool in Seattle 'led to the inclusion of more actions that lie outside the realm of city departments' (Lerman, 2011, p.3). This could be described as a whole-of-society approach. In these examples, new knowledge gathered from the development or application of indicators was applied in city-wide activities to improve urban health.

4.6.5 Facilitators and barriers of UHI tool development and use

There were a number of facilitators and barriers to both developing and applying UHI tools that affected their ability to influence policy and decision-making (Table 4-9). The facilitators and barriers spanned technical, political, knowledge and organisational factors. Facilitators listed under a particular category in Table 4-9 (e.g. knowledge) may have helped to overcome barriers of that same category or other categories (e.g. political).

Table 4-9 Facilitators and barriers to applying (A) or developing (D) UHI tools

Facilitators	Type	Barriers
Data related to policy (A) Data measures of policy inputs and outputs (A) Data available at small geographic scales and is comparable (A) Data not expensive to obtain (D) Indicators include social and built environment elements (A) Provides evidence to support advocacy (A) Measures public service performance (A) Data collected over a long period (A)	Technical	Not related to relevant policy or policy area (A) Lacked new information/or adequate information (A) Inappropriate scale of data availability (D/A) Data availability and cost of obtaining data (D/A) Limited relevance of indicators to specific users (A) Variation in how indicators are prioritised by different groups (D/A) Data did not match the population affected by new development (A)
City managers receptive to indicator data (A) Indicator work is embedded in a local government department with influence over relevant policy or other departments (A)	Political	Politicians' concern that indicators would reveal negative issues (A) Concern that indicators would be used to stop development (A) Concern that UHI tool would be used to create new regulations (A) UHI tool not accepted/valued by all stakeholders (A) Conflict between UHI tool stakeholders (A) Indicator outputs not politically or financially feasible (A) Complexity of policy-making process (A) Local leaders did not want policy advice from indicators (D/A)

Facilitators	Type	Barriers
Diverse knowledge incorporated via broad participation (D/A) Indicators are perceived as 'neutral' or 'objective' (A)	Knowledge	Knowledge gap about health and land-use (D) Knowledge gap about creation and application of indicators (D/A) Knowledge gap about translating indicator data into development plan recommendations (A)
Residents/citizens are involved in selecting indicators (D/A) Indicator developer (or owner) is embedded in local authority (A) Indicator data is integrated early in the planning process (A)	Organisational	Conflict or disagreement within the indicator producer group (D/A) Stakeholder availability and 'permission' to participate (D) Limited agency/power of the indicator producer or users (D/A) Difficulty finding neutral space for all stakeholders to meet (D) Focusing stakeholder involvement away from grievances (D) Lack of collaboration across municipal departments (A) Not all stakeholders equally interested in producing indicators (D) Resource constraints (A)

4.6.5.1 *Technical*

Technical facilitators and barriers were widely reported in the included studies, including data and indicator selection challenges. Where technical challenges could be overcome, this was described as supporting the use of UHI tools by policy and decision-makers. If these challenges could not be resolved, in some cases the UHI tools were at risk of having very little value once published.

Technical challenges and opportunities related to data availability, scale and cost were frequently described. Corburn and Cohen (2012) stated that neighbourhood scale data was important to identify urban health equity issues, yet 'very few cities in the global north or south collect data on the social determinants of health at the neighorhood scale' (p.5). Bhatia (2014), Lerman (2011), and Shepherd and McMahon (2009) all found benefits from gathering and reporting neighbourhood scale data. For example, in the case of Bristol's Quality of Life Indicators:

> *'…the data is broken down to local levels and mapped which powerfully represents inequalities and has led to targeted work to address those inequalities. Localised data has led to QoL indicators becoming the building blocs not only of policy but of action to improve local sustainability in Bristol' (ibid; p.113).*

Data which were only presented at city scale were identified as not supporting built environment policy and decision makers, specifically planners. Landis and Sawicki (1998) argued that planners required data at sub-city scales and that data comparisons at the wrong scale 'may be worse than no comparisons at all' (p.344). The desire to compare areas within a city was echoed by planners in Lucknow and Calcutta, who were interested in service level differences across their city (Hunt and Lewin, 2000). However, in this case, comparison was not possible due to data variation across local areas. In addition, local planners in these cities identified the process of UHI tool development and data collection as unfeasible. Despite interest from planners and residents, the study authors reported that after the study ended (and external support for the project ceased) neither group pursued the indicator project any further (ibid).

4.6.5.2 *Political*

UHI tools encountered political barriers to application in policy and decision-making processes for two main reasons. First, the complexity of the policy process meant that scientific evidence and UHI tools were seen as being of lower importance than other political and economic factors. Second, UHI tools were not accepted by all urban environment stakeholders as a valid or welcome resource to inform policy and decision-making. Political facilitators included broad stakeholder engagement and policy-relevant indicators. The former was used in UHI tool development as a facilitator to improve buy-in and raise the importance of indicators in policy and decision-making processes (grouped under 'knowledge' in Table 4-9), such efforts may not have changed existing suspicions of UHI tool motivations (for example, as being 'stacked' against developers) or the weight of this resource in comparison with other factors.

The complexity of the policy-making process was explicitly discussed by Hunt and Lewin (2000) as a key barrier for UHI tools. They argued that in contrast to the widely held views of indicator producers, their study found that environmental health policy and decision-making did not always represent a 'rational' process using evidence:

> *'...scientific evidence did not appear to be a key element of decision-making in the settings examined in this study. Other factors, such as political processes and affiliations and economic constraints were more important and played a larger role in determining the selection of environmental health priorities for intervention at the local level' (ibid; pp.203–204).*

In Lucknow and Calcutta, Hunt and Lewin observed multiple barriers to applying UHI tool data, many of which were political. They found that the process of developing indicators, including who participated and the wider context, were important factors in overcoming these political barriers. However, they concluded that such barriers had a stronger influence than indicators for local decision-making.

Researchers in Flanders found that local politicians and policy-makers did not all welcome UHI tools as a valid source of information to inform decision-making. Some policy-makers expressed concerns about publishing data that revealed unattractive facts about the city or could be used to contradict plans for economic development (Van Assche et al., 2010). These groups did not value the comparative information provided by indicators (ibid). The indicator producers sought to allay these concerns by explaining their motives and what they called a 'needs oriented' approach (about satisfying the needs of all residents) underpinning the UHI tool development (ibid; p.351). In addition, Van Assche et al. claimed that the tool's participatory design supported the use of indicators, however it did not 'guarantee they played a crucial role in policy debate or decision-making' (ibid; p.351). The participatory development process was seen to help mitigate stakeholders' fears of publishing data and to promote networking between city authorities (ibid).

One commonly referenced political facilitator and barrier was the relevance of indicator data to policy. Where data were relevant to policy aims, they were able to support policy development in some cases. For example, in San Francisco indicators about noise pollution and residential displacement led to new policies to minimise noise pollution exposures in new development (Bhatia, 2014). Where data were not related to topics under the control of built environment policy-makers, indicators could not be translated into policy and decisions. Landis and Sawicki (1988), Bhatia (2014), and Lowe et al. (2015) gave examples where indicators about housing price, cultural services, job opportunities and recreation facilities were largely controlled by private sector providers or other policy domains and could only be influenced to a limited extent by built environment policy-makers.

4.6.5.3 *Knowledge*

The type and source of knowledge underpinning indicators were both potential facilitators or barriers to UHI tool development and use. In participatory approaches, community groups did not always have relevant knowledge about health and the environment, creating a potential barrier to indicator development. Evidence-based indicators were supported and desired by stakeholders in expert-led and participatory approaches. Study authors recognised that a diverse range of knowledge was required to develop and apply UHI tools.

The selection of indicators based on research evidence about the urban environment and health, including health equity, was important in participatory and expert-led approaches. Seven out of ten UHI tools reported using research evidence to underpin indicators through peer-reviewed literature (6/10) or expert input (1/10), see Table 4-7. The combination of a scientific evidence base and an expert-led approach were seen to add to the utility of Community Indicators Victoria for urban planning policy and decision-makers:

> *'…indicators must be credible and difficult to disregard. [they]…must be developed through rigorous research, and proven to be valid and reliable. …[Those who] develop and report indicators also need to be influential and respected'(Lowe et al., 2015, p.140).*

Participatory approaches also valued inclusion of research evidence to underpin indicators. Corburn and Cohen (2012) explained that in Richmond and Mathare the indicators included a 'health and equity-based rationale' from peer-reviewed literature and this was seen as important to all stakeholders, including community residents (p.5).

Inclusion of community knowledge was a facilitator of UHI tool indicators and this was achieved in several ways:

- communities developed indicators based on their knowledge and experience (Corburn et al., 2014; Corburn and Cohen, 2012; Hunt and Lewin, 2000)
- communities were involved in the definition of urban health challenges or selection of indicators, alongside other experts and stakeholders (Bhatia, 2014; Davern et al., 2011; Farhang et al., 2008; Van Assche et al., 2010)
- community perceptions (from resident surveys or workshops) informed UHI tool domains (Shepherd and McMahon, 2009; Davern et al., 2017)
- communities were invited to use a framework of evidence-based indicators or prompts upon which their local experiential knowledge could be layered (Lerman, 2011).

These methods of eliciting and integrating community knowledge were applied to varying degrees across participatory and expert-led UHI tool projects, with the exception of the Places Rated Almanac which had no community participation.

4.6.5.4 *Organisational*

The status and ownership of UHI tools within city government and the ability of different stakeholders to participate in their development were common organisational facilitators and barriers to UHI tool development and application. Organisational barriers included practical issues about availability of 'neutral' places to meet and permission for city officials to participate (Hunt and Lewin, 2000, p.198). There were also very practical organisational facilitators such as locating UHI tool development in appropriate departments within city government and applying them early in the planning process (Shepherd and McMahon, 2009; Lerman, 2011). Some organisational barriers were more difficult to resolve and study authors did not always identify satisfactory solutions to these challenges, such as diverse perceptions of UHI tool motivations and conflict and tension among indicator users and producers.

The ownership of UHI tools by city government, and location within specific departments, were both barriers and facilitators to application of indicators. In Bristol, the

Quality of Life Indicators were deemed to be more influential across council departments because they were developed and managed by the Sustainable Development Team (Shepherd and McMahon, 2009). The UHI tool was populated by data gathered through an annual resident survey, which Shepherd and McMahon reported 'feeds a virtuous circle of measurement, communication, raising of profile, targeted local work and improvement' (ibid; p.117) They noted that staff at all levels of the council used indicators to support policy and decision-making and this increased evidence-based decision-making. They attributed these benefits to the longevity of the tool, the availability of data at ward level, and the 'influence of individuals and the organisational location of QoL indicators' (ibid; p.118).

In some cases, city departments lacked power or ability to effectively collaborate across departments to enable indicator application to policy and decision-making. In San Francisco, Farhang et al. (2008) described the public health department as having a

> *'legitimate agency interest in integrating health considerations into land use decision making; however, [the department] had limited power in the planning process and could not promise Council stakeholders that other public agencies would adopt the Council's findings or recommendations' (p.264).*

In this case, the public health UHI tool producers did not have enough influence over built environment policy and decision-making to ensure the indicators would have impact. A similar example emerged in Lucknow and Calcutta where Hunt and Lewin (2000) described lack of collaboration across built environment and health teams as a significant barrier. Built environment city officials were not empowered to make changes to the environmental health problems exposed by indicators.

Stakeholders involved in developing and applying UHI tools had diverse perceptions of the value and motivations of indicators and indicator producers. Examples from San Francisco and Flanders showed that local politicians, policy-makers and developers expressed concerns about the motivations, risks and duplication of existing processes that UHI tools represented. In San Francisco, Farhang et al. (2008) reported the following concerns from different groups:

- property developers: the UHI tool and wider HIA process would result in new regulations for development
- city officials: indicators would be used to block development

- city planners: the UHI tool would duplicate or compete with existing aspects of the formal planning process.

In response, the Community Council (that developed the UHI tool) reassured developers and officials that the tool was voluntary and 'provided only one "lens" (ie, health) to evaluate a project or plan, and was intended to inform and not resolve debates over conflicting priorities' (ibid; 261). This account of SFIP was slightly different to Bhatia's (2014) which stated that the use of indicators did not have many 'public detractors – a fact that may reflect their perceived neutrality and objectivity' (p.7). These differing accounts serve to underscore the diversity of stakeholder perceptions and concerns about a single UHI tool.

Conflict among UHI tool stakeholders about the purpose and outcomes of indicators was a barrier for developing and applying indicators. In San Francisco, Farhang et al. (2008) reported conflict and disagreement within the indicator producer group arising from the 'competing agendas' of different stakeholders (p.264). This created challenges for developing and applying the UHI tool in a manner that all participants found appropriate. In India, Hunt and Lewin (2000) observed significant conflict between local government officials, politicians and communities. Officials did not want to admit a lack of knowledge about community needs regarding environmental health (ibid). Politicians and officials argued about each other's understanding of community needs (ibid). Local government stakeholders did not want to reveal their knowledge gaps about community needs, yet the UHI tool process demonstrated that existing community engagement exercises were not working (ibid). There were significant challenges with stakeholder relations in this setting which were seen to inhibit application of the UHI tool.

4.7 Relations between characteristics and use of UHI tools

Three insights were identified by combining data gathered through the census of UHI tools (part A) with qualitative data about perceptions and the use of UHI tools (part B). First, a number of UHI tool uses and benefits were more commonly achieved through UHI tools which measured data at the neighbourhood scale and lower. Of the ten UHI tools in part B, six measured data at the neighbourhood scale and four measured city scale data (Table 4-7), compared with 59.3% (86/145) of UHI tools in part A measuring data at neighbourhood scale. Some outcomes of developing and applying UHI tools were more frequently achieved by the neighbourhood scale tools, such as: creating awareness of urban health issues, monitoring policy and providing evidence of health or spatial inequalities (see Table 4-8).

Second, despite the large number of UHI tools which mapped data (44.1% (64/145) of UHI tools in part A), mapping was not frequently mentioned in the part B studies. In the qualitative portion of the review, four out of ten UHI tools mapped data; three interactive maps and one static map (Table 4-7). Presentation of data via maps was rarely mentioned as a useful feature of UHI tools, with one exception. In Bristol, multiple city stakeholders identified benefits of locally mapped data, including: helping with communication and comparing areas to identify inequalities and building a case for funding, among other benefits (Shepherd and McMahon, 2009). Maps or mapping exercises were used tangentially in Mathare and Seattle. Following the UHI tool project in Mathare, the community-derived indicator data were combined with spatial maps about community assets and hazards (Corburn and Cohen, 2012). The maps were then used during participatory planning exercises. Rather than presenting data through maps, Seattle's Healthy Living Assessment tool gathered data through community mapping exercises, where participants identified health-promoting assets and challenges on maps (Lerman, 2011).

Third, only one UHI tool reported data through an index and this was not found to be useful for built environment policy and decision-making. The census identified 53/145 UHI tools (36.6%) which reported indicators in a composite indicator, or index. The Places Rated Almanac was the only composite UHI tool in part B. Landis and Sawicki (1988) summarised the views gathered through interview and survey data about its utility as follows:

> *'Is the Places Rated Almanac useful to planners and public officials? No, not in the slightest sense. For planners, the purposes of comparing places are to learn from other communities and to gain an understanding of how planning can or cannot help reduce crime, improve the quality of health care…[etc.] (...) For planners, the problem with volumes like Places Rated is that we never learn why some places may be superior to others' (p.343).*

Although Landis and Sawicki found the Places Rated Almanac to affect public opinion and raise the importance of issues to politicians and officers, they did not believe that the indicators were sufficiently robust to inform decision-making on their own. This was not solely attributed to the tool being an index, yet Landis and Sawicki did note challenges with the index methodology and misinterpretations of the rankings by the public and city officials (ibid).

4.8 Addressing complexity with UHI tools

Complexity was investigated in the census of UHI tools and the narrative synthesis of studies about their use. The census showed that although complexity was frequently discussed in UHI tool methodology documents, there were few examples of how UHI tools addressed the complexity of urban health. The narrative synthesis studies included several examples of how the use of UHI tools may address the complexity or urban health and policy-making.

A substantial number of part A UHI tools referred to complexity in the methodology (43%, 63/145). The word complexity was mentioned in 128 instances covering multiple topics, including:

- indicators/indices can simplify or mask the complexity of the concepts being measured
- the urban environment impact on health and behaviour is complex
- measuring the urban environment's impact on health is complex
- the process of policy and decision-making is complex.

Eleven UHI tools stated that indicators or composite indices can simplify the complexity of the concepts being measured. In relation to the City of Winnipeg Quality of Life Indicators, Hardi and Pintér (2006) explained:

> *'[i]ndicators are used to simplify information about complex phenomena, such as sustainable development or, in this case, QOL, in order to make communication easier and quantification possible' (p.130).*

This was contrasted by the opposing view that indicators/indices can mask complexity (two instances). The authors of the London Quality of Life Indicators stated:

> *'[a]lthough the Commission have sought to identify and report on 20 headline indicators, to constitute a popular 'barometer' for London's quality of life, it is clear that single figure measures can mask a much more complex situation' (London Sustainable Development Commission and Greater London Authority, 2004, p. 8).*

Three UHI tools referred to the complex process of policy and decision-making, sometimes in recognition that indicators may not inform policy due to this complexity. For example, Hunt and Lewin (2000) commented that

> *'policy action may not easily follow the identification of environmental health problems [through indicators], which is due both to the large numbers of other factors that also affect health and to the complexity of the policy process' (p.189).*

UHI tools rarely explained strategies used to help account for complexity. Feneri et al. (2014) used Multi-criteria Decision Analysis to 'conceptualize the complex issue of evaluating quality of life' (p.574). They specified the use of Analytical Hierarchy Process to prioritise indicators. The AARP Livability Index used a high number of indicators to address complexity, stating: '[s]imple questions about livability can have complex answers. This is why the index includes a large number of metrics' (AARP, n.d. section: "How are Livability Scores Determined?").

The narrative synthesis studies recognised multiple challenges and solutions related to complexity for the production and application of UHI tools. There were four complexity challenges: 1) measuring complex urban health systems, 2) reporting and representing this complexity through UHI tools, 3) developing appropriate policies from UHI tools given underlying complexity and uncertainty, and 4) influencing the complex nature of policy and decision-making for urban health objectives. The studies offered two potential solutions to these challenges: 1) using an 'adaptive management approach' (Corburn and Cohen, 2012) and 2) underpinning UHI tools with a normative or systems framework (Van Assche et al., 2010). First this section briefly summarises these approaches. Then the section compiles solutions to address seven complexity characteristics through UHI tool development and application identified through both parts of the systematic review and wider literature.

Corburn and Cohen (2012) noted three complexity challenges including: the complexity of urban health (and equity), measuring this system through indicators, and the resultant effect on policy-making. These challenges are summarised in the following quotes:

> *'…the danger of indicator efforts is that they portray a too simplified picture of a complex reality and policy solutions may suffer the same defects' (ibid; p.1).*

> *'The complexity of cities and the variegated forces that contribute to (in)equity in urban neighborhoods demands that indicator development processes are similarly dynamic.' (ibid; p.2)*

They proposed using UHI tools in a process of ‘adaptive management’, borrowed from environmental sciences, which involved co-defining problems, co-producing indicators, co-designing policy and co-monitoring and responding to impacts over time (as introduced in chapter two). Furthermore, they argued that this approach was well-suited to complex urban health challenges, including equity, because it recognised the failure of linear models and promoted ongoing experimentation and learning in the face of complexity and uncertainty (ibid). Their adaptive management UHI tool process took place with residents and other urban stakeholders in Richmond, USA and Mathare, Kenya (Corburn and Cohen, 2012; Corburn et al., 2014). However, the stages related to ongoing monitoring and policy adjustments were not reported in either of these settings. Corburn and Cohen (2012) reported that this approach was still new and required further adoption and evaluation to determine its effectiveness.

Van Assche et al. (2010) proposed that indicators could support the complexity of policy and decision-making in cities by providing local knowledge and feeding policy debate. They recognised that ‘a complex urban policy debate weighs heavily on decision making in public policies’ and that indicators could help reduce uncertainty in this process (ibid; p.343). They used uncertainty and complexity as ‘theoretical building blocks’ for creation of the UHI tool, alongside a ‘value base’ which consisted of a ‘normative framework on liveable and sustainable urban development...’ (ibid; p.343). Through this approach, Van Assche et al. intended to provide decision-makers with indicators which represented local knowledge to inform policy debates. In their estimation, the Flemish City Monitor had not been widely adopted by city officials and politicians because they did not support the monitoring and city comparison elements. They argued that ‘carefully selected, relevant and interpretable indicators can contribute, but the real issue is likely to be about the integration of needs in all policy domains’ (ibid; p.351). In other words, UHI tools could help with complex challenges if they succeed in influencing multiple policy domains.

Based on their experience in India and South Africa, Hunt and Lewin (2000) were not convinced that UHI tools could influence the ‘complexity of the policy process’ (p.189). They identified political and economic constraints as key barriers to UHI tools that were not overcome in the projects in Lucknow and Calcutta. They concluded that

> *‘As tools, community-based indicators are unlikely to become a part of the existing decision-making process unless they are integrated with local agendas, backed by strong local representation, and receive strong institutional support’ (ibid; p.204).*

This aligns with Van Assche et al.'s (2010) previous point from the Flanders example. Hunt and Lewin (2000) also observed that many international indicator projects overlooked the complexity of policy and decision-making processes and assumed that indicators would be used in a linear fashion.

Table 4-10 outlines seven characteristics of complexity in urban health systems identified in the academic literature, adapted from Pineo et al. (2018b): dynamic, number of elements, interconnected, non-linear structure, feedback, counterintuitive and emergent behaviour. Table 4-10 then summarises potential solutions to these challenges identified in the systematic review (parts A and B). In the fourth column, an asterisk denotes the researcher's suggestions for how UHI tool characteristics could help address complexity challenges in addition to those found in the review. The fifth column does not map to specific rows, rather it describes how UHI tools could support policy and decision-making in relation to the overall complexity of urban health systems.

Table 4-10 Characteristics of complexity in urban health systems (adapted from Pineo et al., 2018b) and proposed characteristics of UHI tools which could help address complexity. An asterisk in the fourth column indicates suggestions provided by the author

Characteristic	Description (in urban health terms)	Example for urban health system	How could UHI tool characteristics help address this challenge?	How could UHI tools help address this challenge in policy and decision-making?
Dynamic (Sterman, 2000)	Health and wellbeing impacts and/or exposures change over time (possibly in unpredictable ways)	E.g. Air pollution has long term trends (increasing over time), seasonal trends and extremes (spikes).	Monitoring urban environment exposures and outcomes over time (Corburn and Cohen, 2012; McCarney and McGahan, 2015).	• Involving multiple stakeholders and the community in a process of 'adaptive management' including co-design of indicators and policy and co-monitoring of impacts and policy adjustments (Corburn and Cohen, 2012). • Using cross-departmental and multi-stakeholder UHI tool development processes to identify and discuss interconnections and policy responses (Corburn and Cohen, 2012). • Providing policy and decision-makers with indicators which measure and monitor multiple factors across policy areas (Shepherd and McMahon,
Number of elements (Glouberman et al., 2006; Luke and Stamatakis, 2012)	High number of variables within system	E.g. Transport system includes many elements which interact to create effects such as a walkable community.	Including a large number of indicators of exposures and outcomes (AARP, n.d.; Block et al., 2008).	
Interconnected (Sterman, 2000)	Multiple interactions across and within systems	E.g. Transport emissions affect health through air pollution whilst contributing to climate change which has additional health impacts.	Including quantitative and qualitative data to provide a holistic picture (McCarney and McGahan, 2015). Including measures of known interactions across indicators or domains (e.g. transport and air quality) and making known interactions explicit in reporting.*	

Characteristic	Description (in urban health terms)	Example for urban health system	How could UHI tool characteristics help address this challenge?	How could UHI tools help address this challenge in policy and decision-making?
Non-linear structure (Sterman, 2000)	Non-linear relationship between exposure and health and wellbeing impact – effects are rarely proportional to causes	E.g. Impact of vehicle speed on pedestrian injury/death does not change proportionately as speed increases.	Reporting clear thresholds or tipping points alongside indicators.*	2009; Van Assche et al., 2010; Corburn and Cohen, 2012). • Making the components of urban health and liveability (and interconnections between these) explicit to decision-makers through a normative or systems framework underpinning indicators (Van Assche et al., 2010; Corburn et al., 2014).
Feedback (Sterman, 2000)	System elements interact recursively (in feedback loops) to change the behaviour of the system	E.g. Increasing road capacity usually has the unintended effect of increasing traffic congestion by attracting more drivers.	Reporting links between indicators with description of feedback relations.*	
Counter-intuitive (Sterman, 2000)	Health and wellbeing impacts distant in space and time to exposures	E.g. Presence of many fast food outlets in a community may result in increased obesity levels over time.	Ensuring exposures and outcomes are measured at appropriate spatial scales and longitudinally. Making delays explicit in reporting.*	
Emergent behaviour (Glouberman et al., 2006; Luke and Stamatakis, 2012)	Health and wellbeing effects are greater than the sum of individual effects within the system	E.g. A park or 20mph limit are not sufficient on their own to support physical activity, but are effective if combined with other elements (such as pavements, mixed land uses, etc.).	Reporting data which form part of an urban health system (behaviour, outcome or exposure, e.g. physical activity), crossing typical UHI tool domains.*	

4.9 Theory of change

This section presents the final ToC of the process through which UHI tools influence healthy urban environment policy and decision-making. The ToC elaborates what worked (inputs and activities, leading to outputs and outcomes), in which circumstances (UHI tool development approach and wider context), and for whom (residents, local government and other stakeholders). The ToC is presented in a summary diagram (Figure 4-11) and a more detailed description of the inputs, activities, outputs and outcomes (Table 4-11).

The high-level ToC in Figure 4-11 does not differentiate between participatory or expert-led UHI tools. The four quadrants (i.e. inputs, activities, outputs and outcomes) are not intended to be sequential (e.g. occurring clockwise). Each quadrant contains summary characteristics. The quadrants are affected by the external ring of contextual factors which were identified from the studies.

The detailed ToC in Table 4-11 describes diverse inputs, activities, outputs and outcomes as they related to expert-led and participatory UHI tool approaches. Many inputs were common to both approaches (marked as 'shared' in Table 4-11), such as the requirement of resources and data. However, the importance and function of inputs and activities varied across the approaches. Furthermore, participatory approaches required different inputs and activities to involve the community. Both participatory and expert-led UHI tool processes shared outputs. However, participatory processes that involved the community resulted in many additional outputs related to a wider group of stakeholders gaining and applying new knowledge of urban health issues across multiple policies and activities. Furthermore, participatory approaches led to increased collaboration and communication among stakeholders. Over the longer term, both participatory and expert-led UHI tools were seen to achieve outcomes which improved built environment policies, decisions, and development projects. However, participatory approaches resulted in policies which more directly responded to residents' needs and also supported city-wide activities and policies to promote urban health (i.e. health in all policies and whole-of-society approaches).

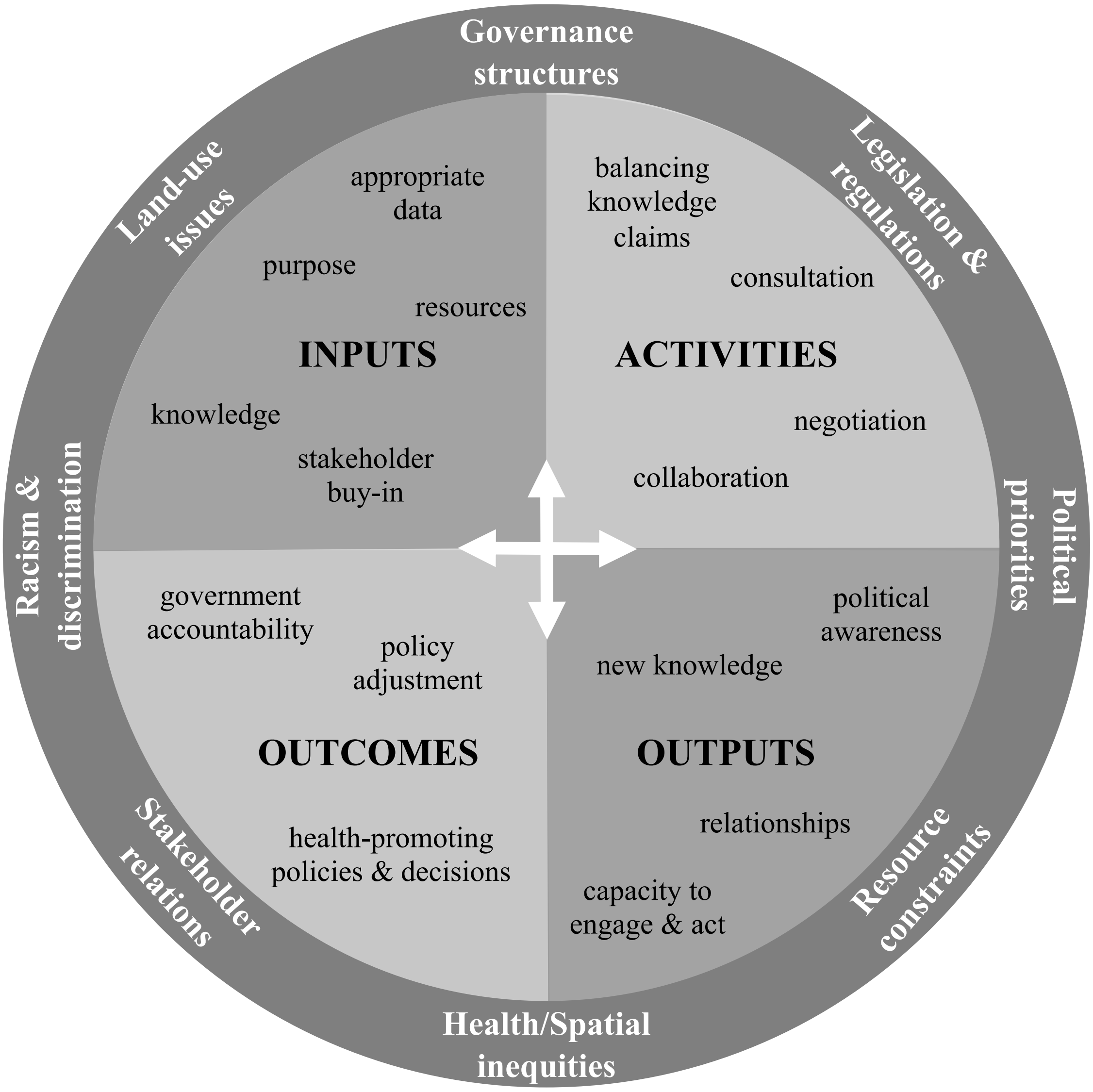

Figure 4-11 Summary diagram of theory of change regarding urban health indicator tool influence on urban environment policy and decision making

Table 4-11 Detailed theory of change of UHI tools influence on municipal built environment policy and decision-making

Context	Approach	UHI tool development		UHI tool application	
		Inputs	Activities	Outputs	Outcomes
Governance structures, Legislation & regulation, Political priorities, Resource constraints, Health/Spatial inequalities, Stakeholder relations, Racism & discrimination, Land-use issues	Participatory (with an emphasis on community involvement)	Resources for wide stakeholder involvement Places to meet Buy-in and permission to participate Wide stakeholder knowledge	Balance competing knowledge claims Negotiate pre-existing conflicts or tensions	City officials & residents gained new knowledge New knowledge applied to wide range of city activities & policies by all stakeholders Stakeholders gained mutual appreciation of constraints & opportunities Increased collaboration and new relationships across stakeholder groups Residents empowered to take further action Improved communication among stakeholders	Adopted policies to improve urban health through built environment which respond to residents' (and other stakeholders') needs City-wide activities and policies address urban health challenges
	Shared	Resources for data collection (over time) and analysis Appropriate data Identified indicator user	Link indicators to policy Underpin indicators with urban health research evidence	New knowledge about urban health, inequalities and priorities Increased awareness and political importance of urban health issues Indicator users monitor government performance Stakeholders use data to lobby for policy, action or funding Decision-makers use data to justify city policies or decisions	Built environment decisions support urban health objectives New development is designed to promote urban health Urban environment is monitored over time and policies are adjusted Residents or city stakeholders hold government to account
	Expert-led	Expert knowledge	Involve relevant indicator users Consult community in indicator development		Adopted policies to improve urban health through built environment

4.10 Discussion

This review has contributed new knowledge about the characteristics of UHI tools and synthesised existing knowledge about their use for the first time. Given the great diversity in the purpose and characteristics of UHI tools found in part A, and the heterogeneity of studies in part B, it is difficult to draw simple conclusions. However, the census and narrative synthesis generated novel findings about UHI tools as they relate to the needs of built environment policy and decision-makers. The taxonomy demonstrates the importance of considering users' needs when developing indicator tools to ensure they can be used to support built environment practitioners. The theory of change fills a gap in the indicator literature by providing a model of indicator use that opposes the dominant linear model described in chapters two and three. The ToC demonstrates the conditions and processes involved in developing and applying UHI tools that determine their influence on urban policy and decision-making. Furthermore, it shows how both participatory and expert-led UHI tools can influence policy and decision-making, and details how this is achieved through shared and separate routes.

The main findings from the review are summarised here with implications discussed below. These findings will inform the conceptualisation of indicator users' and producers' mental models about UHI tool use (Chapter 5) and the topics to be discussed in semi-structured interviews (Chapter 6).

The following findings emerged from the census:

- The proportion of tools with data aggregation/measurement at the neighbourhood and lower scale and presentation of data via digital interactive maps have both increased over time.
- The majority of UHI tools intend to inform policy and decision-making, yet it is unclear whether a significant number achieve this aim.
- The majority of UHI tools are evidence-based and therefore provide a potential route from research through to policy.
- There is a degree of similarity in the domains measured across UHI tool topics.

The narrative synthesis identified the following:

- Both expert-led and participatory indicator projects can be underpinned by research evidence and residents' knowledge; providing a middle ground for opposing epistemological characterisations of indicators.
- The facilitators and barriers identified in the synthesis contradict the dominant view of indicator use by policy-makers as a simplistic linear process.

- The synthesis provides evidence that supports the view that the process of UHI tool development brings about useful outcomes for urban environment policy and decision-makers; however, this is not the only route to implementation of indicators.
- Participatory UHI tools were more effective at achieving uses and benefits that would support health in all policies (HiAP) and whole-of-society approaches to governing healthy cities.

In combining data from the quantitative and qualitative parts of this review, the review has shown that features of UHI tools which were identified as important in the wider literature, such as neighbourhood scale data and underpinning research evidence, were also reported as important by built environment policy and decision-makers. The review also explored the nature of how UHI tool methodologies address complexity, identifying specific strategies in terms of UHI tools methodologies and approaches to influencing policy-makers.

4.10.1 Strengths and limitations

In comparison to existing reviews of indicators which measure the urban environment's impact on health, this review cast a wider net by including measures of health, QOL, liveability, wellbeing, and walkability/physical activity. This enabled a detailed analysis of a large number of indicator tools and their respective characteristics, including 8006 individual indicators. The narrative synthesis of studies on the use of UHI tools is believed to be the first systematic review on this topic, contributing new synthesised knowledge on what works, for whom and in what circumstances. The overall study design was published prior to conducting the review (Pineo et al., 2017a) and followed best practice procedures for systematic review design (e.g. PRISMA-P) (Shamseer et al., 2015) and reporting (Moher, 2009). The synthesis procedure followed best practice guidance (Popay et al., 2006). A research log was maintained throughout the conduct of both stages of the review to document process and decision-making.

There are a number of limitations to this review. The search was limited to English language publications, potentially excluding many UHI tools from non-English language countries. For the census, the method used to classify whether a tool had been used beyond research was simplistic. References to the UHI tool in a single report, case study or policy document were noted as 'used beyond research', although these examples may have been a one-off use of that particular tool, potentially overestimating use of UHI tools. Conversely, the Google search may not have identified all cases where UHI tools were used, potentially underestimating the use of such tools. The included studies in Part B were primarily conducted by the same individuals who developed the UHI tools and therefore may have overemphasised positive benefits of using indicators. The study designs were heterogeneous involving a range of methods (mainly case studies) making it difficult to appraise and compare quality. One included report was not a peer-reviewed journal paper. In conducting this review, the researcher acknowledged that use of UHI tools is an under-researched topic and therefore all studies and reports which met the eligibility criteria were included, regardless of methods and risk of bias. The quality appraisal for each study is included in Appendix A1.5. Although the review covered a range of income settings, further research is needed to understand how the context in different income settings may affect the use of UHI tools. Finally, a ToC opens the 'black box' to uncover how a proposed programme or policy will achieve change (Morra Imas and Rist, 2009); however it does not necessarily explicitly uncover the feedback relations between inputs, activities, outputs and outcomes. The ToC will form an input to conceptualising the development of a causal loop diagram which will explore these dynamics in chapter five. A limitation of the ToC also relates to the source data in terms of heterogeneity in study design and findings. Future research could test the ToC with a selection of indicator producers and users to test the extent to which this model matches their views of the value of UHI tools. Furthermore, collaboratively developing a ToC as part of developing a new UHI tool may help improve the resulting impact of the tool.

4.10.2 Discussion of key findings

4.10.2.1 *Data scale and presentation*

The increasing number of UHI tools with data aggregation at neighbourhood or lower scale is of significance for built environment policy and decision-makers. Talen (2002) questioned the usefulness of indicators to inform urban planning because the majority were comparing cities (inter-city) rather than neighbourhoods (intra-city). Neighbourhood and lower scale of measurement or data aggregation is more appropriate for identifying health inequities and environmental deprivation which may contribute to poor health (Prasad et al., 2014). Indicators at this scale can be used to inform neighbourhood development/regeneration policies and monitor the impact of these over time. In the narrative synthesis, six out of ten studies reported UHI tools that measured data at the neighbourhood scale. These UHI tools were more likely to result in a number of benefits, including: creating awareness of urban health issues and providing evidence of health or spatial inequities.

Data visualisation is also frequently noted as a helpful feature of UHI tools for built environment policy and decision-makers, particularly in relation to displaying data on maps (Rothenberg et al., 2015; Prasad et al., 2016). McGill et al. (2015) found that data presented on maps were evaluated as relevant evidence to inform decision-making by local built environment professionals. The growing number of UHI tools which present data on interactive maps at the neighbourhood or lower scale are therefore likely to be a powerful source of information for built environment policy and decision-makers. However, in the narrative synthesis presentation of UHI tool data on maps was not frequently discussed. This may relate to the rapidly changing nature of data presentation as disaggregated data and GIS software are increasingly accessible and user friendly.

4.10.2.2 *Knowledge basis and transfer*

The narrative synthesis found that both expert-led and participatory indicator projects can be underpinned by research evidence and residents' knowledge. This provides a middle ground for debates about the epistemological basis of indicators. Such debates are characterised by diverse claims of how indicators are constructed. A rationalist technical approach would claim that indicators should be based on validated associations between environment exposures and outcomes (e.g. Briggs, 1999). A social constructivist approach acknowledges that indicators can no longer be seen as technical tools; they require input from diverse forms of knowledge from the community and others (e.g. Pastille Consortium, 2002). In the synthesis of studies, knowledge was combined from multiple sources using a range of techniques to gather such knowledge. This demonstrates that in practice multiple UHI tools have combined rationalist and constructivist approaches to indicator selection. Scientific evidence-based indicators were supported and desired by stakeholders in expert-led and participatory approaches in the narrative synthesis. Regardless of the type of knowledge claim underpinning UHI tools, some stakeholders were suspicious of the use of such metrics for justifying built environment policies and decisions. For example, politicians and developers argued against indicators which could be used to block (economic) development (Farhang et al., 2008; Van Assche et al., 2010).

The distinction provided by the census of whether UHI tools were used beyond research is of interest when considering transfer of research knowledge to practitioners. Although 74/120 tools (61.7%) which intended to inform policy/decision-making were found to have done so, the researcher was unable to confirm whether 46/120 tools (38.3%) achieved this aim. This finding is interpreted with caution due to the limitation of how UHI tools were marked as 'used beyond research'. Furthermore, this finding does not give any context to how the UHI tools were used and whether they had an important impact on policy and decision-making. With regard to the UHI tools that were not used beyond research, there could be a delay between research and use or there may be other knowledge translation issues. UHI tool producers should consider the needs of their audience and may benefit from wider strategies to increase research use by policy and decision-makers (see Giles-corti et al., 2015; Oliver and Cairney, 2019), such as greater stakeholder participation.

4.10.2.3 *Indicator validity and standardisation*

Building on the previous point, a number of UHI tools in the census (31.7%, 46/145) did not explain the evidence used for indicator selection, creating questions over their suitability to inform policy and decision-making. In contrast, seven out of ten UHI tools in the narrative synthesis reported using research evidence to underpin indicators, and this was described as important to diverse stakeholders. Although the validity of individual indicators (evidence for an association between exposure and outcome) was not assessed by this review, the range of evidence used to select indicators demonstrated that this process was not always informed by scientific evidence about environmental exposures and health effects. Badland et al. (2014) called for further research about the validity of indicators within UHI tools (specifically in relation to liveability indicators). However, this review suggests that there is a large selection of validated indicators in the published literature and research efforts may be better directed toward understanding how existing indicators are used to guide the policy and decision-making process.

The apparent low use of many UHI tools, and the significant number of validated indicators currently available, leads the researcher to consider the argument for greater standardisation of indicators. The main argument supporting standardisation is that there is *some* agreement about what to measure, shown by two points: 1) there is significant overlap across indicator domains measuring health, QOL, liveability, and wellbeing and

2) there is wide acceptance of existing frameworks (e.g. DPSEEA) that emphasise the requirement for an evidence-based, often causal relationship between environmental exposures and specific health outcomes. There are two counter-arguments: 1) there is ongoing debate about how to define and measure related topics like QOL, wellbeing and liveability (despite similarity in existing UHI tools) and 2) it is unclear whether standardised indicators could produce the benefits of participatory UHI tools.

Given that many global UHI tools are already available and new tools are continually produced, the process of indicator development may be more important than indicator validity and agreement over what to measure. Scholars have argued that the role of sustainability and social indicators within governance processes (Pastille Consortium, 2002; Rydin et al., 2003) and the process of developing indicators (Innes, 1988, 1989, 1990; Innes and Booher, 2000) is equally or more important than the resulting indicator data. The ToC developed from the synthesis supports these views and contradicts the dominant view of indicator use as a linear process where policy-makers directly use published indicator sets when developing policy. A number of inputs and activities (translated from the facilitators and barriers in section 4.6.5) spanning technical, organisational, political, and knowledge topics were influential in determining whether indicators could achieve the ToC outputs and outcomes (translated from uses and benefits identified in section 4.6.3 and 4.6.4).

In conclusion, standardisation of indicators may reduce duplication of research effort at the local level; but would potentially risk the achievement of local learning and relationship-building which supported the use of UHI tool data by policy and decision-makers. Indeed, the ToC demonstrated that the process of indicator development was integral to their achievement in most, but not all, cases. If an internationally published set of evidence-based urban health indicators could be promoted globally (such as a more detailed version of the SDGs), communities (including researchers, practitioners and the public) could choose appropriate indicators for their area based on data availability, health priorities, and community opinion (Pineo et al., 2018b, 2018a) which may provide a middle ground between locally-led indicator development and standardised indicator sets.

4.10.2.4 *Community involvement and participatory approaches*

There were a number of benefits to including wide stakeholder involvement in UHI tool development, as highlighted in the theory of change. Participatory processes generally (involving a wide group of stakeholders) were found to be more effective at achieving uses and benefits that would support HiAP and whole-of-society approaches to governing healthy cities. This is likely explained by a greater number of individuals and organisations learning about the urban environment's impact on health, allowing participants to apply this knowledge in their respective policy domains or other activities, in line with Innes and Booher's (2010) argument for distributed intelligence.

Community involvement in the UHI tool development process did not necessarily increase a tool's legitimacy to influence the policy and decision-making process due to actors' suspicions about the underlying motivations of UHI tools (e.g. Farhang et al., 2008; Van Assche et al., 2010). This points to potential power struggles among actors in the process of urban governance. The validity of UHI tools appears to have been contested in settings where stakeholders felt that existing powers and governance mechanisms were at risk of being disrupted through the use of indicators. This reflects findings from the Pastille Consortium (2002) that conflict among actors reduced the likelihood that indicators would inform policy. Power and conflict in relation to UHI tool use will be explored further in the remaining thesis chapters.

4.10.2.5 *Complexity and indicators*

Whilst some indicator producers recognised that indicators could help explain complex phenomena (e.g. Hardi and Pintér, 2006), others noted that indicators may not be effective at influencing the complex policy and decision-making process (Hunt and Lewin, 2000). This review compiled solutions to complexity challenges through the processes of developing and applying UHI tools, such as explicitly showing interconnections among indicators (and policy domains) and involving a wide range of stakeholders. Although the UHI literature frequently references the challenge of complexity, the synthesis did not show that indicators helped policy-makers make sense of complex urban health and policy-making issues. This topic will be covered more extensively in the remaining thesis chapters.

4.10.3 Critical reflections on UHI tools

Observing the similarity across indicator measures, there is a question about whether some data are included simply because they are easy to measure (or commonly measured via routine statistics), while other more difficult topics are excluded. For example, although noise is known to impact multiple health outcomes (WHO, 2011b), it is less frequently measured in UHI tools, reflecting the difficulty of measuring this exposure. This is an area for further investigation.

The growth of city datasets emerging from open data initiatives may increase the need for indicators to help interpret and make sense of data. This may also support increased small-scale spatial comparisons, improving usability by built environment policy and decision-makers. New data from smartphones, social media and other sources are also likely to increase available datasets for UHI tools and may be a useful way to increase citizen participation in generating and evaluating indicator data. However, these advances in data collection may also result in the production of new indicators which reflect more about what is possible with data analytics than what is required by indicator users. This review provides a note of caution for the hype over smart city programmes (e.g. Townsend, 2013) and using city data to inform policy-making by emphasising that other factors beyond technical means are important.

4.11 Conclusion

This chapter has presented a mixed-methods systematic review involving a census of UHI tools and a narrative synthesis of studies about their use, providing contributions to knowledge and methods. The data from both parts of the systematic review were integrated to produce additional findings than could be found from the constituent elements of the review. A key finding from this chapter was that indicator use by policy-makers is not typically a linear process, highlighted through the theory of change. The discussion section reflected on the key findings in relation to the wider literature. The outputs from this chapter will be used to conceptualise mental models of UHI tool use by built environment policy and decision-makers using systems thinking approaches in the next chapter. Results from this chapter also inform the selection of interview participants and the topics to be explored with UHI tool producers and users, presented in chapter six.

CHAPTER 5

Conceptualising mental models of UHI tool use

5.1 Introduction

The systematic review demonstrated that a large number of UHI tools have been developed to inform policy and decision-makers; however, it is unclear whether many of these have been used in the way intended by their producers. This section builds on the findings from the systematic review to conceptualise and develop mental models for how UHI tools inform urban planning policy and decision-making, particularly in relation to promoting health. The chapter begins with an introduction to mental models and an overview of the motivation for modelling. Then the chapter describes the conventions for creating causal loop diagrams from system dynamics research. Next the chapter outlines the problem statement, emergence of the problem (based on the systematic review data) and the model boundaries. Finally, the chapter presents three dynamic hypotheses of how UHI tools influence urban policy and decision-making, based on data from the systematic review narrative synthesis. The dynamic hypotheses inform the interview topics to be explored in the next chapter.

5.2 Representing mental models of indicator use

Developing causal loop diagrams (CLDs) using system dynamics is one method to represent mental models. Johnson-Laird (1983) provides a useful introduction to mental models by describing them as a 'psychological core of understanding' about a phenomenon (p.81). He also argues that '[l]ike clocks, small-scale models of reality need neither be wholly accurate not correspond completely with what they model in order to be useful' (ibid, p.82). Individuals' mental models of UHI tool use could be described as 'dynamic hypotheses' or 'stories about how dynamic systems work' (Luna-Reyes and Andersen, 2003, p.281). Mental models of real-world phenomenon are a representation of how something works, but Johnson-Laird cautions that it is not possible to have 'complete mental models for any empirical phenomenon' (ibid, p.83). He argues that more information does not necessarily increase the usefulness of a model 'beyond a certain level' (ibid). Therefore, any representation of mental models must strike a balance between detail and accuracy.

5.2.1 Objectives of modelling

Causal loop diagrams seek to surface hidden understandings of how something works to enable stakeholders to explore and evaluate parts of the system, including opportunities to improve desirable impacts. The study aims to identify the mental models of both indicator users and producers regarding UHI tool use in urban planning policy and decision-making. Furthermore, it aims to understand the potential value of UHI tools to promote health within this complex policy and decision-making process. These aims were first analysed through the secondary literature and synthesised in chapter 4, resulting in a theory of change. In this chapter, the systematic review data (from the census and narrative synthesis) is used to conceptualise the problem to be modelled through the causal loop diagram.

A key part of developing CLD representations of mental models is to communicate the shared models to problem stakeholders, in this case indicator users and producers. The CLD will be tested and refined through a participatory workshop with indicator producers and users in one of the case study cities. Sharing the CLD with workshop participants may change the way they think about the impact of UHI tools, however the main aims of conducting a participatory modelling workshop are to improve and test the usefulness of the model.

5.2.2 Overview of qualitative system dynamics

System dynamics is the method used to develop a causal loop diagram in this study. As previously introduced, system dynamics is a way to model problems in complex systems (Sterman, 2000). This approach typically results in a formal quantitative model, yet practitioners have long recognised the value of qualitatively diagramming the structure of a problem through cause and effect diagrams, or causal loop diagrams (Wolstenholme, 1990). Qualitative modelling is also called 'systems thinking' which involves 'formalizing and analysing feedback loops but never results in the simulation of a mathematical system dynamics model' (Luna-Reyes and Andersen, 2003, p.274). In the thesis, systems thinking references this interpretation of qualitative system dynamics modelling and the wider theory informing the modelling approach.

The purpose of developing CLDs as an aggregated representation of individual mental models is to communicate with a group of stakeholders to 'broaden the understanding of each person and, by sharing their perceptions to make them aware of the system as a whole and their role within it…' (Wolstenholme, 1990, p.5). Similarly to Johnson-Laird's caution of the limits of mental models, Sterman (2000) also argues that a system dynamics model does not attempt to represent an entire system in detail, but should be limited to a specific problem with recognition that the model is a simplified representation of a system.

The founder of system dynamics, Jay Forrester (1961), was motivated by the observation that problem solving techniques, for example those used in management science, did not suit the complexity of real-world strategic problems (Wolstenholme, 1990). Forrester (1992) describes management as 'the process of converting information into action' (p.42). Planning scholar John Friedmann (1987) also said that urban planning is the process of moving from knowledge to action, a definition still widely recognised today (Bolan, 2017). Forrester (1992) explains that this information to action process is called 'decision making' in the system dynamics literature and it is governed by 'policies' or rules about how decisions are made (p.42). It would be tempting to align these terms to planning processes of policy and decision-making, yet the meanings are not the same. In applying system dynamics in this study Forrester's policy and decision-making terminology is not used to avoid confusion. System dynamics provides a valuable method to build a qualitative model, using causal loop diagrams, to shed light on the mental models of the use and value of UHI tools.

Modelling is an iterative process which involves a 'continual process of formulating hypotheses, testing, and revision, of both formal and mental models' (Sterman, 2000, p.83). The system dynamics literature provides methods for developing causal loop diagrams using qualitative data from interviews (Luna-Reyes and Andersen, 2003; Kim and Andersen, 2012; Turner et al., 2013; Eker and Zimmermann, 2016) and for testing such models through participatory workshops or interviews (Andersen and Richardson, 1997; Andersen et al., 2007; Luna-Reyes et al., 2012). In this study, the development of the CLD benefits from detailed evaluation of secondary literature, synthesised and represented as a ToC, and elicitation of expert knowledge through semi-structured interviews and a group workshop.

5.2.3 Causal loop diagram construction

Development of a causal loop diagram follows simple but important conventions to ensure accurate representation of the feedback structure of a complex system (Sterman, 2000). These conventions are outlined in this section, including: 1) the meaning of arrows and polarity symbols and 2) the nature and naming of variables and feedback loops. An example CLD is used to illustrate these points.

CLDs are composed of variables which are linked by arrows, or 'causal links' representing cause and effect relations (ibid, p.138). Causal links represent the direction of change between variables, noted through polarity symbols (+/-) next to the arrow. Sterman (2000) emphasises that causal link polarity represents the structure of a system, not the behaviour of individual variables for two reasons. First, he explains that variables are not connected in isolation, but they are linked to multiple interconnected variables within the system. A positive link indicates that change to the independent variable results in change to the dependent variable in the same direction (either increasing or decreasing from where it would have otherwise been). Whereas a negative link indicates that change to the independent variable will result in change in the opposite direction to the dependent variable (e.g. increase in the independent variable results in decrease in the dependent variable from where it would have otherwise been or vice versa). Each change is relative to what it would have otherwise been, if everything else had remained constant, which is unlikely. Second, Sterman argues that CLDs do not identify and differentiate between stocks and flows within a system, defined as 'the accumulations of resource in a system and the rates of change that alter those resources' (ibid, p.140). To understand how stocks and flows affect behaviour, it is necessary to assign rates of change and simulate the results (Sterman, 2000). Further to labelling causal link arrows, modellers should also label important feedback loops as either reinforcing or balancing. This is denoted with an arrow in the direction of the causal loop (clockwise or counter clockwise) and the letter 'R' or 'B'. To avoid confusion in large CLDs, loop labels should be differentiated with numbers (e.g. 'R1', 'R2' and so forth) and should also be described with a brief phrase.

The previously described terminology is evident in Figure 5-1. There are three variables: problem, fix and unintended consequence. A 'problem' causes a 'fix' which then reduces the 'problem' in the top balancing loop. However, the 'fix' also causes an 'unintended consequence' over time (the delay is marked with the double lines crossing the arrow between variables) which then increases the 'problem'. This is part of a reinforcing feedback loop which could be described in lay terms here as a vicious cycle. This is called a 'fixes that fail' systems archetype (Senge, 2006). Systems archetypes are reoccurring patterns of causal structure that 'embody the key to learning to see structures' (ibid; p.93), of which Senge provides ten examples that are widely referenced in the system dynamics literature.

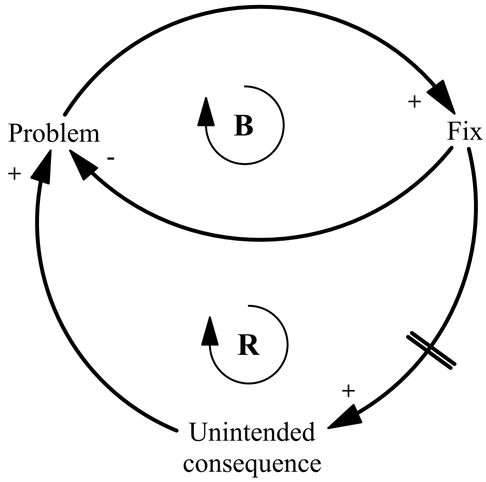

Figure 5-1 Causal loop diagram showing a 'fixes that fail' archetype (Senge, 2006)

In addition to the requirements to annotate and denote causal loop diagrams according to convention, Sterman (2000) also describes a number of other conventions for modelling with CLDs. Causal links must represent actual causality and not correlation. Delays in the system should be annotated if they are important in relation to the modeller's dynamic hypothesis and time horizon. Variables should be nouns or noun phrases that can be understood as increasing or decreasing, but normally would be understood as positive (in other words, they would not start with 'non', 'un', etc.). There are a number of other conventions related to the appearance, layout and construction of diagrams, emphasising the importance of elegant modelling to achieve clarity for the intended audience.

5.3 Conceptualising the model

The process of developing a model should not be conceived as a linear or discrete process that results in a final picture of the real world (Sterman, 2000). Modelling is an iterative process which benefits from multiple sources of information, stages of testing and reconfigurations (Luna-Reyes and Andersen, 2003). However, it is important to follow a structured process to model development (Sterman, 2000) and to document links between the structure of the model and the data used in its development (Luna-Reyes and

Andersen, 2003; Eker and Zimmermann, 2016). Table 5-1 outlines the CLD modelling process based on the literature (Wolstenholme, 1990; Sterman, 2000). Luna-Reyes and Anderson (2003) compared Sterman's (2000) modelling approach with four others in the system dynamics literature and found that the activities were relatively similar, although they were grouped differently. Table 5-1 serves as a structure for this section which outlines a problem statement, describes the emergence of the problem, sets boundaries for the modelling process and introduces dynamic hypotheses.

Table 5-1 Causal loop diagram development process summarised from Sterman (2000) and Wolstenholme (1990)

Stage	Summary
1	Articulate the problem through problem definition, identification of key variables, development of reference modes (observed behaviour over time) and model boundaries (informed by quantitative or qualitative data from written or verbal sources).
2	Formulate dynamic hypotheses about the problem.
3	Map the causal structure of the hypotheses using the identified variables, ideally with direct input from problem stakeholders.
4	Explore the system structure and behaviour by tracing change around loops and considering alternative structures, ideally with problem stakeholders.
5	Refine the model structure as new information or purposes for the model become available.

5.3.1 Problem statement

Defining the problem can be done through a variety of methods, including the collection and assessment of quantitative and qualitative data, the latter incorporating written information and unpublished knowledge that must be elicited from experts (Forrester, 1992; Luna-Reyes and Andersen, 2003). This range of numerical, written and mental data is also used for model development and may be gathered using a range of methods including interviews, workshops and archival research (Sterman, 2000; Luna-Reyes and Andersen, 2003). The problem addressed by the model in this study was set out in the literature review and systematic review chapters and can be summarised as:

Problem statement: the number of UHI tools which seek to influence built environment policy and decision-making is growing; however, the intended audience does not appear to value or use many of these UHI tools as envisaged by UHI tool producers.

This problem has been articulated through the collection and analysis of quantitative and qualitative data. Together these data describe 'reference modes' which are defined by Sterman (2000) as 'graphs and other descriptive data showing the development of the problem over time' (p.90).

5.3.2 Emergence of the problem

The reference modes for the problem statement were identified during the systematic review. The first part of the problem statement relates to the growing number of UHI tools. This was established through the census of UHI tools which showed an increasing number of UHI tools over time (Figure 5-2) (Pineo et al., 2018a). Furthermore, the number of UHI tools which display data at the neighbourhood scale or lower, and the number which present data via static or interactive maps, are both growing over time (ibid). Both of these characteristics are suggested to be useful for policy and decision-makers (Prasad et al., 2014; Rothenberg et al., 2015).

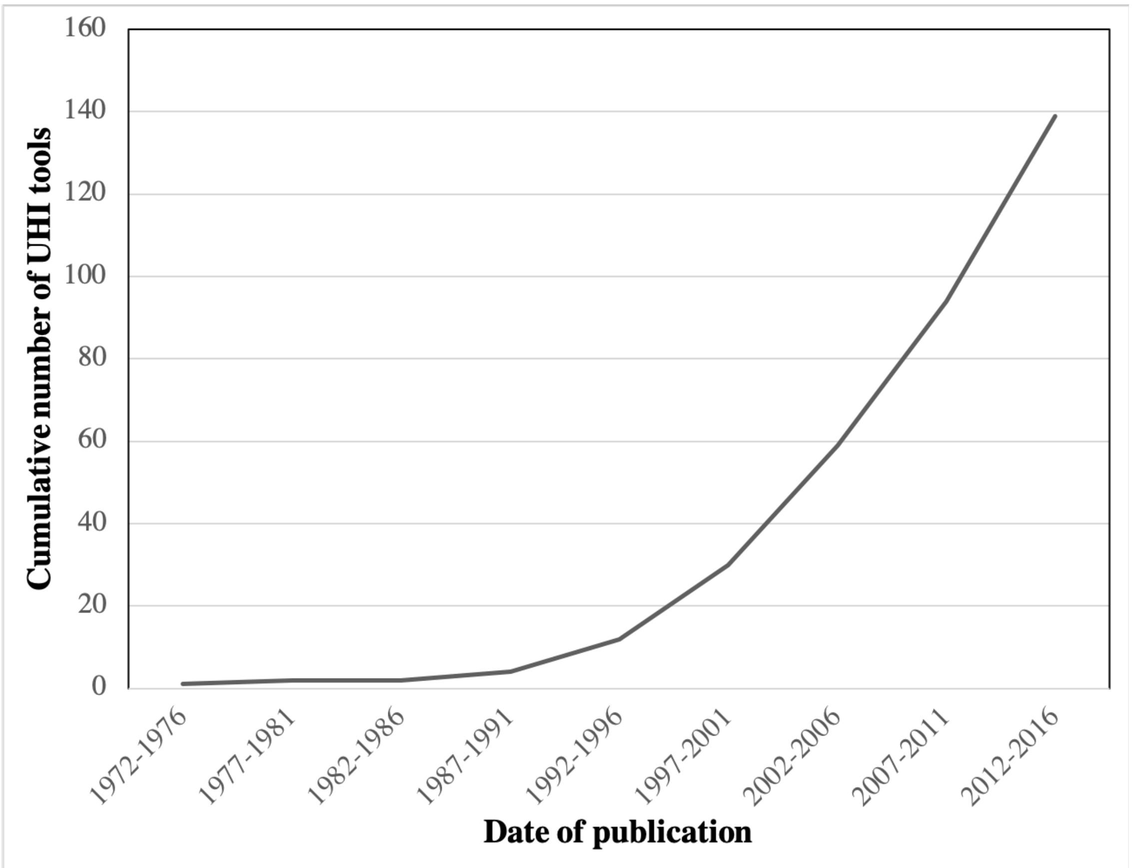

Figure 5-2 Cumulative growth of UHI tools over time

The second part of the problem statement relates to policy and decision-makers apparent low valuation and use of UHI tools. The narrative synthesis portion of the systematic review descripted in chapter four did not uncover a uniform story about the value and use of indicators, however it did show that the mechanisms through which UHI tools influence policy and decision-making are not as simplistic and linear as many UHI tool producers may envisage. The included studies described a number of barriers that hindered the use of UHI tools in municipal government built environment departments. For example, many of the published UHI tools evaluated in part A of the systematic review did not meet the information needs of urban planners, such as provision of data at neighbourhood scale, although a growing number do achieve this aim. In summary, despite the growing number of UHI tools, the literature suggests that there may be low adoption of these tools to inform urban planning policy and decision-making.

An important aspect of developing reference modes is consideration of the time horizon of the problem and modellers often underestimate how far back the problem and its symptoms emerged (Sterman 2000). This is partly related to cognitive difficultly estimating cause and effect relations (ibid). Sterman explains that people often view cause and effect as 'local and immediate' when in complex systems, cause and effect are usually 'distant in space and time' (ibid, p.91). In a simulation model, the system's behaviour can be modelled over time to understand the impact of delays and dynamic behaviour. In a causal loop diagram, a time delay can be indicated through a visual representation and this can be narratively described to aid in understanding. In relation to articulating the problem, the time horizon is important for quantitative and qualitative modelling. Looking back at the emergence and symptoms of the problem helps modellers to understand what should be included in the model.

The development of UHI tools was well-documented in chapter four, showing growth over time in published tools (Figure 4-3). It is less clear how the perceptions and use of UHI tools may have changed over time. The use of indicators is generally under-researched, with most researchers focusing on developing best practice for the creation and validation of indicators (Innes and Booher, 2000; Pastille Consortium, 2002; Wong, 2006; Sébastien et al., 2014). The narrative synthesis of studies on the use of UHI tools included ten studies which were published relatively recently (two between 1988 and 2000 and eight between 2008 and 2015). Given the narrative synthesis' mixed results regarding indicator use, it is not possible to use these studies to describe a general trend over time. Likewise, the wider literature does not provide a good description due to the general lack of research in this area. The assumption of indicator producers appears to be relatively static, following the linear model set out by Briggs et al. (1996). While the evaluation of indicator use by urban planning scholars such as Innes and Booher (2000), the Pastille Consortium (2002) and Wong (2006) contests the underlying assumptions of this model and is echoed in more recent evaluations of indicator use by planners (Rae and Wong, 2012; Sébastien et al., 2014; Decoville, 2018). Therefore, the perceived problem of low uptake of UHI tools can be viewed as relatively constant over time, although there are local variations in this trend, as described in some of the systematic review studies.

5.3.3 Boundaries for the modelling process

Forrester (1992) explains the importance of selecting an appropriate perspective or boundary of a system before modelling. He notes that system dynamics does not intend to model 'each separate decision, but instead observe a modulated stream of decisions' (p.46). Sterman (2000) recommends outlining a model boundary chart which describes the general scope of the model, listing key variables which are both included and excluded. A modeller should generally aim to explain a problem through behaviour of variables within the system, 'endogenous', but it is possible to include a small number of variables which are outside of the system, 'exogenous'; both of which should be listed as 'included' in a model boundary chart (Sterman, 2000, pp.95–96). Potential endogenous, exogenous and excluded variables were identified through the narrative synthesis of studies about the use of UHI tools (Table 5-2), however these require iterative review, particularly after the semi-structured interviews. Thus, the final variable names and their status as endogenous, exogenous or excluded changes in the final causal loop diagrams. The variables in Table 5-2 were identified in the systematic review as important facilitators/barriers and uses/benefits of UHI tools.

Table 5-2 Initial model boundary chart for UHI tool use in urban planning policy and decision making

Endogenous	Exogenous	Excluded
Appropriate data scale Stakeholder knowledge Diversity of knowledge types in UHI tool	Resources for UHI tool development Resources for stakeholder involvement Stakeholder ability to participate	Specific urban planning policies and regulations Urban health issues measured by UHI tools

Endogenous	Exogenous	Excluded
Pre-existing conflict amongst stakeholders Involvement of community representatives Involvement of diverse stakeholders New knowledge of UH New knowledge of urban planning processes & constraints Collaboration across stakeholders New relationships Community capacity Communication among stakeholders Awareness of UH Political importance of urban health Monitoring UH impacts Lobbying for UH improvements Health-promoting policy and decision-making City-wide UH activities	Identified indicator user Indicators tied to policy areas Accountability of local government	

5.3.4 Dynamic hypotheses

The systematic review of qualitative studies forms the dataset for initial model conceptualisation and formulation of dynamic hypotheses. In the systematic review there were many, sometimes conflicting, accounts of how UHI tools influence urban planning policy and decision-making. There was not a consistent view about the value of UHI tools, with studies providing either highly positive or more cautionary accounts. In some cases, these accounts represented the views of an individual stakeholder, while in other cases a summary view was presented. Therefore, the modelling process begins with a range of potential dynamic hypotheses which are later explored during the semi-structured interviews (in Chapter 6).

Causal relations describing the value and use of UHI tools were identified throughout the narrative synthesis process described in chapter four. Data extracted from studies about the use of UHI tools were coded in NVivo under codes for facilitators and barriers to indicator use and benefits and uses. Study authors' narrative descriptions and quotes from study participants about how UHI tools influence built environment policy are interpreted as representations of their mental model. In addition to coding in Nvivo, causal relations were also sketched throughout the narrative synthesis process to begin formation of dynamic hypotheses. This section describes three dynamic hypotheses which were identified through the systematic review. The hypotheses are described narratively and through causal loop diagrams which are not connected to each other at this stage.

5.3.4.1 *Community engagement in UHI tools leads to municipal action*

The first dynamic hypothesis (Figure 5-3) is in the form of a 'limit to growth' systems archetype, as defined by Senge (2006, p.390). This hypothesis explains how 'community concern about UH [urban health]' increases 'community engagement in UHI tool' which increases 'community knowledge of UH' in a reinforcing loop. However, if the community concern then increases 'demands to improve UH' which increases the 'municipality's perception of importance of UH' this increases the 'municipal action to improve UH'. Thereby the 'municipal action to improve UH gap' reduces, which also reduces 'community concern about UH' in a balancing loop. In other words, UHI tools may spur some initial community engagement and action from local government, but over time communities may lose interest in the UHI tool if urban health problems are resolved, thereby reducing municipal action over time.

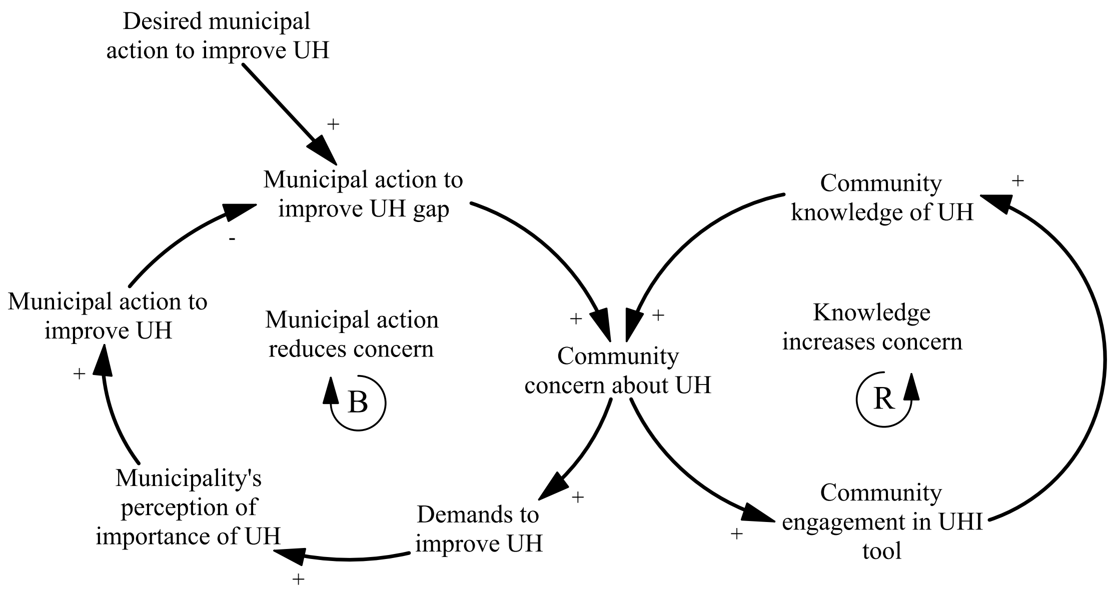

Figure 5-3 Dynamic hypothesis: community engagement in UHI tools leads to municipal action on urban health (UH)

Part of this hypothesis was generated from examples including Seattle's Healthy Living Assessment tool and the SFIP where community engagement with the UHI tool helped city planners to understand the community's urban health concerns. A quote from a study participant in Cape Town also described some of the causal relations in this hypothesis:

> *'Yes, [community-based indicators] would be a better tool, and then people would start understanding how it affects your lives, and once they get involved, the more involved they get the more demands they would make of the local authority. And the more they [the local authority] would see a greater need' (Hunt and Lewin, 2000, p.199).*

The final causal connection from 'municipal action to improve UH gap' to 'community concern about UH' was speculated by the researcher as a potential explanation for the apparent reduction in community engagement over time. Other explanations could include that community groups did not feel their demands significantly affected municipal action, such as in the Core Environmental Health Indicators in Lucknow and Calcutta examples. This could be due to many factors such as resource limitations in local government or the private sector to build and maintain health-promoting places.

5.3.4.2 *UHI tool engagement leads to dispersed knowledge*

The next hypothesis involves a balancing feedback structure in which engagement in UHI tools reduces the 'effectiveness of UH [urban health] governance gap' through 'dispersed knowledge of UH fixes'. In the latter variable, 'fixes' is shorthand for policies or design measures to improve urban health. In this hypothesis 'engagement in UHI tool' increases 'interaction among UH stakeholders' which increases 'dispersed knowledge of UH fixes' and 'effectiveness of UH governance', thereby reducing the 'effectiveness of UH governance gap' with a delay. The hypothesis recognises that a number of exogenous factors would affect the governance gap, thus reintroducing a requirement for 'engagement in UHI tools' over time. This structure is a systems archetype called a 'balancing process with a delay' which can lead to overshooting the goal (Senge, 2006, p.389).

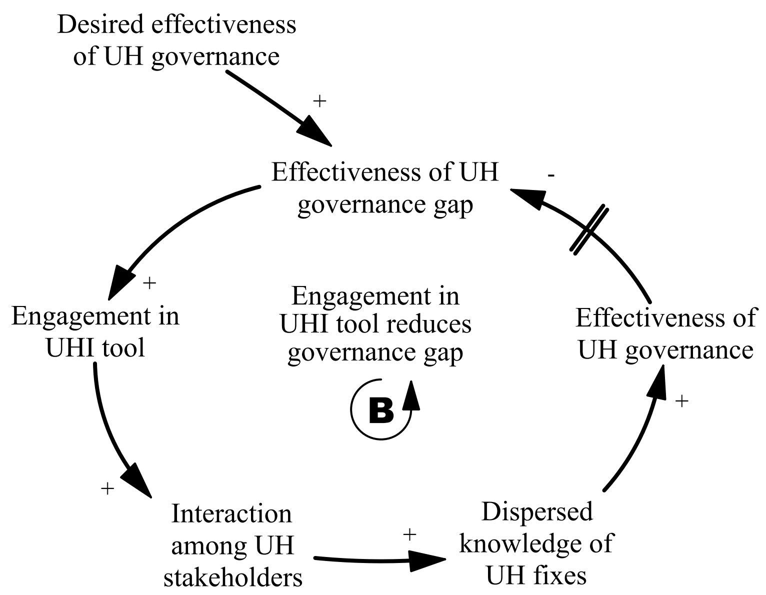

Figure 5-4 Dynamic hypothesis: Engagement in UHI tools increase effectiveness of urban health (UH) governance

This hypothesis was informed by the narrative synthesis finding that use of UHI tools helped to promote a health in all policies and whole-of-society approach to urban health governance. Examples in Bristol, San Francisco and Seattle showed that new knowledge gained from using UHI tools informed policies and decisions in built environment agencies which would not typically have seen health as part of their remit.

5.3.4.3 *Poor performance leads to political action*

The structure in Figure 5-5 also represents a 'balancing process with a delay' systems archetype. In this case, there are two delays. First, there can be very long timescales between the 'municipal action to improve UH gap' and 'health-promoting built environment'. Second, improvements to the physical built environment will be reflected in 'performance in UHI tool' after a long delay in data collection and analysis, potentially even longer when health impacts are measured. Therefore, 'performance in UHI tool' does not necessarily match the actual state of the 'health-promoting built environment' and municipal action may not be appropriately targeted as a result. The long delays may also cause frustration among actors when changes do not register an impact. In this hypothesis, poor 'performance in UHI tool' leads to increased 'political awareness of health-promoting BE' which increases 'municipal action to improve UH', thereby reducing the 'municipal action to improve UH gap'.

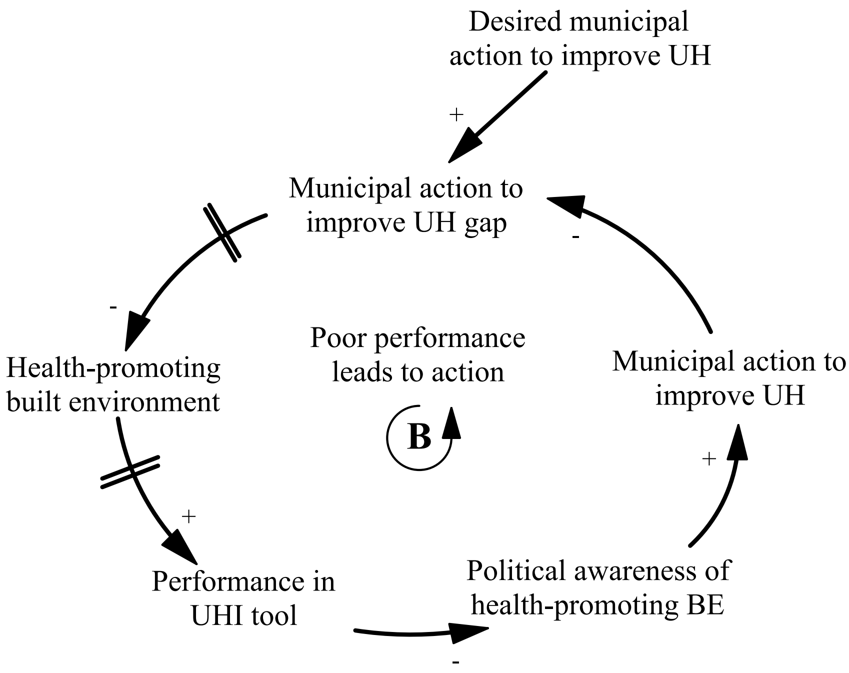

Figure 5-5 Dynamic hypothesis: poor performance in UHI tool affects political awareness and action on urban health (UH), BE: built environment

This hypothesis was based on observations by Landis and Sawicki (1988) about the impact of UHI tools on political awareness and decision-making. They found that the Places Rated Almanac affected public opinion, and this raised the importance of quality of life issues to politicians and municipal officers, spurring action.

In summary, the three dynamic hypotheses in this section represent a selection of the many, and sometimes conflicting, views in the systematic review papers. The first two hypotheses look at the impacts of engagement in UHI tools, either involving the community (Figure 5-3) or wider urban actors (Figure 5-4). In the former, the increased knowledge among community members leads to concern about urban health and increased demands that municipal leaders take action. In the latter, engagement leads to dispersed knowledge which increases the effectiveness of urban health governance. Effective urban health governance is about action across multiple policy domains and sectors within society. Thus, in both cases engagement brings about positive benefits for urban health governance. However, the hypothesis in Figure 5-3 recognises that such engagement does not necessarily last, resulting in a decrease of municipal action over time. The final hypothesis (Figure 5-5) shows how a UHI tool may lead to action even in cases where there has not been engagement with the community and other actors. It also raises the challenge of delays from municipal action to the status of the health-promoting built environment and how this is registered as performance in the UHI tool.

5.4 Conclusion

This chapter has explained the motivation and methods for representing mental models of UHI tool use with a systems thinking approach. The chapter outlined a problem statement, described the problem's behaviour over time, suggested key variables and model boundaries and proposed several dynamic hypotheses regarding the influence of UHI tools on policy and decision-making. The hypotheses are limited by the available data on the use and value of UHI tools which often gave a snapshot of this information in time or described a case study over a number of years. The secondary data on UHI tool use lacked a long enough timespan to understand the impacts of urban health policies on UHI tool performance, community engagement and political awareness. Furthermore, the studies presented different perspectives on the value and use of UHI tools which means that a hypothesis which explained one UHI tool would not necessarily fit others. However, the hypotheses attempt to explain common themes which emerged in the systematic review studies such as community engagement. These themes will be further explored in the semi-structured interviews in chapter six.

CHAPTER 6

Interviews and thematic analysis of indicator use

6.1 Introduction

This portion of the study describes primary data gathering and analysis related to all three research questions. The chapter outlines the methods for semi-structured interviews, including case study and participant selection and interview procedures. The thematic analysis method was introduced in chapter three and applied first in chapter four. This chapter describes a more in-depth application of thematic analysis in relation to the qualitative data collected in the interviews. Much attention is devoted to the thematic analysis process including a detailed description of the iterative process of data coding and theme development. The final thematic analysis themes are presented with selected quotations from interview data. The discussion section in this chapter is relatively short as the main interpretation of findings is reserved for chapter eight.

6.2 Multiple case study design

The initial plan for this portion of the study was to conduct a multiple case study analysis of two UHI tools, the San Francisco Indicators Project (SFIP) and Community Indicators Victoria (CIV). The selection of these cases was based on several rationale. First, this choice built on the findings from the systematic review which suggested that community involvement in developing UHI tools had the potential to significantly influence urban planning and promotion of health more widely. The SFIP and CIV projects were categorised as being participatory-led and expert-led respectively, and were thus useful 'exemplifying' cases through which an emerging theory in the thesis could be tested (Bryman, 2004, p.51). Second, both projects were published around a decade before this investigation (SFIP in 2007 and CIV in 2006) and were therefore deemed mature enough for both indicator producers and users to be able to describe their potential value and use. Third, both UHI tools have characteristics which have been suggested to be useful for urban planning policy and decision-makers such as displaying data at the neighbourhood scale via interactive maps, allowing these components to be explored more thoroughly.

There are published studies on the use of these tools, however they do not fully respond to the research questions for this project. Bhatia (2014), Bhatia and Corburn (2011) and Farhang et al. (2008) wrote case studies on the development and use of SFIP. Davern et al. (2017, 2011) described the use of CIV in health planning and policy. Lowe et al. (2015) gathered views on the development and use of indicators (including CIV) to support integrated urban planning. The authors of each of these studies were involved in developing or working with the UHI tools and therefore findings may be biased. None of these studies evaluated the UHI tools ability to aid with the complexity of urban health and planning.

Although the initial plan was to conduct a study using the multiple case study design of SFIP and CIV, it became clear during early interviews and pre-interview discussions that participants did not view these UHI tools as discrete phenomena. Both indicator producers and users spoke about a wide range of indicator-related projects, some of which grew out of the SFIP and CIV tools or were created by their producers. Therefore, the initial study design was altered to include investigation of both UHI tool producers and users who had relevant experience about the use and value of any UHI tool by urban planners in San Francisco, Victoria and New South Wales. All of the interview participants had knowledge of either the SFIP or CIV, however some participants had developed or worked with other UHI tools as well.

6.3 Sampling and interview participants' characteristics

Purposive sampling was conducted to explore the research questions among UHI tools producers and users. Specifically, a snowball sampling strategy was employed to identify interview participants. The researcher contacted the SFIP and CIV producers through their university/departmental contact information. Producers were asked if they knew of cases where the indicators had been used by urban planners and individual contacts were requested. At the same time, the researcher used city planning department websites and a social media professional networking site (LinkedIn) to identify and contact urban planners. In e-mail correspondence the researcher asked whether the planners were aware of either SFIP or CIV and if they would be willing to attend an interview. Additional contacts were requested from each potential interview participant. The goal was to interview approximately 20 individuals across the two case studies and 22 participants were eventually interviewed, with knowledge beyond the original two UHI tools.

Consistent themes (although sometimes contradictory within and across interviews) emerged from these 22 interviews and this helped to determine that additional interviews or case studies were not required (Taylor et al., 2016).

Of the 22 interview participants, the number of indicator producers and users were evenly split (Table 6-1). The indicator producers were primarily public health/epidemiology professionals (81.8%, 9/11) working in academic or government organisations. The indicator users were primarily urban planners (81.8%, 9/11) working in city or state government planning departments (81.8%, 9/11). Geographically, interviews were conducted in San Francisco (n=6), Victoria (n=12) and New South Wales (n=4).

Table 6-1 Interview participants characteristics. Uni=University, Gov.=Government

UHI role	Professional field		Organisation type		Location	
Indicator producers (n=11)	Public health	8	Uni - Public health	4	Victoria	5
	Urban planner	2	City Gov. - Health	3	San Francisco	3
	Epidemiology	1	State Gov. - Health	2	New South Wales	3
			Uni - Urban planning	2		
Indicator users (n=11)	Urban planner	9	City Gov. - Planning	6	Victoria	7
	Community planner	1	State Gov. - Planning	3	San Francisco	3
	Public health	1	Freelance Planner	1	New South Wales	1
			City Gov. - Health	1		

6.4 Interview procedure

The interviews followed a semi-structured approach and were audio-recorded and transcribed for analysis. Interviews took place in San Francisco, United States (April 2016), and Melbourne and Sydney, Australia (March 2018), typically in participants' offices.

Interviews were undertaken with BSEER low risk ethics approval. All interview participants received an information sheet and consent form explaining the research via email and had the opportunity to ask questions via email and in-person before signing the consent form. The consent form allowed participants to select if they wanted the indicator system and/or their employer to remain anonymous in reporting. Eight out of 22 (36.4%) participants selected anonymity for both the UHI tool and employer. As a result, all analysis and quotes have been anonymised in relation to the city, employer and UHI tool. This reduces the likelihood that any specific quotes could be attributed to organisations or individuals.

The interview questions were developed to answer the study's research questions and were informed by the wider indicator literature, particularly the findings from the systematic review. The questions were slightly different for indicator producers and users (see Appendix A2.1). Following the first round of interviews in San Francisco, the interview questions were slightly modified and several prompts were added to increase clarity and understanding of the interview questions. Given the semi-structured nature of interviews, participants were able to direct the conversation if they wanted to tell stories or express opinions and many participants adopted a more free-flowing approach. However, the researcher did redirect the conversation back to the questions if the desired information was not otherwise elicited through the discussion.

6.5 Thematic analysis process

As described in chapter three, the thematic analysis followed Braun and Clarke's (2006) six phase approach, further developed by Nowell et al. (2017). The six phases are applied flexibly and recursively to develop codes and themes. Table 6-2 outlines the six phases and links each phase to sub-sections in this chapter documenting how each phase was conducted. This section is about the thematic analysis process and the results are in the following section.

Table 6-2 Six phases of thematic analysis described by Braun and Clarke (2006) and Nowell et al. (2017) with links to thesis sub-sections describing each phase

Description of phase	**Tasks outlined in Braun and Clarke (2006) and Nowell et al (2017)**	**Sub-section describing this phase**
1. Familiarisation with the data	Read through the entire data set at least once. Consider researcher's own perspective and document reflections, e.g. in a research journal.	6.5.1
2. Generating initial codes across the full data set	Identify important excerpts of text and label these with a code. Follow good practice for identifying, labelling and describing codes. Choose to develop codes deductively from theory or prior literature, inductively from the qualitative data, or using a hybrid approach (any approach must be applied consistently). Write a reflexive journal during coding to aid with the iterative coding process (where codes may be combined or added) and create an audit trail.	6.5.2
3. Searching for themes through the collation of codes	Develop themes inductively or deductively, analogous to code development. Apply judgement to flexibly develop themes, however the final approach must be applied consistently. Arrange codes in tables, templates, code manuals, mind maps, other diagrams or thematic networks to organise codes and themes. Do not discard codes at this stage. Codes may become themes or subthemes, alternatively they may be grouped under a miscellaneous theme to inform wider context or ultimately be removed. Keep notes about the development of themes for the audit trail.	6.5.3

Description of phase	Tasks outlined in Braun and Clarke (2006) and Nowell et al (2017)	Sub-section describing this phase
4. Reviewing themes in respect to coded extracts and creating a thematic map	Review the coded data under each theme and consider each theme's coherence in relation to the underlying data and the dataset as a whole. Change codes as necessary, including adding, deleting or combining. Change themes as necessary, including merging or separating. Ensure there is clarity about how each theme is supported by the data.	6.5.4
5. Defining and naming themes, including refining themes	Determine the most interesting and important characteristics of themes, based on the data. Name each theme and write a description to capture its story. Recognise that theme refinement could go on indefinitely and stop once there are no sections of text that clearly relate to the research questions and are not covered by themes. Be clear about what themes do and do not represent. Check themes with colleagues or external experts.	6.5.5
6. Producing the report with compelling extracts from the text	Write-up themes using concise, clear, logical and interesting reporting of the data within and across themes. Explain the process of thematic analysis and detail coding and theme development decisions. Include direct quotes within the narrative using short and/or long excerpts. Move beyond a description of the themes and data to interpretation of the significance of patterns and implications, potentially in relation to the existing literature or theory.	6.5.5

6.5.1 Data familiarisation

All of the audio recordings were transcribed by a professional transcription service. The researcher listened to the audio recordings and read the transcriptions to check for accuracy. Then the transcriptions were read through a second time, whilst making notes in the margins. Influence diagrams were sketched in the margins when interview participants spoke about cause and effect relations or described key processes about the use of indicators.

6.5.2 Codebook development and initial coding

The thematic analysis followed a hybrid inductive and deductive approach, analysing data at the latent and semantic levels. For the deductive element, a codebook was derived from key elements of the theory of change and conceptual framework including concepts related to: knowledge, social context, governance, professional factors and complexity (see Table 6-3 for a full description). These categories related to the conceptual framework's description of assumptions, beliefs and values and the theories (collaborative rationality and systems theory).

Coding was done using a computer-aided qualitative data analysis software (CAQDAS), NVivo (QSR International, version 11.4.3). The category titles were entered as five 'nodes' in Nvivo, under which additional codes were added through an inductive process. Some data were coded into the category level if the existing categories were not appropriate.

The coding process involved going through interviews and looking for important 'moments' and labelling these with a code (Boyatzis, 1998). 'Moments' that fit the initial codebook categories were listed as sub-nodes, others were grouped separately. During the first round of coding two additional high-level categories were created: 'perceptions of UHI tools' and 'UHI tool projects'. These typically contained semantic level codes such as 'data quality and availability' and 'number of indicators'. At the end of the first round of coding there were seven categories and 77 codes (Appendix A2.2).

During the coding process, the researcher made notes of ideas and key concepts that emerged in the transcription margins. The codes were developed following the methods of Braun and Clarke (2006) and Nowell et al. (2017), including writing a description of each code in Nvivo.

Table 6-3 Initial codebook for thematic analysis informed by conceptual framework

Category	Description
Knowledge	The type of information or knowledge used or valued by interview participants and its basis (e.g. scientific or community-derived). Specific claims of knowledge. Ways in which knowledge is shared among actors through conversations and communication.
Social context	Wider context within the city such as social, economic and environmental issues. How actors relate to each other and dynamics between them, including: power relations, subordinated interests, unheard voices and ownership.
Governance	Ways in which policies and decisions are made and influenced by all actors.
Professional	Professional norms, values, processes, constraints, opportunities, training and education.
Complexity	Characteristics of complexity (e.g. non-linearity, interconnectivity, unintended consequences, etc.) and descriptions of complexity.

6.5.3 Identifying themes in the data

Themes were developed in an iterative manner involving reviewing coded data, developing mind maps and mapping codes across emerging themes in an Excel spreadsheet. In developing themes, researchers are seeking 'something important about the data in relation to the research question, and [a representation of] some level of *patterned* response or meaning within the data set' (Braun and Clarke, 2006, p.82).

The process began with identification of an interesting code to the researcher, often a topic that was frequently mentioned and related to many other codes. One such example was the code 'building relationships and networking'. The coded data were reviewed and a mind map was created in Nvivo which mapped factors that led to relationships and factors that emerged from relationships. During the mapping process it became clear that some codes (or bubbles in the mind maps) were part of feedback loops and these were drawn onto the printed mind maps. After an initial map was drawn, related codes were identified and explored, resulting in some adjustments to the mind map. Appendix A2.3 contains the nine mind maps developed to explore potential themes.

A spreadsheet of the codes was created to track relationships across potential themes and to ensure all of the codes were addressed systematically (see a screenshot of this spreadsheet in Appendix A2.4). The mind maps of potential themes often contained codes that were relevant to multiple themes. The Excel spreadsheet allowed visualisation of codes mapped across each theme.

All of the data were evaluated in a consistent manner at this stage. Some codes were parked in a 'miscellaneous' category with a short note about whether they provided interesting context (e.g. 'proud of professional achievement') or could be collapsed into other codes (e.g. 'knowledge' had three references which were either not useful (n=1) or overlapped with other codes (n=2)). A new code was added ('focus on strategic indicators') and some text was re-coded into other codes.

At the end of the theme identification stage there were nine candidate themes (Table 6-4). The 'complexity' category was treated as an exception to the process outlined above. Complexity codes were rarely mapped to emerging themes. The complexity code references were typically direct responses to a specific interview question, although this was not always the case. These data related to one of the study's research questions but did not generally fit the wider narrative from indicator producers and users about the value and use of UHI tools. As a result the mind map approach was not used for the complexity codes. Rather these codes were mapped on to a table of complexity characteristics with descriptions of how these were understood or addressed by interview participants (see Appendix A2.5).

Table 6-4 Nine initial themes (with abbreviations) developed through thematic analysis

Initial themes	Abbreviation
Building relationships and networks	BRN
Re-framing knowledge and understanding	RKU
Economic constraints and opportunities	ECON
Legal & Technical constraints and opportunities	LET
Political constraints and opportunities	POL
Professional norms, knowledge, values, ways of working, and remit	NORM
Motivation and value	MOV
Reasons that UHI tools fail (or how to avoid)	FAIL
UHI tool design and use strategies	DES

6.5.4 Reviewing themes

The candidate themes outlined in Table 6-4 were further reviewed and refined by re-reading print-outs of the Nvivo codes, grouping these under the printed mind maps, removing codes where necessary and developing an overall thematic map.

There were a number of changes to the nine candidate themes. An overarching theme 'strategies of successful UHI tools' was created to house 'UHI tool design and use strategies' and to tie together three sub-themes: 're-framing knowledge and understanding', 'building relationships and networks' and 'turning constraints into opportunities' (which further breaks down into three additional sub-themes related to economic, political and legal and technical constraints). The latter theme and its constituent sub-themes also related to the 'reasons UHI tools fail' theme as they were frequently mentioned as constraints for implementing indicator evidence into policy and decision-making.

This stage of analysis also involved changes to codes. Some codes were deleted (e.g. 'knowledge' which was covered by 'knowledge basis' and 'knowledge claims') and 'persistence' which was very thin and did not fit any themes. Many codes were related to multiple themes. Likewise, many data extracts were related to multiple codes. At this stage, some data extracts were additionally coded to existing codes (yet they retained the original code). The codes in the miscellaneous category were retained for context and did not relate to the other themes.

The study's conceptual framework and research questions influenced decisions about which aspects of themes to explore and whether the meanings in the data were accurately reflected by the candidate themes. For example, 'controversy' was an inductively developed code which sat under the 'social context' category. The contested nature of planning is emphasised in the conceptual framework (Healey, 1997; Innes and Booher, 2010). The 'controversy' code related to multiple themes and included data extracts about arguments and contested relationships between actors within government, the community and the private sector.

The potential themes were arranged into an initial thematic map (Appendix A2.6) which visually displayed and prompted further consideration about the relations between themes.

6.5.5 Defining and naming themes

The final stage in the iterative theme development process involved 1) further theme refinement and 2) naming and describing the final themes based on their most interesting characteristics.

To refine themes, each of the candidate themes were reviewed again, with attention to the most interesting and important characteristics of each theme. The researcher also evaluated whether the themes adequately covered the research questions. A new thematic map (Figure 6-1) was drawn which re-positioned themes and involved revising the 'motivation and value of UHI tools' theme to focus on a specific motivation which was widely discussed: representing community interests and inequity. Other aspects of the motivation and value theme were picked up through the other themes. Figure 6-1 shows how the initial set of nine themes (Table 6-4) map across to the final themes through the abbreviations. The themes moved beyond a surface level description of the text to an interpretive description, informed by the study's conceptual framework. Themes one to four (see Table 6-5) all relate to the complexity of the policy process, but this has not been drawn out as its own theme; it is weaved through the narrative description of each theme. Furthermore, UHI tools needed to meet certain characteristics to be effective at promoting health. These were previously grouped under two candidate themes: 'reasons that UHI tools fail (or how to avoid)' and 'UHI tool design and use strategies'. These candidate themes are incorporated as 'avoiding failure through design'.

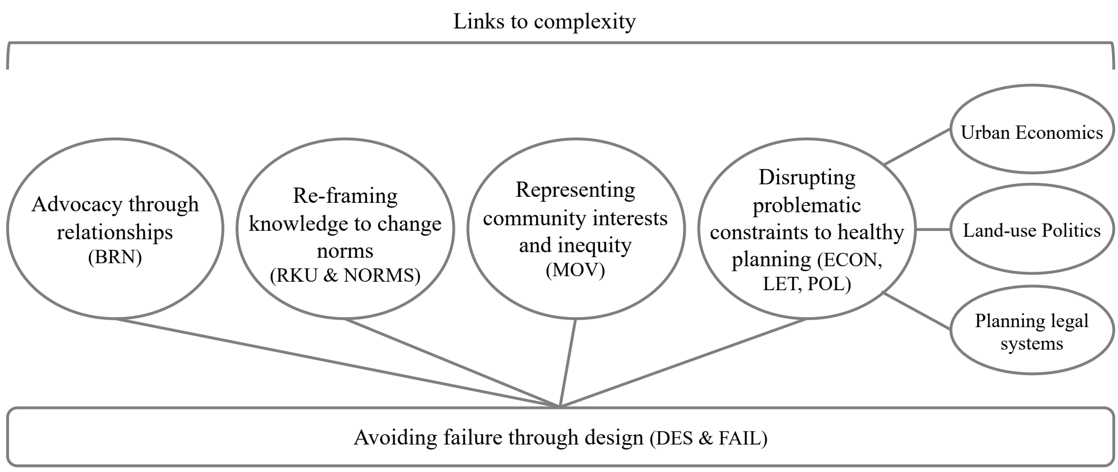

Figure 6-1 Final thematic map portraying five themes and three sub-themes with reference to the nine themes identified in the previous stage (abbreviations in brackets)

The final step was to name and describe themes as shown in Table 6-5. Names were selected to highlight the most important characteristics of each theme. The results section contains a full account of the final set of themes.

Table 6-5 Final thematic analysis themes with a brief description

Theme and sub-theme names	Brief description
1. Advocacy through relationships	Indicator producers built and maintained a wide range of relationships during the development and ongoing use of UHI tools, resulting in a network of advocates for health promotion across the public and private sector. Collaboratively developing and using UHI tools created new relationships among indicator users which supported healthy urban planning.
2. Re-framing knowledge to change norms	UHI tools and producers' advocacy activities re-framed knowledge and challenged professional norms and ways of working toward the inclusion of health-related issues. These efforts affected urban planners and wider stakeholders including: the community, politicians and developers.
3. Representing community interests and inequity	Indicator producers and users employed UHI tools to gather community perceptions and raise awareness of challenges to inform policy and decision-making, particularly related to the urban environment and health conditions of disadvantaged communities.
4. Disrupting problematic constraints to healthy planning	Indicator producers and users deployed UHI tools in multiple ways to disrupt a wide range of constraints inherent to the planning system. Each of the sub-themes (4a-4c) represents an area where multiple constraints were present.
4a. Urban economics	Urban economics affected many aspects of policy, decisions and implementation, resulting in 'winners and losers'. UHI tools were used to challenge economic arguments against designing and building health promoting environments.
4b. Land-use politics	The democratic nature of planning and land-use politics were viewed as controlled by specific powerful groups and therefore antithetical to the creation of healthy urban environments. Politicians were characterised as prioritising short-term gains and money over evidence and long-term community needs. Indicator producers used UHI tools with other strategies to influence political decision-making. Other strategies included building trust over time and being ready to support politicians when opportunities arose.

Theme and sub-theme names	Brief description
4c. Planning legal systems	The planning system was described as operating within a legal framework where some health promoting policy and implementation options were unavailable. UHI tools were used to influence legislation and local planning policy, as well as local development negotiations.
5. Avoiding failure through design	UHI tools required significant resources and technical skills, primarily for indicator producers but also for indicator users. Users and producers worked together to shape UHI tools which would be effective, with recognition that indicators would always only be part of a bigger picture.

6.6 Results of thematic analysis

This section begins with a description of the UHI tools that were discussed by interview participants. Then the five thematic analysis themes are described in relation to the research questions with direct excerpts from the interview data to illustrate each theme. The interpretation of the themes in relation to patterns, implications and the existing literature is addressed thoroughly in chapter eight. The text is anonymised in relation to characteristics of the speakers (such as gender and employer) and characteristics of the UHI tool and city. Some words have been removed and replaced with a generic term in brackets to ensure anonymity, for example the name of a city is replaced by [the city].

6.6.1 Background and context of UHI tool settings

Interview participants described the timeline and context for the development of UHI tools. In all settings, indicator producers and users described the social context as contributing to the motivation for UHI tool development. Participants described significant population growth coupled with housing affordability crises. They identified "winners and losers" of the housing development being produced to meet demand, resulting in "disenfranchised" communities and "gentrification". The changing urban context resulting from an influx of high-income residents and a widening of wealth inequalities was described by one participant as: "the city is starting to lose its soul". Understanding and addressing inequities through urban planning was frequently mentioned as a reason for producing and using UHI tools, described in section 6.6.4.

The UHI tools discussed by interview participants were broader than initially expected partly because CIV and SFIP were the catalyst or starting point for other indicator projects. Indicator producers sought to avoid duplication and built on the reputation of these tools through new UHI tool projects, both in San Francisco and Victoria, and more widely in Australia. Within San Francisco and Victoria, new UHI tools were developed for specific community engagement or thematic projects (e.g. San Francisco's Climate and Health Program indicators). Table 6-6 shows the indicator projects that were described by interview participants and whether participants said that these tools were linked to SFIP or CIV, meaning they were inspiration, data resources or other general information resources to inform new projects. Other emerging indicator projects were raised by participants that were not far enough developed to be included in Table 6-6.

Table 6-6 Indicator projects (and location) described by interview participants and whether they linked to SFIP or CIV. *Linked refers to inspiration, data resource or general information resource to inform further projects.

Indicator tools	Location	Described as linked* to SFIP or CIV
Central SoMa indicators	San Francisco, CA, USA	SFIP
Sustainable Chinatown indicators	San Francisco, CA, USA	SFIP
Climate and Health Programme	San Francisco, CA, USA	SFIP
EcoDistricts protocol for San Francisco	San Francisco, CA, USA	SFIP
Community Indicators Victoria	Victoria, AU	N/A
Maroondah's Community Vision indicators	Maroondah, VIC, AU	CIV
Indicators of Community Strength	Victoria, AU	-
Vic Health Indicators Survey	Victoria, AU	-
Fishermen's Bend Framework indicators	Melbourne, VIC, AU	-
Healthy Built Environment Indicators	New South Wales, AU	CIV
Liveability Assessment Tool	New South Wales, AU	CIV
Liveability Index (in development)	Australia	CIV
Movement and Place, SmartRoads	Victoria, AU	-
National Cities Performance Framework	Australia	CIV
Pedestrian Environmental Quality Index (PEQI)	San Francisco, CA, USA	SFIP
San Francisco Indicators Project	San Francisco, CA, USA	N/A
Trans Base SF	San Francisco, CA, USA	SFIP
Economist Intelligence Unit's Global Liveability Ranking	International	-

In many cases, indicator producers described the fragility of UHI tools which were dependent on funding that could end with very little warning. In 2016, after being funded for a decade, CIV's funders discontinued support of the UHI tool. The CIV website was still live when interviews were conducted in March 2018. Other UHI tools had small time-bound budgets to begin with, and indicator producers could not follow-up or support the implementation of indicators beyond publication. Indicator users were frustrated by the lack of consistently funded indicator projects because indicators could not reliably be used to track progress over time. Furthermore, new projects did not necessarily measure information in comparable ways to existing indicator projects, making benchmarking difficult across geographic areas.

6.6.2 Advocacy through relationships

The first theme resulting from the thematic analysis relates to the emphasis placed on building and maintaining relationships by interview participants. Indicator producers, usually public health professionals, cultivated relationships with a range of non-health stakeholders as a means of health advocacy. UHI tool development and use were effectively opportunities to create and maintain relationships. These relationships built a network of advocates for health promotion across the public and private sector. Furthermore, collaboratively developing and using UHI tools created new relationships among indicator users which supported healthy urban planning.

The main ways in which UHI tools were used to create relationships included: collaboratively building UHI tools; meetings and correspondence between indicator producers and users about indicator results; and training sessions, conferences and events run by indicator producers. These activities occurred over multiple years and facilitated ongoing communication between producers and users. Even after there were established UHI tools, such as SFIP and CIV, indicator producers continued to engage stakeholders in updates to the tools and discussions about future indicator development. In several cases, relationship building was recognised as an essential part of the overall indicator approach and it was resourced by the indicator producer organisations, including forming part of the job description for staff involved in indicator development and management.

The benefits of building relationships across public and private sector stakeholders were multiple and these benefits grew over time. The main benefit was that some relationships resulted in partner organisations (or individuals) becoming advocates for the messages which the UHI tool sought to communicate. Other related benefits of relationships described by participants included:

- building trust and credibility
- supporting funding applications
- creating a receptive audience for knowledge about urban health
- creating positive relationships in the contentious planning environment
- understanding actors’ constraints and opportunities
- spreading ownership of UHI tools across multiple organisations.

Indicator producers had the opportunity to earn trust and demonstrate knowledge, increasing the credibility of the individuals and the indicators. Involving stakeholders in developing indicators resulted in a broad range of actors who felt ownership over the UHI tool and advocated its use in their respective roles within government, non-governmental organisations (NGOs) or the private sector. For example, one indicator producer stated:

> *“Engaging with industry partners is so incredibly important, because it's not the indicator… that's going to make the difference. It's all the people. Because we've done something that's relevant to them, and they are using it to amplify it, because the amplification is really the critical thing.”*

These non-health actors may not have initially understood concepts related to urban health or the wider determinants of health. Building relationships with these individuals created opportunities to share knowledge about how urban environments impact health and how this can be addressed through policy and decision-making. Furthermore, in discussing indicators, public health and urban planning professionals were collaborating across government agencies creating opportunities to share and learn about each other’s opportunities and constraints. Building relationships also created opportunities to overcome the reluctance to engage with indicators that some departments or politicians expressed, usually related to concerns that UHIs would be used to block development. The following example from an indicator producer explains typical discussions with city agencies about an emerging UHI tool, showing the benefits of relationships:

> *“… when we've had discussions with other city departments around these tensions [about infrastructure and health], it's been good to understand where they're coming from and where we're coming from, because there's definitely an inherent misunderstanding... Because a lot of these city departments are worried about their infrastructure project not getting developed, or about these other consequences of what our [indicator] research might be when our research isn't trying to advocate to not doing*

> *any infrastructure, it's more just like what [are] the public health impacts."*

Urban planning indicator users also employed UHI tools to create relationships with public health colleagues and wider stakeholders, such as community representatives. Indicator producers recognised that UHI tools were an important tool for communication and described indicators as "a launching pad for engagement" and a "lubricant" to talk about research findings. The key message from this theme is that UHI tools were a means to develop relationships which resulted in advocacy and knowledge sharing for healthy urban planning policy and decision-making.

6.6.3 Re-framing knowledge to change norms

UHI tools and indicator producers' advocacy and relationship-building activities re-framed knowledge about urban health issues and challenged urban planning professional norms and ways of working. These efforts affected urban planners and wider stakeholders including the community, politicians and developers. This theme relates to the ways in which UHI tools helped users to understand and manage complex urban health systems (described in section 6.7).

By re-framing knowledge, indicator projects did not necessarily provide users with *new* knowledge, rather they provided a different way of looking at a problem, showed "interconnections" or a "fuller picture" and may have "expand[ed]" knowledge. The term "frame" was mentioned in multiple examples in the interview data. For example, participants generally said that concepts about the urban environment's impact on health had been around for a long time, but were previously framed differently, such as through sustainability. UHI tools and related advocacy activities were seen as shifting the agenda from sustainability or quality of life to health, wellbeing and liveability, but covering familiar planning concepts such as creating pedestrian-friendly neighbourhoods and open space. Participants also referred to UHI tools as re-framing health under a popular term, such as liveability, because this helped indicator users apply a health "lens" to their work. This health lens implied that users would be looking at situations from different perspectives and applying different background knowledge.

Another context in which framing was discussed related to problems which indicators were used to solve. One indicator producer described designing a specific indicator for an urgent problem "to change the problem frame". This was a strategy that the producer found was an effective means of influencing policy-makers, described as the "indicator fills an information gap that moves the solution forward". The producer illustrated this strategy with the following example:

> *"The problem frame was…behavioural, pedestrian or automobile driver behaviour. [The city] had the highest injury rate in the country… We [indicator producers] knew that this was environmental. It was based on traffic design and traffic volume and traffic speed. We knew that, and we did lots of research projects that demonstrated that. (…) We did epidemiology that demonstrated that,… but that wasn't useful evidence. Then, we created a new measure which instead of doing the intersection density of the injuries, we calculated the linear density of injuries on cumulative road segments. (…) It became a manageable problem, so 5% of the streets accounted for 55% of the serious and fatal injuries. (…) What that said was, this was a road problem. When we did that, almost immediately city policy shifted from focusing on residential neighbourhood traffic calming, to the realisation they need arterial traffic calming."*

This quotation also demonstrated that the indicator producers had tried to communicate epidemiological research knowledge about the problem through other means that were unsuccessful ("but that wasn't useful evidence"). In this example, one specific indicator was more effective than other research outputs for communicating to policy-makers. The idea that single indicators are powerful communication tools which can change a problem frame to motivate action was a sentiment shared by some indicator users. They described "numbers" as useful for communicating with politicians and also being used by politicians to rally effort and focus attention.

Another example of re-framing knowledge relates to the use of UHI tools to represent community views, thereby broadening the scope of knowledge that informs planning. Some indicator users and producers gathered community knowledge with UHI tools to bring this into the mix of evidence that was used for urban design and policy-making. In this context, indicators were also seen as helping "provide citizens with the language to understand" and articulate environmental health issues. Similarly, community knowledge represented in indicators was portrayed as powerful evidence to argue for different ways of working in terms of planning policy and decision-making, challenging existing norms. Two excerpts from different indicator users describe how community-informed UHI tools influenced awareness, norms and decision-making:

> *"…when you think about design you think about engineers that are only thinking about curb radii and widths of streets. So this adding more a*

> *human dimension to thinking about how we design places. (...) It maybe adds leverage. And we know in terms of implementing these things in [this city] in particular, it's very expensive. So having that rich data is also really helpful too, for our politicians. Because it gives them something to help state the case to get funds for things."*

> *"...[the] planning [department] is thinking a lot more about health than it ever did before the [UHI tool]. In part because [the indicator producers] were very persistent, and they said, "You have to look at this, this is what the community is demanding." (...) And I think there's more awareness than there was."*

In these examples the indicators were seen to represent community demands or views and this was given as evidence to focus attention and justify funding. In the last example, the UHI tool was described as being responsible for planners thinking more about health than they did previously.

This theme related strongly to interview participants' descriptions of ways in which UHI tools were described as helping users understand and manage the complexity of urban health. Some of the strategies included: incorporating community views to provide a "richer" picture of urban health issues, using UHI tools to show "interconnections" among features in the urban environment, and providing a different "problem frame" to address a challenging issue. However, some participants felt that UHI tools did not go far enough in showing the interconnections between indicators. Section 6.7 describes complexity and UHI tools in greater detail.

There were limits to how far interview participants thought people may expand their knowledge or thinking as a result of UHI tools. Some indicator producers perceived indicator users as "programmatic in their work" and not interested in wider issues. Alternatively, producers recognised that users may be too busy to engage with multiple indicators and therefore dipped into indicators to serve a particular purpose, not necessarily engaging with the UHI tool or indicator producers more widely. This theme demonstrated that UHI tools were used to re-frame knowledge about urban health issues, although not all participants perceived UHI tools to result in new or expanded knowledge.

6.6.4 Representing community interests and inequity

Using UHI tools to gather community perceptions and increase awareness and action about disadvantaged communities' challenges was a core driver for many indicator producers and users. The previous theme described cases where indicators represented community interests, bringing their views to provide a "richer" picture of urban health issues or providing evidence to justify action or funding. This theme builds on those examples but specifically relates to disadvantaged or under-represented community perspectives.

Many indicator producers described themselves as being particularly interested in uncovering and addressing inequities, particularly those brought about by planning decisions. This was primarily achieved in two ways: first, by publishing indicator data at a spatial scale allowing comparison between neighbourhoods within a city to identify inequity; and second, by involving disadvantaged communities in selecting indicators. UHI tool producers used advocacy and relationship building to raise awareness among stakeholders about inequity issues related to the urban environment. UHI tool users exploited indicator data to demonstrate where changes to the urban environment might disproportionately affect disadvantaged communities. Examples related to the housing affordability impact of neighbourhood improvements and the location of alcohol or gambling outlets in poor neighbourhoods.

In the context of disadvantaged communities, multiple actors used UHI tools to: challenge powerful interests (such as developers), tell difficult truths to politicians or community representatives, legitimise community concerns within the planning system and mitigate the impact of new development on these communities. A commonly discussed problem related to rapidly growing areas, where indicator users described a lack of control over the delivery of infrastructure. In these communities, planners sought to bring in private sector developers to build houses and associated infrastructure to accommodate population growth, such as supermarkets. The following account provides a useful example of the use of indicator tools to overcome this problem and wider constraints.

In one local authority, indicator users described their relationship with "big multinational" developers and retail businesses as "a challenge we have no control over" and "we're a bit beholden to them". In negotiations with these businesses over planning matters, planners requested "more pedestrian-friendly" design or relocation of alcohol outlets and were met with responses from the developers such as "well we won't build your supermarket then." Planners described these relationships as involving "ongoing arguments" but stating that these challenges were "tricky" to address through the planning system. Although planners in two neighbouring local authorities could not stop such development, they sought to reduce the impact on inequities as explained by this exchange between planning and public health colleagues who were interviewed together:

> *Planner: ...it's a very big [alcohol outlet] it's almost like the size of a supermarket. And they offer really cheap prices so-*
>
> *Public health professional: Again, one of the first things to come into new developments.*
>
> *Planner: (...) It is a tricky one but it's just trying to, I guess, restrict... ...avoid, as well, the location of them in vulnerable communities because it's interesting if you look at where a lot of them are located, I don't think it's accidental.*
>
> *Public health professional: They've got their business model down pat.*

In this example, neighbouring authorities were working together using data from local police, emergency services and academic partners, to build a case for restricting the location of cheap alcohol outlets in deprived communities. In this example and others, indicator users and producers brought health and environmental data together to build an argument about disproportionate impacts on disadvantaged communities that may not have had the power to otherwise resist undesirable or health-harming developments. This example also demonstrates the value of building relationships among indicator users who combined different knowledge and resources, such as local planning instruments or local authority health and wellbeing plans, to tackle the challenge.

In summary, this theme highlighted the core driver of equity for indicator producers and users. Participants used UHI tools to challenge powerful interests, tell difficult truths to politicians or community representatives, legitimise community concerns within the planning system and mitigate the impact of new development on disadvantaged communities.

6.6.5 Disrupting problematic constraints to healthy planning

Indicator producers and users deployed UHI tools in multiple ways to disrupt a wide range of constraints inherent to the planning system and its function within urban contexts. Each of the sub-themes (urban economics, land-use politics and planning legal systems) represent an area where multiple constraints were present and interview participants devoted considerable attention to describing these challenges, including cases where they were disrupted through the use of UHI tools.

Although indicators were sometimes successfully used to overcome these constraints, the interview participants frequently described setbacks, and found their work applying indicators as “very tiring”, “frustrating” and needing “courage”. Some participants spoke of themselves as being very different from their professional peers in the public health or planning fields. They described their professional institutions or employers as not being set-up to recognise their work associated with indicators. They also described a sense of personal investment and urgency in their work. This theme addresses some of the most significant challenges faced by professionals seeking to promote health through the urban environment. Although indicators were successfully used to disrupt these constraints in some cases, it was not without difficulty. Indicators appeared to be a small disruption in the overall urban development system.

6.6.5.1 *Urban economics*

Urban and development economics affected many aspects of planning policy, decisions and implementation, resulting in “winners and losers” of actions within this system. UHI tools were used to challenge economic arguments against designing and building health-promoting environments. Lack of understanding of urban economics, and development economics specifically, were key challenges raised by some indicator users and these were manifest in two ways. First, some participants claimed that indicator producers did not understand urban economics and therefore created poor indicators that resulted in unintended consequences when implemented through policy. Second, whilst indicator users regularly emphasised development economics constraints, indicator producers rarely spoke about this challenge suggesting an uneven view of this barrier to implementation.

Evidence from UHIs was used to increase health-related design and planning through: negotiation with developers, strengthening arguments for policies, and determining how development impact fees should be allocated. Impact fees are financial contributions by developers to mitigate undesirable impacts of developments or otherwise make them acceptable, such as paying for local street improvements or schools. Each of these uses of indicator evidence related to economic considerations by different planning policy and decision-makers (officers and politicians).

Urban planning UHI users described applying indicators as “leverage” during negotiations with developers, characterised as “a lot of push and pull.” Negotiations with developers were discussed in the previous section regarding alcohol outlets. Some indicators were viewed as easier to require in policies and in development negotiations because they had been adopted in national or state guidelines, such as access to public transport within 400 meters of new houses. One planner said:

> *"…we push quite hard for that. We do get a lot of developers that will push back and try and argue that they don't have to do that."*

Developers were frequently described as pushing back and arguing that modifying urban or building design for health purposes would come at the expense of other policy objectives.

A UHI tool developed with significant community involvement was successfully used to challenge the health impact of new development in the face of economic arguments from the developer. In this case, the indicator producer provided evidence to the local planning authority and developer about the health impact of gentrification caused by a proposed development. The indicators were seen as a powerful argument about value within the economic and political context of planning decision-making:

> *"The developer and the planning department said, "One, we don't want to set precedent. Two… we don't want to have to study this problem, because it's going to look bad," and they decided to mitigate and give all those residents right of return and rent control. (…) That was the result of the authority of health… the power of the value of health, the currency of health, with evidence, into the political process and making a law that should have been already enforced, enforced."*

This excerpt also demonstrated, that even though there may have been a policy (or "law") in place about avoiding health impacts, this would not necessarily have been followed if decision-makers prioritised other policy objectives for economic and/or political reasons.

One indicator user described indicators as helping to counter developers' arguments by providing evidence of "co-benefits", although it remained possible for these to be overshadowed by other economic arguments. In this example, the multiple benefits of providing shade through green infrastructure, such as UV (ultraviolet) protection, cooling, and biodiversity, were seen as "co-benefits" that provided a stronger argument than an indicator with a single purpose. Yet the planner claimed that cost could still overshadow those arguments:

> *"[If] …just tweaking the design, and the roof design, and the provision of landscaping… was going to add, I don't know, 5%, 2% to the budget, then*

> *you may well have the developers whinging at the council as, "Oh, there's all these things, they make it more expensive, and we're trying to provide affordable housing," and there you go, affordable housing is the number one thing in [the area]."*

As this example demonstrated, negotiations about small design revisions could quickly be ended by the developer's claim that such requirements would jeopardise the delivery of affordable housing. Thus, a discussion about development economics on a particular site became part of a wider economic and political issue of housing affordability that may be more important to planning decision-makers. In the previous two examples, indicators were used in either policy or negotiations, but neither of those factors meant that the indicator would necessarily influence the final development design due to economic constraints.

Where indicator producers and planners did not understand urban economics and other policy implementation challenges, indicators were seen as potentially resulting in significant unintended consequences. One experienced urban planning indicator user explained how indicators to limit urban sprawl (such as urban growth boundary targets) led to policies which affected housing affordability. This was seen as resulting from flaws in the indicators and the policy, but also a "profound lack of understanding of urban economics in the planning profession" and beyond. The potential for indicators to result in unintended consequences is further discussed in section 6.7.

6.6.5.2 *Land-use politics*

The democratic nature of planning and land-use politics were viewed by many interview participants as controlled by specific powerful groups and therefore antithetical to the creation of healthy urban environments. Politicians were characterised as prioritising short-term gains, including tax receipts from new development, over evidence and long-term community needs. However, politicians were also recognised as important drivers of change who could positively impact healthy urban environments by overcoming constraints in the planning system. Indicator producers used UHI tools with other advocacy strategies to influence political decision-making in attempts to promote healthy urban environments and re-balance the power, or lack thereof, of particular groups, including disadvantaged communities.

The context of land-use politics at the local level was described as a "blood sport" where people with "detailed knowledge and manipulation of… the way [planning regulations] can be presented or applied" were able to work the system to their benefit, resulting in "winners and losers". Local land-use politics primarily involved elected and non-elected officials, the community and the private sector, and involved controversy over local policies or proposed development. Another level of politics related to interactions between multiple tiers of government (city, state and national) that held different legal powers or controlled resources in relation to planning and decision-making, resulting in "a very contested, uneasy relationship." The media, non-governmental organisations and academics were also described as actors within land-use politics.

Both indicator users and producers described political decision-making as being more driven by political agendas, election cycles and short-termism than evidence, such as that provided through indicators. Several planners, sometimes reluctantly, described local politicians as being "uneducated" or driving "silly" policies which were not evidence-based. Interview participants also described a context where higher tiers of government did not put health considerations into planning legislation, or would not approve their inclusion in local government policies, due to fear that such policies would be used to block development. For example, one indicator user said:

> *"…there's no way that the state government would let you suddenly whack in a clause in your local environmental plan about health indicators at this point."*

To overcome these challenges, interview participants described using indicators and related advocacy and relationship building strategies. This was achieved in multiple ways, including: publishing indicator evidence to directly disrupt or influence political processes, working with political decision-makers to influence change (building trusted relationships over time), and being ready to support politicians when opportunities arose to influence politicians and decision-makers.

A somewhat contradictory view to the claim that politicians did not value evidence, was the observation by several participants that politicians were interested in numbers and effectively used indicators to drive action. Politicians were seen as important advocates for health promotion which was sometimes achieved through indicators and relationship building. Furthermore, where politicians or other influential indicator users had “ownership” of indicators, they would effectively drive change, exemplified by this excerpt:

> *“There has to be that kind of, let’s just say, the political engine behind the indicator, whether it’s a mayor or an empowered bureaucrat… or a citizen, that you want to see. (…) You have to create ownership of the user, and the best way to do that is to do it with them.”*

In this context, creating ownership among indicator users through co-production was a way to ensure that the indicator would be used to drive change. As another indicator producer described it, this guarded against indicators becoming a “vapid intellectual activity”. In this sense, collaborative development of indicators with citizens and politicians was described as “participatory democracy” and a “collective impact process” which was viewed as the reason some indicator projects successfully achieved changed, while others did not. Politicians or citizen demand could “rally” efforts, focus attention and drive cross-departmental working in a way that un-elected officials could not.

In addition to working with local politicians, indicator producers put indicator data into the public sphere through publications and events that caught the attention of politicians and the media. One producer described a senior planning minister as publicly discussing the poor results in their indicator report. This was viewed as “success” because the indicators were contributing to a debate about healthy urban environments. This relates to the ways in which indicators were used to re-frame knowledge of problems by highlighting such problems alongside potential solutions that may not have otherwise received political attention.

6.6.5.3 *Planning legal systems*

The planning system was described as operating within a legal framework where some health-promoting policy and implementation options were unavailable. In general, indicator producers and users were frustrated about the use of knowledge within the planning system, particularly in relation to what they perceived as a lack of evidence-based policy and decision-making. However, evidence from UHI tools and related advocacy were used to influence legislation and local planning policy, as well as local development negotiations, when indicators and advocacy fit into the requirements of the planning legal system.

Indicator users, more so than indicator producers, discussed the legal system binding planning practitioners and reducing their ability to incorporate health considerations. The legal framework in which planners operated was coupled with other professional norms and constraints leading to de-prioritisation of health, such as balancing a plethora of other issues and not having sufficient time or resource to engage with UHI tools. Planners were also aware that if their decisions were contested, they could face legal challenges resulting in costs to their employer and political ramifications. One planner explained that under planning legislation,

> *"…development applications are considered on their merits… (…) …which involves a huge level of juggling, negotiation and understanding…"*

In other words, development applications did not have to tick all of the policy boxes. Therefore, any decision to particularly push for health-related design considerations, or refuse an application on this basis, needed to be strongly backed by evidence, otherwise it could be contested through risky and costly appeals. Another interview participant described going to great lengths to ensure that their policy was "development viability friendly" but nevertheless it had resulted in "[lawyers] at paces tearing it apart because it's not doing what the developers want, making a maximum profit". When developers' arguments against planning policies or decisions resulted in appeals this was another context in which health issues may not be prioritised. One producer explained that adjudicators in the legal appeals system were either unaware or "hostile" toward "scientific method" and "may represent an ideological position that's pro-development". Interview participants were aware of the limited power of planning to promote health in relation to the legal framework and contested landscape in which it operated.

Indicator producers and users spoke differently about the legal constraints binding planning activities. Some indicator users argued that there was a mistaken perception that planning had significant power over health-related topics and land uses. Planners at different tiers of government pushed back against advocacy, for example related to stopping fast food outlets. One planner said, "planning can't do that" because fast food outlets were classed as "convenience restaurants" in the planning scheme and could not be restricted on the basis of what they were selling. Additionally, the planner viewed the system as "quite rigid" and "controlled by the state government." Thus, the legal and political context of the planning system created challenges to health promotion.

Indicators were used to disrupt legal constraints by providing evidence to be used within the system, or by creating advocates to influence the system. In the first case, indicator users described indicators as powerful evidence to build a “business case” and to challenge “business as usual models”. Some planners required evidence to justify health-related policies in statutory plans because these were approved by state government. Interview participants attributed great value to indicators to move toward “evidence-based decisions” but described many instances where factors other than evidence had driven planning decisions.

There were several examples where advocacy with indicators was used to influence legislation relevant to planning, such as economic development, employment and transport. Producers sought to influence stakeholders across these departments through the inclusion of a broad definition of the social determinants of health, couched in the term ‘liveability’, that indicator producers sought to have included in the state’s public health legislation.

> *“We had internal advocates and we were advocating for it and so it's in there. And… that means local government has to look to it.”*

By influencing state legislation through advocacy, all of the local government planning and public health teams were then required to use their liveability definition, which created further engagement with the UHI tool and indicator producers. The indicator producers worked directly with several local authorities to implement liveability plans, creating exemplar projects to increase learning and improve practice across other authorities.

In summary, the theme of ‘disrupting problematic constraints to healthy planning’ described three key constraints (economic, political and legal) and the use of indicators to overcome these challenges. In relation to the urban economics constraint, indicators were used as evidence in negotiations with developers, policy development and determining the allocation of development impact fees. Land-use politics created both opportunities and constraints where politicians were seen as champions or barriers to healthy urban planning policies and decisions. Finally, the planning legal system meant that certain healthy planning options were not possible. However, UHI tools were part of advocacy and lobbying efforts to change legislation and open opportunities for local or state healthy planning policies.

6.6.6 Avoiding failure through design

Many of the indicator producers had at least a decade of experience with UHI tools that led to their deep understanding of the features which were essential to their success. Indicator users and producers worked together to shape effective UHI tools, with recognition that indicators would only tell part of a story and would only be part of a bigger picture of health promotion activities. Indicator producers explained how they used a range of strategies to ensure that indicators could influence policy and decision-makers. These strategies were developed over time and improved through trial and error. In interviews, indicator producers devoted a considerable amount of time to describing these success factors. Indicator users did not generally discuss these factors in such detail; however, they did identify problems with UHI tools that hindered their implementation.

UHI tool producers explained the following strategies to develop useful indicators, which relate to many of the themes previously described:

- creating ownership among users, usually by involving them in indicator development;
- building relationships with indicator users and other advocates, and being available to provide data or support when required;
- focusing on the problems that need to be solved, not the available data;
- focusing on strategic indicators to drive policy change, which are likely tied to existing policy mechanisms;
- presenting data in a captivating format (including maps) at the scale of interest to the audience;
- building on the success of previous UHI tools where concepts have become institutionalised; and
- communicating with audiences in their language about their problems, avoiding terms like 'health' and 'social determinants of health'.

Indicator producers saw the powerful strategies of relationship building and advocacy as being in a mutually reinforcing relationship with the view of their UHI tool as being credible, scientifically valid and appropriately presented for their audience. In other words, policy-makers would interact with indicator producers because they perceived UHI tools to be credible, valid, etcetera, and therefore they would engage with indicator producers increasing the success and credibility of the tool. Indicator users described the benefits of working with indicator producers to more fully understand specific challenges, validating some of the strategies presented by producers.

Indicator users described cases where UHI tools fell short of expectations or were otherwise problematic. Users described a lack of knowledge, time and skills to use indicator websites and analyse or interpret data. There was a gap between the anticipated and actual knowledge which indicator producers expected indicator users to have in relation to website and data interpretation. In addition, indicator users described the following shortcomings of some UHI tools:

- data quality and availability: including spatial scale, age of data, collection over time, and comparability across geographic areas;
- number of indicators: too many indicators available, but not necessarily the right indicators (see data quality and availability) to support decision-makers; and
- fragility of UHI tools: indicators or resources to support their use were stopped due to funding or political changes.

Furthermore, several indicator users said that knowledge about indicators faded within institutions. There were fads where indicators became popular, such as sustainability indicators, and then dropped out of the organisational consciousness, at times because they became politically problematic. Several planners said that although indicators were regularly put into planning documents, they were never (or rarely) measured. Indicators were the "Cinderella of planning" and legislation was described in many cases as being the only way to ensure indicators were regularly reported by planners.

This theme described the characteristics of UHI tools which indicator producers found to be effective at driving engagement with policy and decision-makers. It also described the shortcomings of some UHI tools or their application within planning from the perspective of indicator users.

6.7 Dealing with complexity through indicators

Participants described multiple ways in which indicators helped planning policy and decision-makers understand or address the complexity of urban health. Overall, participants emphasised the importance of understanding the multiple interconnected urban environment domains that impact health and the ability to see problems in a different way (for example, through richer data, community perspectives or different angles of problems). In many cases, there were contradictions within the data about how UHI tools helped to address complexity, with some participants identifying risk in applying a single indicator devoid of contextual information to justify policies. This section describes how indicator producers and users accessed UHI tools to present and manage the complexity of urban health, within complex policy and decision-making contexts.

6.7.1 Multiple interconnected variables and feedback

Many interview participants spoke of UHI tools as being a useful resource about the many urban environment issues affecting health, however participants were divided in opinion about whether the tools helped to show or explain interconnections among variables or domains. Furthermore, participants spoke differently about how UHI tools could help policy and decision-makers address interconnected urban health challenges. Several indicator producers and users spoke about identifying interactions among parts of the urban health system, which two participants called feedback loops.

Indicator producers spoke of the benefits of UHI tools to show interconnections, referencing a number of specific characteristics that achieved this, including:

- presenting a conceptual framework showing UHI tool domains and indicators;
- listing a number of indicators or domains to show the multiple urban environment issues that affect health; and
- reporting cause and effect relations among indicators to show interconnections.

The final strategy required reporting more information than indicator data. Producers spoke of using presentations, training and meetings to help indicator users understand interconnections and cause and effect relations among the data. One producer described how the number of indicators across domains allowed for analysis to show interconnections:

> *"…if you're tracking it across multiple domains, even where improvement in one area may come at the expense of something else… (…) I think those inherent tensions are not addressed directly by the indicators that we're looking at, but by the fact that we're providing a suite of indicators across multiple domains at least means that if you're pushing to heighten a particular area and it's driving something else down, at least you're starting to see that emerge in a way that you can act on it."*

This description implied that indicator users would require data about trends over time and relations among indicators.

In contrast, indicator users described difficulty "drawing relationships" between indicators and different UHI tools. Users spoke about the "messy web" of urban health relations and wanting to "untangle that", however they did not necessarily think that indicators were currently helping with this challenge. One indicator user wanted to see fewer overall indicators within UHI tools, with more focus on single indicators that represented interrelations among different systems, stating:

> *"But maybe the interrelation part is the difficult piece… and so that's why we're thinking what sort of indicators can create more of those interrelations. So things that are not necessarily just an indicator of one thing, but of many different systems."*

A few participants discussed "feedback loops" in the context of interrelations among indicators and trying to affect change within the urban health system. One indicator producer in particular described understanding feedback loops as a starting point for producing effective indicators, stating:

> *"You have to first think about what feedback loop you want, and then what levers and actions need to happen, and then, what is the information system that drives those levers and actions?"*

Only one indicator user discussed feedback loops, and this was in the context of not having the time and resource to properly understand this characteristic of complex systems. Describing indicators in relation to feedback was not generally part of indicator users' conceptualisation of the value of UHI tools.

In summary, although indicator users understood the complexity of urban health, they did not necessarily find UHI tools a helpful resource to draw connections among indicators, unless a single indicator could represent multiple interconnections. In contrast, indicator producers spoke of the benefits of indicators to show interconnections and cause and effect relations, including feedback.

6.7.2 Unintended consequences and policy resistance

In a number of cases, indicator producers and users relayed stories about the use of UHI tools to detect unintended consequences of policies or a lack of change in the system following policy implementation, known as policy resistance. Some indicator users also described circumstances where poorly devised indicators could drive unintended consequences when adopted through land-use policies. Detecting unintended consequences and policy resistance effects required monitoring data over time, recognising the dynamic nature of urban systems.

One indicator producer explained that there were limited resources to improve health through the built environment, and therefore trade-offs between objectives were perhaps inevitable but could be monitored through indicators. For example, the first quote in the previous section (6.7.1) discussed identification of unintended consequences where policies to raise improvement in one domain may cause a worsening of conditions in another domain. The producer identified value in identifying such unintended consequences to inform further action among policy-makers.

Similarly, indicator users recognised the value of longitudinal indicator data to identify policy resistance. In one case, indicator users were working with indicator producers to delve into the potential causes and effects of transport infrastructure and pedestrian injuries:

> *"…the city has… looked at what are the major causes of injuries. (…) And then they have specific counter measures that are supposed to address those types of collisions. And we've been doing it for about two years and the fatalities aren't going down. And so it's been sort of this larger conversation and just kind of thought process about how you address this. We're doing very detailed analysis over what are the cause and effects and what are the right tools to address these things. We aren't seeing the results that everyone wants us to see. That's somewhere we're really using this data and [these] indicators to really inform traffic engineering."*

This case represented a significant amount of data analysis led by the indicator producers, echoing a point in the previous section that UHI tools on their own may not be sufficient to understand certain characteristics of complex systems.

There was also a sentiment among some indicator users that inappropriately devised indicators could "drive bad behaviour" or otherwise produce unintended consequences. Examples were given in relation to policies to control density and urban sprawl. For example, setting floor area ratio targets to control density has resulted in a market response to build smaller apartments unless such policies were accompanied with other policy incentives to produce bigger apartments. In this example, UHI tools could be seen as responsible for driving unintended consequences rather than trying to detect such effects within a system.

6.7.3 Risks of identifying and simplifying complexity with indicators

There were conflicting views of how UHI tools presented or addressed the complexity of urban health with some participants stating that indicators helped to see a "fuller" picture with interconnections, whilst others claimed that indicators only presented a starting point and did not show the "full picture." These diverse views of indicators created problems for their application by policy and decision-makers and related to the political attraction to simple figures which represented complex problems.

The perspective that UHI tools provided a "richer" or "fuller" picture of urban health challenges than would otherwise be detected, was described in section 6.6.3. In this sense, UHI tools were seen as presenting interconnections across systems and adding different types of information, such as qualitative and quantitative perspectives. Some participants built on this idea to say that by seeing information in a new way, indicator users may be inclined to undertake further analysis of the urban health challenge. One indicator producer described indicators as "icebergs" which could give users "a sense of what's going on" but further investigation would be needed to fully understand the issue.

The opposing view that indicators only provided part of a complex picture was seen as an inherent limitation that could result in inappropriate application in policy and decision-making. In this sense, indicators could be seen as simplifying information to such an extent that the full story or important information was lost. This view highlighted a tension between the number of indicators presented in UHI tools and the ability of users to process and act on that information. Two quotes from indicator users described this challenge of simplification for policy-making:

> *"…you can't just focus on certain things and expect everything else to fall into place. Indicators will show a particular issue from a particular angle that can be used to help inform your response to that. …but they aren't the full picture. (...) …it's certainly helpful when used in the right way and not used to just support a certain contention in isolation, but when used as just one of a number of data sources..."*

> *"…we need to simplify things for people, but it's such a complex issue. And the simplification is really helpful for political action… (…) …when you have those very clear benchmarks, it gives something for everyone to work towards… (…) …[the UHI tool] is very comprehensive. But it's also just so much information that we almost need a level on top of that... Fewer, I think."*

In summary, there were two contrasting views about the use of UHI tools to represent complex systems and how this information was applied for policy and decision-making. Some participants found that simplifying complex issues was helpful for policy and decision-makers and could help to spur on more detailed analyses of problems. Other participants cautioned that indicators were only part of a complex story and should not be applied out of context to justify particular decisions or be viewed in isolation.

6.8 Discussion

This investigation of the value of UHI tools in promoting health through urban planning has identified multiple functions of indicators which have not previously been discussed in the UHI literature, but many themes resonate with the sustainability indicators literature. Rather than conceptualising indicators as directly influencing policy, the findings of this research position indicators in a complex policy and decision-making context where the combination of evidence-based indicators and the actions of indicator producers helped to: build relationships, drive advocacy, re-frame knowledge, increase awareness of disadvantaged communities' interests, and disrupt problematic constraints to healthy planning such as urban economics, land-use politics and the planning legal system. These benefits were likely contingent on the quality of the UHI tools and the level of resources put into their initial and ongoing development and application. This section outlines the strengths and weaknesses of the study. The key findings are highlighted but interpretation and future research opportunities are reserved for chapter eight.

6.8.1 Strengths

This study has filled two gaps in the literature by providing a detailed investigation of the use and value of UHI tools, particularly in relation to the complexity of urban health and the policy and decision-making process. The systematic review results presented in chapter four highlighted the lack of research on the use of indicators and the possibility of bias in existing research, in which UHI tool producers have reported the value of their UHI tools through case studies. Furthermore, this may be the first empirical study which examined the value of UHI tools in relation to the above-mentioned complexity challenges. There is a body of work exploring or promoting the use of indicators to address complex challenges within the complex planning policy-making context, for example Rae and Wong (2012) and Innes and Booher (1999, 2000, 2010). In relation to health, Corburn and Cohen (2012) and Davern et al. (2017) have linked UHI tools to complexity theory, although they did not report practitioners' perspectives on the value of UHI tools to address complexity.

This research took place in three settings, linked by similar social and economic urban contexts and planning systems, increasing the translatability of the results to inform other UHI tool producers, users or researchers. In addition to the benefit of multiple linked settings, interview participants also had knowledge of a wide range of UHI tools, beyond SFIP and CIV. This breadth of knowledge was also balanced in the interviews by in-depth knowledge, developed over a decade, of the development and application of the SFIP and CIV tools in San Francisco and Victoria. Analysis of this detailed knowledge within the study's theoretical framework, combining collaborative rationality and complexity theory, has allowed the generation of useful theory-based insights, discussed in chapter eight. Further strengths of the overall study are described in chapter eight.

6.8.2 Limitations

Lack of generalisability is an inherent limitation of case study research (Bryman, 2004), although this research has addressed multiple UHI tools and settings. The significant and long-term resources behind SFIP and CIV mean that they are not necessarily representative of other UHI tools with regard to how they were used to influence policy and decision-making. However, there are experiences and lessons gained from these projects about the development and characteristics of UHI tools which could be applied to other projects. For example, it could be argued that achieving the impact of these tools was contingent on their resources, which is a valuable finding in its own right.

Investigating the relationship between UHI tools and complexity was challenging and the questions in the interview may have influenced participants' responses. Most of the interview questions linked to some aspects of complex systems without using those words specifically. However, participants were also directly asked about how using or selecting indicators could help them understand or manage the complex urban health system. In asking this question, the interviewer spoke about the characteristics of complex systems. It is therefore not surprising that some responses echoed back the language of "interconnections" and "unintended consequences." Furthermore, participants often paused after hearing this question or reformulated their responses as they appeared to change their answer whilst they were talking, perhaps indicating some uncertainty about their perspectives. There were also several contradictions across interview responses. Nevertheless, these results formed a starting point and were analysed in the context of the full interview data which provided other insights into managing complex systems with indicators. Additional limitations to the overall study are described in chapter eight.

6.9 Conclusion

Earlier in this chapter the results of the thematic analysis were described, including the background and context of UHI tools, five themes regarding their health promotion value, and the use of UHI tools to measure and address the complexity of urban health and policy-making contexts. The findings are summarised as follows:

- UHI tools were used as a means to develop relationships across diverse disciplines and organisations. Through these relationships, UHI tool producers were able to spread knowledge about the wider determinants of health, resulting in a range of advocates for improving the upstream determinants of health through urban planning policy and decision-making. Relationship building also had other benefits, such as: building trust and credibility, supporting funding applications, creating positive relationships in the contentious planning environment, understanding other actors' constraints and opportunities and spreading ownership of UHI tools across multiple organisations.
- UHI tools were used to re-frame knowledge about urban health issues, although not all participants perceived UHI tools to result in new or expanded knowledge. Re-framing knowledge encompassed the use of indicators to see: a richer picture, interconnections across aspects of the built environment, a new perspective of a problem, or community perspectives. These new ways of looking at challenges also opened up different solutions.
- Equity was a core driver for indicator producers and users. Participants used UHI tools to challenge powerful interests, tell difficult truths to politicians or community representatives, legitimise community concerns within the planning system and mitigate the impact of new development on disadvantaged communities.
- In relation to economic constraints, indicators were used as evidence in negotiations with developers, policy development and determining the allocation of development impact fees.
- Land-use politics created both opportunities and constraints where politicians were seen as champions or barriers to healthy urban planning policies and decisions.

Politicians were perceived as valuing specific indicators which they could use to rally effort and focus attention.

- The planning legal system, applied at different scales of government, meant that certain healthy planning options were not possible. However, UHI tools were part of advocacy and lobbying efforts to change legislation and open opportunities for local or state healthy planning policies.
- Indicator producers (not exclusively) described a number of UHI tool characteristics that they found to be effective at driving engagement with policy and decision-makers, including: creating ownership among indicator users, building relationships with users, presenting and communicating data to match users' requirements and focusing on users' policy-making issues. Indicator users discussed the shortcomings of some UHI tools or their application within planning, that could hinder the aforementioned benefits from being achieved, such as: poor data quality, too many indicators and the fragility of indicator tools.
- Finally, UHI tools were identified as a means to help present the complexity of urban health systems through: showing multiple interconnected variables and domains, identifying unintended consequences and investigating policy resistance. However, none of these benefits were without limitation and participants identified further risks associated with the inherent simplification of complex issues through production of indicators.

In conclusion, this chapter presented the methods, analysis and initial results of primary data collection for this study. It began with an overview of case study and participant selection and the format of semi-structured interviews. It then described the thematic analysis process that was applied to the interview data. Finally, the results of the thematic analysis were presented with example quotes from interview participants to illustrate each theme. The next chapter will use the thematic analysis codes and interview data in a systems thinking approach to develop causal loop diagrams of UHI tool producers' and users' mental models.

CHAPTER 7

Proposed mental model of UHI tool use and value

7.1 Introduction

Chapters three and five outlined the motivation and process for developing causal loop diagrams of indicator users and producers’ mental models of the use of UHI tools. The problem modelled in this study is that the number of UHI tools which seek to influence built environment policy and decision-making are growing; however, the intended audience does not appear to value or use many of these UHI tools as envisaged by UHI tool producers. Chapter five conceptualised the model by describing this problem and its emergence over time and proposing initial boundaries for the model, using data from the systematic review. Finally, it proposed several dynamic hypotheses of the feedback relations in indicator use, developed from chapter four’s narrative synthesis of existing studies. This chapter describes the iterative development of causal loop diagrams based on the interview data presented in chapter six. It presents a high-level CLD model with supplementary detailed sections. It then describes the process and results of testing and improving the model through a participatory modelling workshop. The chapter concludes with initial discussion of the findings, strengths and weaknesses, which are further elaborated in chapter eight.

7.2 Methods

This section describes the methods for development and testing of the causal loop diagram. The method for development of a CLD using interview data was informed by Eker and Zimmermann (2016) and Kim and Anderson (2012). The researcher followed a modified causal mapping process based on the following: categorisation of themes in coding trees and identification of causal relations from Eker and Zimmermann (2016); and transformation of text into words-and-arrow diagrams from Kim and Anderson (2012). A key diversion from these approaches was the use of thematic analysis rather than grounded theory to code and interpret the interview data. This section describes the research design, in relation to coding, and the specific approach to data coding to develop the causal loop diagram.

7.2.1 Research design dimensions for CLD development with qualitative data

Eker and Zimmermann (2016) showed the value of reporting Turner et al.'s (2013) six research design dimensions related to coding for the development of causal loop diagrams. Making these research design choices explicit helps readers understand how the data collection and analysis techniques have influenced the resulting model. Each of the research design dimensions are summarised in Table 7-1 and elaborated in turn below.

Table 7-1 Six research design dimensions for coding to develop causal loop diagrams, adapted for this study from Eker and Zimmermann (2016)

Characteristics	Research Design Dimension	In this Study
Group characteristics	Synchronous vs. asynchronous communication	Asynchronous
	One group vs. many groups	Many groups
Data collection characteristics	Context set by researcher vs. participants	Researcher
	Data collected by researcher or not	Researcher
Coder characteristics	One coder vs. many coders	One
	Coder engaged in data collection	Yes

Regarding group characteristics, asynchronous data collection in individual interviews (or sometimes pairs) in this study allowed participants to speak freely about their perceptions of indicators. Given the concern that indicators do not directly influence policy and decision-making described in the academic literature, it was important that indicator producers and users could share their experience freely, without risk of offending other research participants. The asynchronous method required the researcher to merge together the individual participants' mental models into a comprehensive group mental model. Mental models for the two main study participant groups (indicator producers and users) were not merged in cases where these groups did not share the same mental model. When analysing data from different groups the researcher kept a note of whether cause and effect relations were shared across the two groups. Similarly to Eker and Zimmermann's (2016) model development, the interview participants described "interconnecting areas, giving us a much broader picture than one interviewee could provide" (p.4). The researcher recorded diverse views across interview participants groups throughout the coding and modelling process. Aspects of the model which were not shared by both groups were represented distinctly (through colour coding in the final model). There was one case in which interview data from the same participant group (indicator producers) provided conflicting accounts of one cause and effect relation. This involved one participant who felt that quantification of urban health impacts did not improve wider knowledge of urban health, which contradicted most other producers (and users). Therefore the perspective held by the majority was used in the model.

In terms of the data collection characteristics, the context was set by the researcher during the introduction of the research project (information sheet and consent form) and pre-prepared interview questions. However, the researcher allowed interview discussions to change course and follow the direction of participants so as to avoid exerting too much control over data generation (Turner et al., 2013). The researcher's engagement in data collection increased the necessary understanding of the context in which the data were situated.

Regarding the coder characteristics, the researcher built on the knowledge gained through conducting interviews to code the data, which facilitated a more streamlined approach than may have been achieved through the involvement of multiple researchers in the coding stage. Only the researcher was involved in coding data. This increased the coder's ability to draw on the context and meaning of the interviews to develop generic variable names (Turner et al., 2013). The coder's interpretation of qualitative data was documented throughout the thematic analysis and causal mapping process to "maintain objectivity" as much as possible (ibid, p.258). The thematic analysis process was documented in the previous chapter and the causal mapping process is documented below.

7.2.2 Coding approach

As Eker and Zimmermann (2016) and Kim and Anderson (2012) used grounded theory, their description of the relation between coding stages and causal mapping inputs and outputs vary to the process used in this study. Table 7-2 is adapted from those two studies and summarises the coding approach related to the thematic analysis tools, inputs and outputs. The six stages of thematic analysis (Braun and Clarke, 2006) are numbered in the second column in relation to their description in chapter six. Although the coding processes in grounded theory and thematic analysis are different, both can serve as inputs to causal mapping, as established in chapter three. In this study, the initial stage of coding was used to identify key variables. Causal relations were noted during the data familiarisation process and during generation of mind maps using codes. However, these were not formally recorded in a chart, as in Kim and Anderson (2012), or coding tree of hierarchical relations, as in Eker and Zimmermann (2016) until all of the themes were fully identified and described in the thematic analysis.

Table 7-2 Summary of the coding and model development approach, adapted from Eker and Zimmermann (2016, p.5) and Kim and Anderson (2012, p.316) numbers in column two relate to phases of thematic analysis

Description of the Process	**Main tool and/or thematic analysis stages**	**Input**	**Output**
1. Identifying concepts and discovering themes in the data	Generating initial codes across the data set (2) and searching for themes (3)	Raw data	A list of codes, mind maps of initial themes composed of codes and a matrix relating codes and themes (in Excel)
2. Determining themes and related variables across themes	Searching for themes (3), reviewing themes (4) and defining and naming themes (5)	The list of codes, mind maps of initial themes and the matrix relating codes and themes	A list of codes with example quotes from both indicator producers and users, linked to themes (in Excel)
3. Identifying causal relationships between variables and themes	Causal links	The list of codes with example quotes	Chart of cause & effect relations from each code, with new variable names and polarity (in Excel)
4. Transforming the word-and-arrow diagrams into causal maps	Causal maps	Chart of cause & effect relations with new variable names	Causal maps linked to original text through cause & effect chart

The outputs in Table 7-2 are linked to outputs in Eker and Zimmermann (2016) and Kim and Anderson (2012). For example, one output of step two in this study is a list of themes with corresponding codes and example quotes from the interview data. This links to the coding tree developed by Eker and Zimmermann (2016). The relations among codes are not necessarily causal, but they are contained within the parent theme. The output in step three is an Excel cause and effect chart describing causal relations and polarity between variables within each theme (Table 7-3). This aligns with the word-and-arrow diagrams used by Kim and Anderson (2012), but uses Excel to connect the chart to the earlier list of codes with example quotes. The final output is a causal map which links back to the original data through the trail of word-and-arrow diagrams and the list of variables with example quotes.

Table 7-3 Excerpt from cause and effect chart (output of step three in the coding process)

ID	Theme	Code	Indicator producer example quote	Indicator user example quote	Consistent view	Cause	Effect	Pos/ Neg	Producer/ user/both
9	Advocacy through relationships	Disadvantaged communities	"...relationships need to be there between people who know the world of health and health evidence, and can bring that authoritative and moral power to health, and people who are struggling for basic needs…"		N	Relationship between health experts and disadvantaged communities	Advocacy effectiveness of community groups	Pos	Producer
36	Re-framing knowledge to change norms	Knowledge basis	"...we have helped move the [healthy cities movement] agenda forward because we have quantified. I really do feel like that. I really do feel that they had the theory, and we've helped and it's not an either/or."	"...planners are meant to know about a lot of issues but aren't the specialist in anything... With health indicators, they obviously come from a public health background, many of them, and it really helps us as planners…to understand the severity of a problem…	Y	Quantifying urban health in UHI tools	Perceived authority of health evidence	Pos	Both

7.2.3 Iterative model development

The model was developed iteratively, following guidance from Sterman (2000) which states that modellers will have to 'redraw your diagrams, often many times, to find the best layout' (p.153). Iterative development was required for two reasons. First, all of the relations were initially mapped in the same diagram, which is not recommended by Sterman (ibid), but was valuable to initially see connections across the full diagram. Second, the initial number of cause and effect relations identified in the coding process did not meet the criteria in Sterman (ibid) about choosing the right level of aggregation. For example, the initial causal loop diagram contained 115 unique variables and 172 unique cause and effect links. To ensure that the right level of detail was presented in the preliminary model to workshop participants, the researcher went through an iterative process of combining overlapping variables and re-drawing sections of the model to increase clarity.

During the iterative model development process the researcher kept track of the cause and effect relations that were described by different study participants (producers, users or both). The initial coding process resulted in a largely consistent view across stakeholder groups. Out of the 172 unique cause and effect relations described, 110 (63.9%) were consistent (held across both groups), 39 (22.7%) were held only by producers, and 23 (13.4%) were held only by users. These differently held views were represented in the CLDs by coloured arrows: blue for consistently viewed relations, orange for producer-only relations, and green for user-only relations. As variables and interconnections were reduced in the iterative modelling process, the final high-level model does not show coloured arrows to represent divergent views. However, the more detailed views of the model retain this differentiation.

There were four key stages of model development (shown fully in Appendix A3.1). These involved the researcher working on her own to develop the model and in the final stage responding to feedback from experts at a system dynamics seminar and PhD supervisors. In the first stage, the cause and effect relations were mapped resulting in a model with 115 variables, but only one feedback loop. The reinforcing feedback connected 'Community involvement in UHI tool' with 'Community needs met by built environment policies'.

In the second stage of model development, four sub-sectors of the model were separately developed from the full model, using selections of variables and arrows from the full model. Working with small sections of the model made it easier to see the feedback loop structure (Sterman, 2000). These sub-sectors related to themes or stories from the interview data about community involvement, inter-sectoral relationships, policy implementation problems and design of UHI tools. The researcher used her familiarity with the interview data to check whether all causal relations were fully represented in the model. In other words, the researcher reflected on whether the underlying story being described by participants was evident. Additional links between variables were added (initially marked in grey), revealing feedback structures. Where the researcher inserted goals for balancing loops, these arrows were marked in grey.

The third stage of model development involved connecting the four sub-sectors of the model. The sub-sectors contained multiple versions of the same variable, such as 'Ability to challenge business as usual' and 'Wider knowledge of urban health'. At this stage, the researcher worked to reduce duplication in the model in terms of variables and feedback relations. The model visually identified 17 reinforcing feedback loops and three balancing loops. Next the researcher reviewed the inserted grey arrows and identified interview data to support the links where possible. Following this process, there were two cases in which links between variables could not be directly supported by interview text. However, the researcher viewed these cause and effect relations as either self-evident (increased 'Production of new UHI tools' leads to increased 'Number of indicators') or plausible, but requiring testing through the workshop (decreased 'Obstruction of development projects' leads to 'Use of UHI tools based on community knowledge').

The fourth stage of model development involved significantly reducing the detail of the model by removing variables and arrows which were not seen as essential to describe the main feedback relations and interconnections. In this stage, two simplified versions of the model were created, one at a significantly higher level of detail than the other. Both models contained 2 balancing loops, with 13 and 9 reinforcing loops in the more detailed and highest-level models respectively. These versions were compared and contrasted to see which level of detail best communicated the important stories contained in the model.

Finally, the resulting two models were presented at a departmental system dynamics seminar. Feedback in the seminar led the researcher to select the highest-level version of the model to describe the full model structure, with some modifications. Selected sections of the more detailed model were separated out and in some cases more detail from the sub-sectors was re-introduced, allowing the researcher to 'zoom in' for presentation in the workshop (if prompted by participants) and the thesis. The researcher created an Excel chart of the final variables in the high-level model and causal links supported by interview data. One link inserted by the researcher required testing through the participatory workshop (high 'Obstructions of development projects' leads to high 'Use of UHI tools based on community knowledge').

7.2.4 Participatory workshop

A participatory modelling workshop was held on 16 January 2019 in San Francisco to test and refine the model with six participants involved in UHI tools (see section 7.2.4.2). In relation to system dynamics models, testing is designed to 'uncover flaws and, improve the chances your model will be used and useful' rather than proving that a model is 'right' (Sterman, 2000, p.846). In fact, Sterman argues that 'all models are wrong' and that validation and verification are therefore impossible (ibid). A causal loop diagram can be tested in relation to the system boundary, interconnections and feedback structure. Participatory modelling workshops are one method of testing models. There are additional benefits to participatory modelling, particularly with an audience of policy-makers (as set out in chapter three), such as incorporating diverse knowledge and perspectives and changing participants' mental models (Cockerill et al., 2009; Rouwette et al., 2016).

7.2.4.1 *Aims and objectives*

The aims of the participatory modelling workshop were to evaluate the overall usefulness of the model in describing the problem and test specific aspects that were uncertain or lacked consensus between indicator producers and users. Therefore, the workshop objectives were to elicit feedback on the following:

- Overall usefulness and credibility of the model as a representation of the participants' mental models regarding the use and value of UHI tools.
- Plausibility of the variables, interconnections and feedback relations, particularly in loops R1/R2 and B3/R8.
- Opportunities for interventions to improve policy implementation, community involvement and UHI tool use.

7.2.4.2 *Participants*

Interview participants included UHI tool producers, users and researchers from San Francisco. The participants were given an information sheet and consent form via email before the workshop and consented to participate. Of the 12 invited participants, six were present at the workshop (Table 7-4), of whom two were also interview participants in April 2016. Of the two interview participants, one was a producer and the other a user. Richardson and Andersen (1995) suggest that 12 is a manageable number of participants when there are five workshop facilitators (of various roles), thus a smaller number was more appropriate for one facilitator.

Table 7-4 Description of participatory modelling workshop participants

Participant description	Number
UHI tool producer	1
UHI tool user	2
UHI tool researcher	1
Experience as UHI tool producer and user	2

7.2.4.3 *Format*

The workshop format built on group modelling 'scripts', or processes, set out in the system dynamics literature (Richardson and Andersen, 1995; Andersen and Richardson, 1997; Ford and Sterman, 1998; Rouwette et al., 2016). Although there should ideally be several people leading a group modelling workshop (Richardson and Andersen, 1995), the researcher took on the roles of facilitator, knowledge elicitor, educator, modeler and recording secretary. The workshop was audio-recorded and notes from the recording were used to supplement notes taken on the day.

The workshop timings were short (2.5 hours) due to participants' constrained availability, determining the focused agenda for the session (Table 7-5). The tasks within the agenda changed frequently to ensure participants did not get stuck on a particular topic, threatening wider feedback (Andersen and Richardson, 1997). Participants were encouraged to contribute early (from the first item on the agenda) and often (Richardson and Andersen, 1995), primarily through small group discussions. The researcher explicitly recognised the diverse views and knowledge among workshop participants and explained that disagreements would be valuable to discuss (Ford and Sterman, 1998). The researcher included a short explanation of CLDs to ensure a basic level of understanding for participants (Richardson and Andersen, 1995). The model was introduced one relationship at a time (Ford and Sterman, 1998). Prior to the small group discussions, experts were encouraged to engage in the group work by imagining and visualising the use of UHI tools (ibid). Furthermore, they were invited to describe their experiences to their group to either confirm or disconfirm parts of the model (ibid). The content of the workshop focused on the high-level version of the CLD and specifically elicited feedback on uncertain areas (R1/R2 and B3/R8). Two of the more detailed 'zoom in' sections of the model were presented after participants began talking about those variables and relations in the workshop.

Table 7-5 Participatory modelling workshop agenda, facilitator's detailed copy

Schedule	Task
09:30	Participant arrival, welcome and introductions
09:45	Present: Overview of workshop purpose and research project ● Aims/objectives of workshop ● Recognition of diverse views and knowledge in the room ● Research questions ● Key findings from systematic review ● Key findings from interviews with indicator producers and users ● Q&A
10:05	Present: Introduction to causal loop diagrams: purpose, notations, case study examples
10:10	Present: Overview of high-level causal loop diagram ● Explanation of key feedback structures ● Overview of variables (as needed) ● Introduce presence of detailed sections (without explaining each section) ● Q&A
10:30	Small group discussion of causal loop diagram ● Does this model represent your view of how UHI tools are used and their value for health promotion? ● Are there any key processes missing in this model? ● Facilitator to ask participants about loops B1/R1 if time allows.
10:50	Tea and coffee break
11:00	Present: Focus on policy implementation and community involvement ● Areas of uncertainty B3/R8 ● Greater detail in both sections ● Q&A

Schedule	Task
11:10	Small group discussion about policy implementation and community involvement ● Looking at the two highlighted arrows (from 'Obstructions of development projects'), do you agree that these causal relations are possible? ● Do you think UHI tools add value as proposed in the policy implementation and community involvement loops? ● What would you change/add?
11:35	Plenary discussion and sharing between groups ● One person in each group to share the group's discussion. ● Facilitator to elicit consensus/disagreement between the groups.
11:50	Feedback and close
12:00	Lunch

The specific 'scripts' used in the workshop included the following from Anderson and Richardson (1997):

- 'Eliciting mental model-based policy stories' (p.124): Participants were asked to explain examples from their experience during the small group sessions.
- 'Direct feedback loop elicitation' (p.120): Participants were given paper copies of the high-level model and the specific loops for which feedback was elicited (B1/R1, B3/R8, B2/R7). They were invited to draw on the paper copies if they felt any variables, connections or polarities required adjustment.

7.2.4.4 *Evaluating workshop results*

The researcher listened to both sets of audio recordings (one per small group) and made notes of the discussion. The audio recordings were evaluated in conjunction with participants' notes and drawings. In reviewing this data, the researcher looked for participants' views on 1) the model usefulness and credibility, 2) plausibility of the variables, interconnections and feedback relations, and 3) opportunities for interventions to improve policy implementation, community involvement and UHI tool use.

The suggested changes to the model (both drawn on copies of the CLDs and discussed among participants) were reviewed in relation to the interview data. In cases where there were interview data to support changes, these were made to the model. This approach was taken for two reasons. First, workshop participants' views were not representative of the wider group because only two of them were involved as interview participants. The CLDs represent the interview participants' mental models and therefore any changes that diverged from the preliminary model would need to be justified by a more significant representation from the original interview participants. Second, the researcher sought to avoid adding causal links to maintain a relatively simple high-level causal model to communicate with a broad audience. As described in section 7.2.3, many causal links were removed to produce the high-level model and therefore additional links needed to illustrate important relations. Relations would be deemed important if they were represented in both the interview and workshop data.

7.3 Results

The results of the participatory modelling workshop and final causal loop diagram models (high-level and detailed 'zoom in' sections) are described below.

7.3.1 High-level causal loop diagram

The full CLD, shown in Figure 7-1, represents the combined mental models of indicator users and producers regarding the use and value of urban health indicator tools. This model represents the views of interview participants and one change from workshop participants (indicated in red). The model explains themes that arose from the interviews, highlighting the interconnectedness of actions and actors within the system which creates behaviour that is not fully recognised by all participants. It also represents feedback relations that can be explored in more detailed by 'zooming in' to certain sections of the model. This portion of the chapter describes how the model provides an explanation for the reference mode and problem statements described in chapter five. It also explains each of the balancing and reinforcing loops before zooming in to explore more detailed sections of the model.

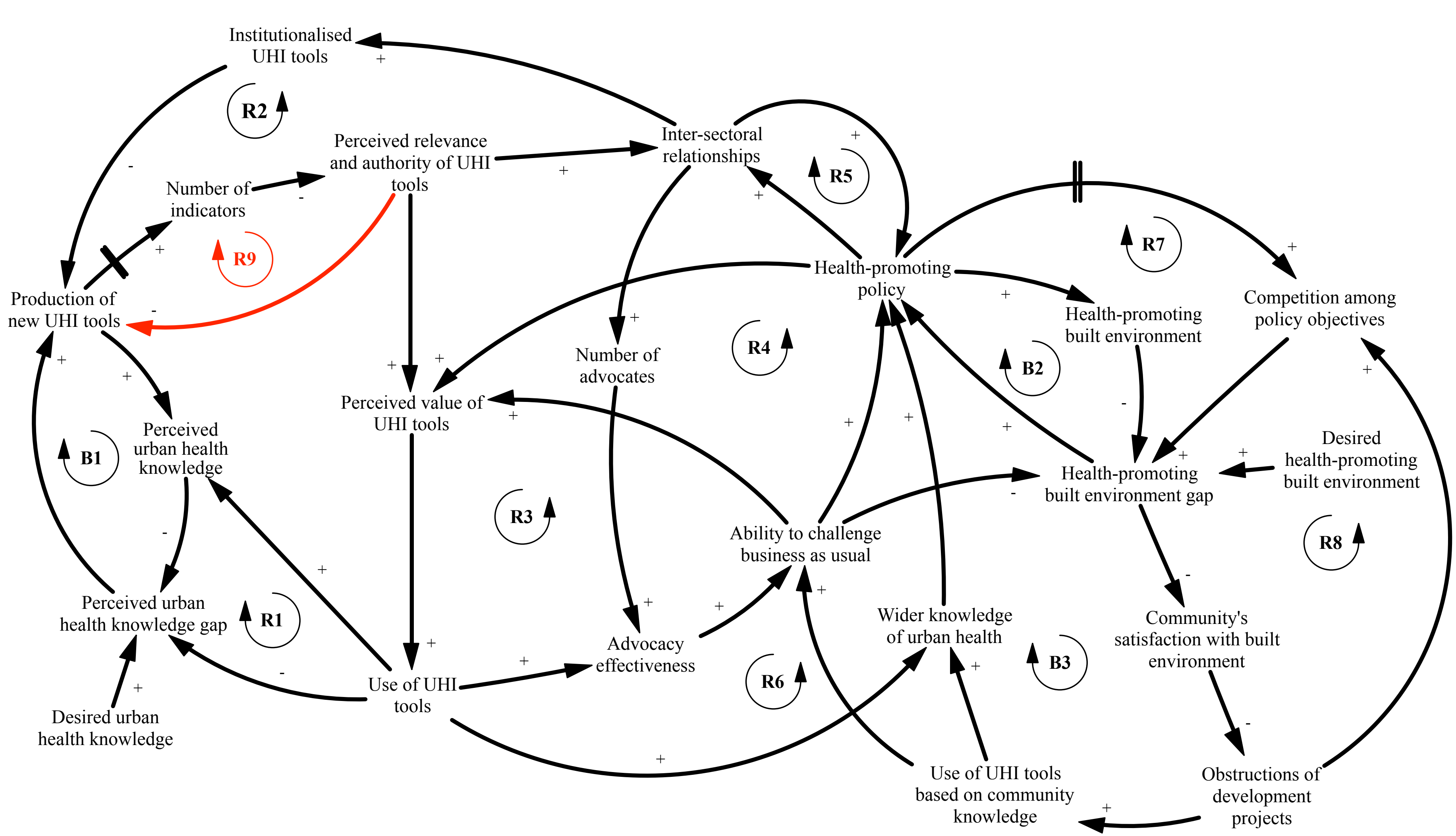

Figure 7-1 High-level causal loop diagram of UHI tool use and value, as perceived by indicator producers and users (workshop modification in red)

The variables in the model are described in Table 7-6. The descriptions summarise the meaning of the variables as interpreted from the interview text. This format is followed throughout the presentation of CLDs in section 7.3.

Table 7-6 Descriptions of the causal loop diagram variable names

Variable name	Description
Ability to challenge business as usual	The extent to which planners in policy and development management teams can challenge status quo approaches (which typically do not consider health and wellbeing impacts) to policy development or decisions taken on development projects related to health and the built environment.
Advocacy effectiveness	The level of effectiveness of urban health advocates, e.g. policy and decision-makers listen to their needs and arguments.
Community's perceived power in governance	The level at which community groups or representatives perceive that their needs are considered and addressed in policy and decisions.
Community's satisfaction with built environment	The extent to which the community is satisfied with the state of the built environment.
Competition among policy objectives	The extent to which built environment policies compete for resources to be applied in new development.
Desired health-promoting built environment	The extent to which advocates, the community and policy-makers would like the built environment to be 'health-promoting' in its design, construction and use.
Desired urban health knowledge	The extent of urban health knowledge that indicator producers believe is required to create health-promoting built environments. Includes knowledge about inequities and community-based knowledge.
Health-promoting built environment	The extent to which the built environment supports and promotes health and wellbeing through its design, construction and use. For example, there is ample green space and low air pollution.
Health-promoting built environment gap	The gap between the desired and actual health-promoting state of the built environment.
Health-promoting policy	The number of urban planning policies at any scale of government which support population health and wellbeing.
Institutionalised UHI tools	The extent to which (a) UHI tool(s) is/are regularly used and recognised within a particular institution.
Inter-sectoral relationships	The number and strength of relationships across urban government agencies and departments.

Variable name	Description
Number of advocates	The number of people or organisations which represent urban health interests in public debate and lobbying efforts.
Number of indicators	The number of single indicators available to urban planning policy and decision-makers.
Obstructions of development projects	Community groups or representatives oppose development through formal planning processes or otherwise, because the proposed development does not meet (at least some of) the community's needs.
Perceived relevance and authority of UHI tools	The extent to which urban planning policy and decision-makers perceive UHI tools to be relevant and useful for their work and credible.
Perceived urban health knowledge	The extent of knowledge about urban health that indicator producers perceive urban planners to obtain.
Perceived urban health knowledge gap	The gap between the desired extent of urban health knowledge and the perceived level of urban health knowledge.
Perceived value of UHI tools	The extent to which stakeholders (planners, politicians, the community, etc), excluding indicator producers, perceive UHI tools to be valuable for their purposes.
Production of new UHI tools	The level of creation of new UHI tools by UHI tool producers.
Use of UHI tools	The extent to which stakeholders (planners, politicians, the community, etc), excluding indicator producers, use UHI tools in their work or for other purposes.
Use of UHI tools based on community knowledge	The extent to which urban planning policy and decision-makers use UHI tools that include the community's knowledge and views about urban health in their work.
Wider knowledge of urban health	The extent to which knowledge of urban health increases. This was described as seeing new connections or seeing a problem from a different perspective rather than new knowledge as such.

7.3.1.1 *Growth of UHI tools reduces perceived relevance*

The quantitative and qualitative reference modes in chapter five described the growth of UHI tools internationally with conflicting accounts of their use and value in urban planning. The section of the model shown in Figure 7-2 represents one explanation for why the growth of new UHI tools may not be matched with a growth in their use by policy and decision-makers.

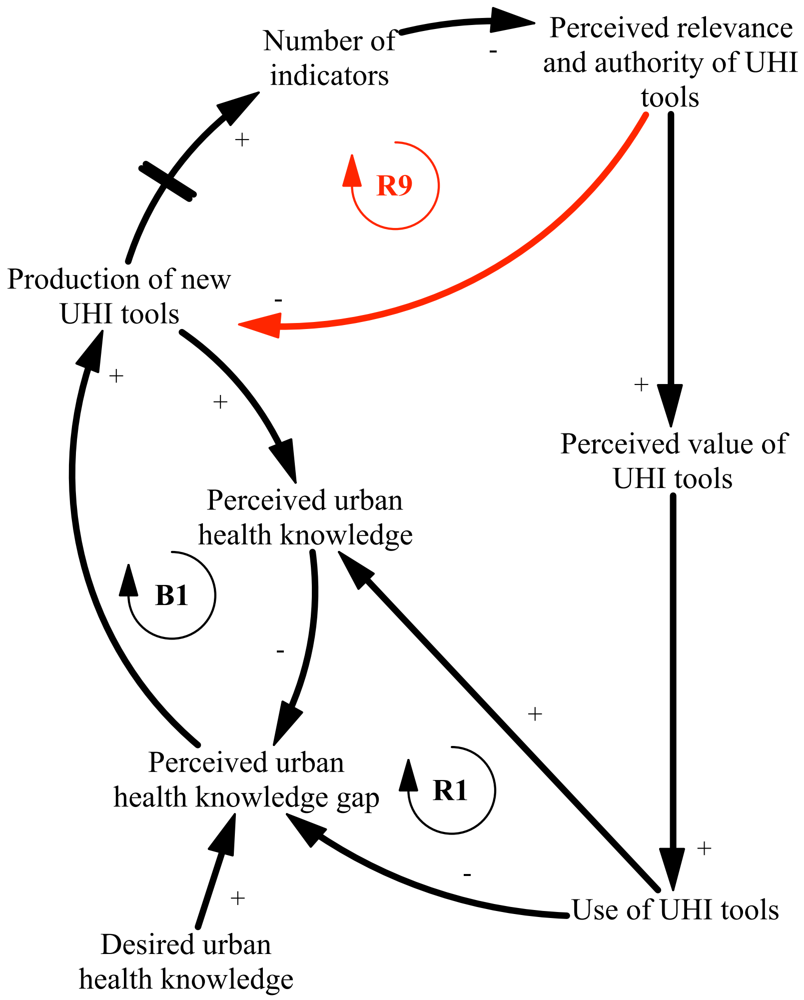

Figure 7-2 Loops B1, R1 and R9 of the causal loop diagram

Beginning with loop B1, indicator producers create new UHI tools because they believe this will fill a necessary knowledge gap for indicator users. However, loop R1 shows that the ‘Production of new UHI tools’ increases the ‘Number of indicators’ over time, which reduces the ‘Perceived relevance and authority of UHI tools’. Indicator users and producers spoke about how there are too many indicators and this creates confusion among users about where to focus their attention. For example, one indicator user said:

> *“[The UHI tool is] very comprehensive. But it's also just so much information that we almost need a level on top of that… (...) So I think having both, the breadth and the depth, but also that other set of, "Here are the key priorities," would really make it even more effective.”*

Then if the ‘Perceived relevance and authority of UHI tools’ is low, this reduces the ‘Perceived value of UHI tools’ and the ‘Use of UHI tools’. Low ‘Use of UHI tools’ then increases the ‘Perceived urban health knowledge gap’ and indicator producers continue to believe that creating more UHI tools will resolve the problem in a vicious circle. Loops

B1 and R1 are a ‘fixes that fail’ archetype, as presented in chapter five. Loop R1 shows the unintended consequences of reducing the perceived relevance of UHI tools by creating a confusingly high number of indicators.

However, there are other factors which affect the perceived relevance, value and use of UHI tools. In loop R1, when UHI tools meet indicator users’ needs (represented as ‘Perceived relevance and authority of UHI tools’ and ‘Perceived value of UHI tools’), then ‘Use of UHI tools’ would increase ‘Perceived urban health knowledge’, thereby decreasing the ‘Perceived urban health knowledge gap’. The factors which result in indicator users’ needs being met are reviewed in the following sections.

Following the workshop, loop R9 was added to this section of the model. If the ‘Perceived relevance and authority of UHI tools’ is low then indicator producers may think that the current indicators need to be improved or changed. Thus, they would increase ‘Production of new UHI tools’ which increases the ‘Number of UHI tools’ resulting in the unintended consequence of reducing the ‘Perceived relevance and authority of UHI tools’.

7.3.1.2 *Inter-sectoral relationships reinforce UHI tool use and a ‘health in all policies’ approach*

One of the principal benefits of UHI tools described in chapter six was the creation of new inter-sectoral relationships which resulted in advocacy and policy improvements. In Figure 7-3 where the ‘Perceived relevance and authority of UHI tools’ is high, this increases the number of ‘Inter-sectoral relationships’ because organisations work together to develop and use UHI tools (also see section 7.3.2.1). These inter-sectoral relationships have a number of benefits, shows in loops R2, R4 and R5.

First, increased ‘Inter-sectoral relationships’ increases the extent of ‘Institutionalised UHI tools’, which reduces the ‘Production of new UHI tools’ in loop R2. In other words, if a particular UHI tool is widely known and used throughout city agencies and departments, there is lower need for new UHI tools. Over time, this would reduce the number of new indicators being developed which increases ‘Perceived relevance and authority of UHI tools’ and ‘Inter-sectoral relationships’ in a virtuous circle. It may be the case that revisions to the institutionalised UHI tool are produced, including project-specific versions. Following around loop R1, lower ‘Production of new UHI tools’ eventually leads to increased ‘Use of UHI tools’. A more detailed section of loop R2 is shown in section 7.3.2.4.

Second, increased 'Inter-sectoral relationships' results in an increased 'Number of advocates' because more people become aware of the determinants of urban health requiring action across different city departments. This cross-sectoral approach is known as 'health in all policies', as introduced in chapter two. A greater 'Number of advocates' leads to higher 'Advocacy effectiveness' because there are more people and organisations representing similar messages. One indicator producer said: '[w]e have NGOs [non-governmental organisations] and advocacy organisations who can use this evidence to push for improvements and to challenge bad decisions on a case by case basis.' This increases the 'Ability to challenge business as usual' which is seen as a key benefit of UHI tools. The 'business as usual' approach to urban planning policy and design of the built environment was not seen by indicator producers or users as promoting health. Therefore, a change to the status quo was required to improve the built environment to promote health. Thus in loop R4 the 'Ability to challenge business as usual' increased 'Health-promoting policy' which also increased 'Inter-sectoral relationships'. This final link occurred because built environment policies related to health often involved collaboration across agencies to draft and implement such policies over a number of years.

In loop R3, 'Ability to challenge business as usual' increases the 'Perceived value of UHI tools'. For example, one indicator user stated the following benefit of a UHI tool:

> *"I also believe [the UHI tool] helps challenge the perception in the business as usual models. (...) you do need some strong evidence base to challenge that orthodoxy."*

When there is increased perceived value, this increases the 'Use of UHI tools' and 'Advocacy effectiveness', further increasing the 'Ability to challenge business as usual'.

Finally in loop R5, 'Inter-sectoral relationships' were seen as directly leading to 'Health-promoting policy' where civil servants worked across sectors to develop policies, without the need for advocates, again a 'health in all policies' approach. In some cases this was driven by political agendas. A more detailed view of loop R5 is shown in section 7.3.2.1.

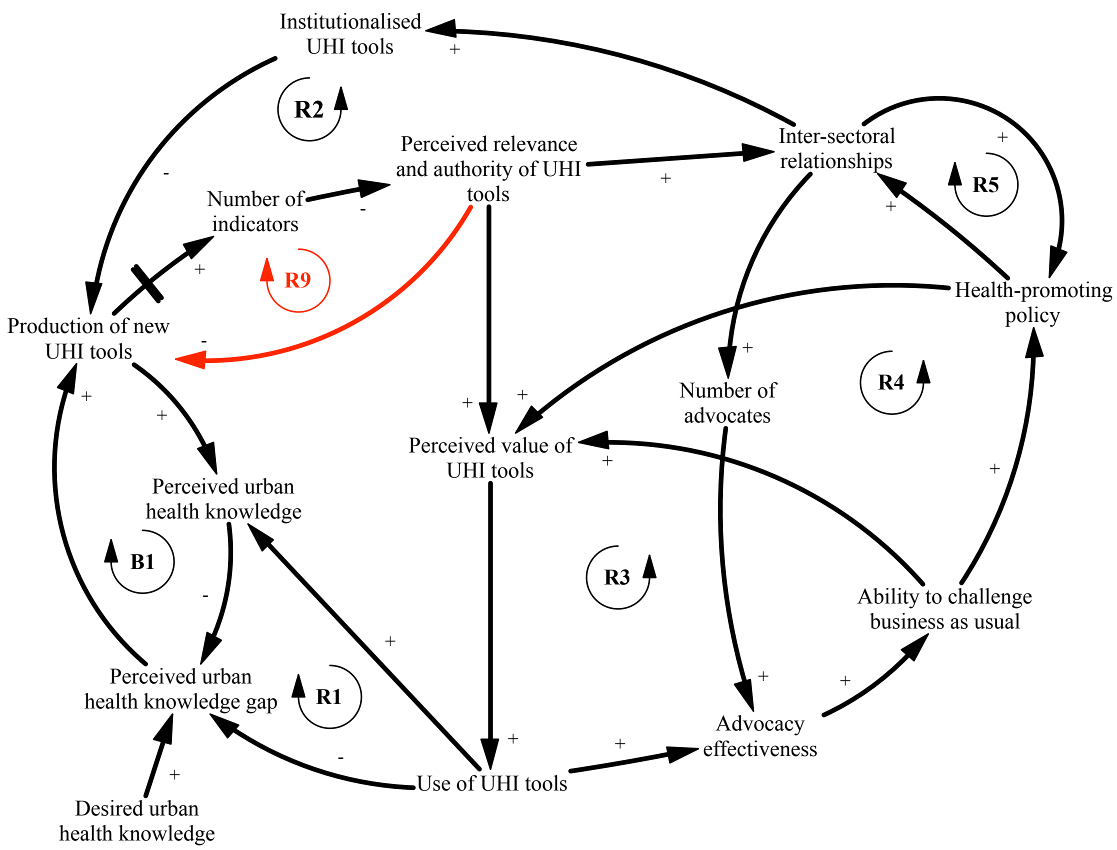

Figure 7-3 Causal loop diagrams loops B1, R1-R5, showing the impacts of inter-sectoral relationships

7.3.1.3 *Competition among policies hinders implementation*

A commonly described problem by interview participants related to the range of factors that affected policy implementation. Loops B2 and R7 (Figure 7-4) describe this challenge in feedback relations. This is a 'fixes that fail' archetype (similar to B1 and R1). In loop B2 policy-makers (including politicians and wider stakeholders involved in the policy-making process) perceive a gap between the extent to which the built environment promotes health ('Health-promoting built environment') and the level at which they desire it to be health-promoting. They create 'Health-promoting policy' to fix this problem, which does work in some cases. However, over time as 'Health-promoting policy' increases it creates more 'Competition among policy objectives'. It is widely recognised in urban planning that not all policies can be delivered on every project due to financial or other constraints. Therefore, this increased competition increases the 'Health-promoting built environment gap'. The previous section showed that, 'Health-promoting policy' is also influenced by the 'Ability to challenge business as usual'. Increased 'Ability to challenge business as usual' decreases the 'Health-promoting built environment gap', which is presented in the next section. Loops B2 and R7 are shown in more detail in 7.3.2.2.

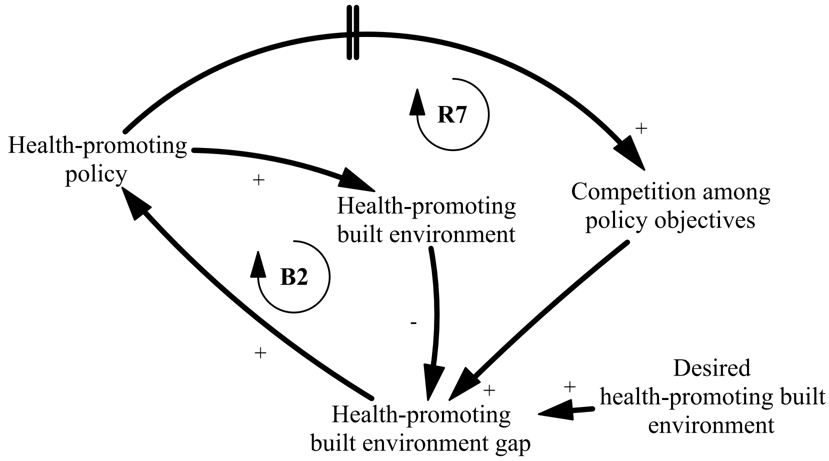

Figure 7-4 Loops B2 and R7 of the causal loop diagram relate to policy implementation

7.3.1.4 *Community involvement in UHI tools helps with policy implementation*

The effects of community involvement in UHI tools are shown in Figure 7-5. In loop B3, a high 'Health-promoting built environment gap' reduces the 'Community's satisfaction with built environment' which increases 'Obstructions of development projects'. Increased obstructions lead to increased 'Use of UHI tools based on community knowledge' by policy-makers. This could occur because policy-makers are seeking ways to address the obstruction or objection to development. It could also result from community groups lobbying with UHI tools based on their knowledge. For example, one indicator producer explained how a UHI tool based on community knowledge legitimised the community's argument which was previously ignored.

> *"[The community groups] made all the health arguments… They didn't have the evidence behind them. They made them, and they were ignored. (…) Working with that group, we found legal language that said human impacts are impacts that have to be [considered] under the law."*

Following through loop B3, higher 'Use of UHI tools based on community knowledge' increases 'Ability to challenge business as usual' which reduces the 'Health-promoting built environment gap'.

Returning to 'Obstructions of development projects', in loop R8 high obstructions increase 'Competition among policy objectives.' One example of this phenomenon relates to affordable housing. Each of the cities in the study have a shortage of affordable housing and planning policies which seek to fix this problem. Obstructions of new development are likely to exacerbate the affordability crisis. The objections to new development may be related to health impacts, such as increased pollution from traffic or lack of green space. However, affordable housing is also important for health. Increased 'Competition among policy objectives' therefore increases the 'Health-promoting built environment gap'. Conversely, if 'Obstructions of development projects' are reduced, for example by the balancing loop, B3, this will reduce 'Competition among policy objectives' and the 'Health-promoting built environment gap'.

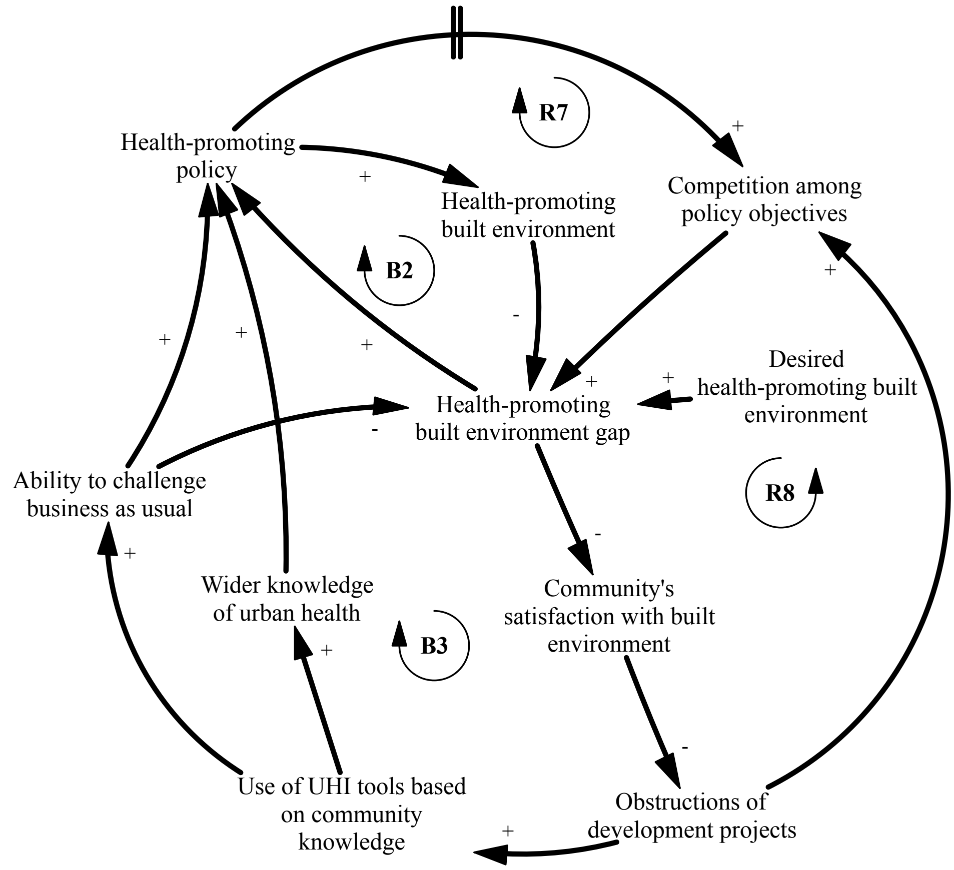

Figure 7-5 Loops B2, B3, R7 and R8 show the effect of community involvement on policy implementation

7.3.1.5 *Use of UHI tools leads to wider knowledge of urban health*

Referring back to Figure 7-1, loop R6 depicts the increased 'Wider knowledge of urban health' caused by increased 'Use of UHI tools' and 'Use of UHI tools based on community knowledge'. The 'Wider knowledge of urban health' variable relates to policy-makers seeing information about a particular place or policy issue from a different perspective, brought on by the use of the UHI tool. In chapter six this was a theme referred to as ‘Re-framing knowledge about urban health’ (section 6.6.3). This theme explained how UHI tools and indicator producers’ advocacy and relationship-building activities re-framed knowledge about urban health issues and challenged urban planning professional norms and ways of working. In the CLD, gaining this different perspective increased ‘Health-promoting policy’ as policy-makers became aware of different policy options and solutions.

7.3.2 Detailed sections of the causal loop diagram

There were several interesting feedback relations and variables influencing sections of the high-level causal loop diagram. To avoid a more detailed overview model, these were excluded from the high-level CLD. This section describes this detail through several CLDs which could be considered as sitting below sections of the higher aggregated model. The CLDs in this section show different views across indicator producers and users using coloured arrows, highlighting how mental models varied among interview participants. There are a few cases where the researcher inserted arrows which seemed plausible based on interviewee’s accounts, however there was no explicit interview text linking these variables (marked in grey), as was the case for all other connections.

7.3.2.1 *Inter-sectoral relationships*

The detailed view of inter-sectoral relationships describes how such relationships are formed and their positive impact on health-promoting policy development, which later can be seen to impact implementation (see the next section). A number of new variable names appear in the detailed sections of the CLD. These are defined in a table at the end of each section, for example see Table 7-7 in this section.

Looking at loop R5 in more detail (Figure 7-6), there are two additional reinforcing loops than appear in the high-level CLD, noted as Ra and Rb, which support ‘Inter-sectoral relationships.’ Both indicator producers and users identified the following causes: ‘Collaborative projects’, ‘Mixed professional training courses’ and ‘Stakeholder involvement in UHI tool.’ Indicator producers also noted that ‘UHI tool training’ and ‘Effort in building relationships’ produced relationships. Indicator producers often spoke of the significant time to build relationships and trust, noted through delays in the arrows leading from ‘Effort in building relationships.’

In loop Ra, both producers and users saw 'Inter-sectoral relationships' as being formed through 'Collaborative projects' and in turn, increasing 'Inter-sectoral relationships.' For example, one indicator producer said

> *"...in that process of bringing a lot of different people around the table, you just start to develop relationships, and new opportunities for collaborative projects start to emerge…"*

In loop Rb, increased 'Trust among actors' reduced 'Inter-agency tensions' from the perception of indicator producers. The researcher suggested that this may also increase 'Stakeholder involvement in UHI tool' and reduce 'Fear that health will block development'.

In the detailed view of loop R5 there are two additional variables than can be seen in the corresponding loop in the high-level CLD: 'Fear that health will block development' and 'Knowledge of others' opportunities & constraints.' Increased 'Inter-sectoral relationships' created increased 'Knowledge of others' opportunities & constraints' where actors met and spoke about each other's policy goals and strategies to achieve those goals. For example, one indicator producer said:

> *"But I do think it's helpful when we've had discussions with other city departments around these tensions, it's been good to understand where they're coming from and where we're coming from, because there's definitely an inherent misunderstanding…"*

By gaining a better understanding of the motivations and goals of other departments, actors were able to allay 'Fear that health will block development' which is the 'inherent misunderstanding' referred to in the previous quotation. Reduced fear then leads to increased 'Health-promoting policy'.

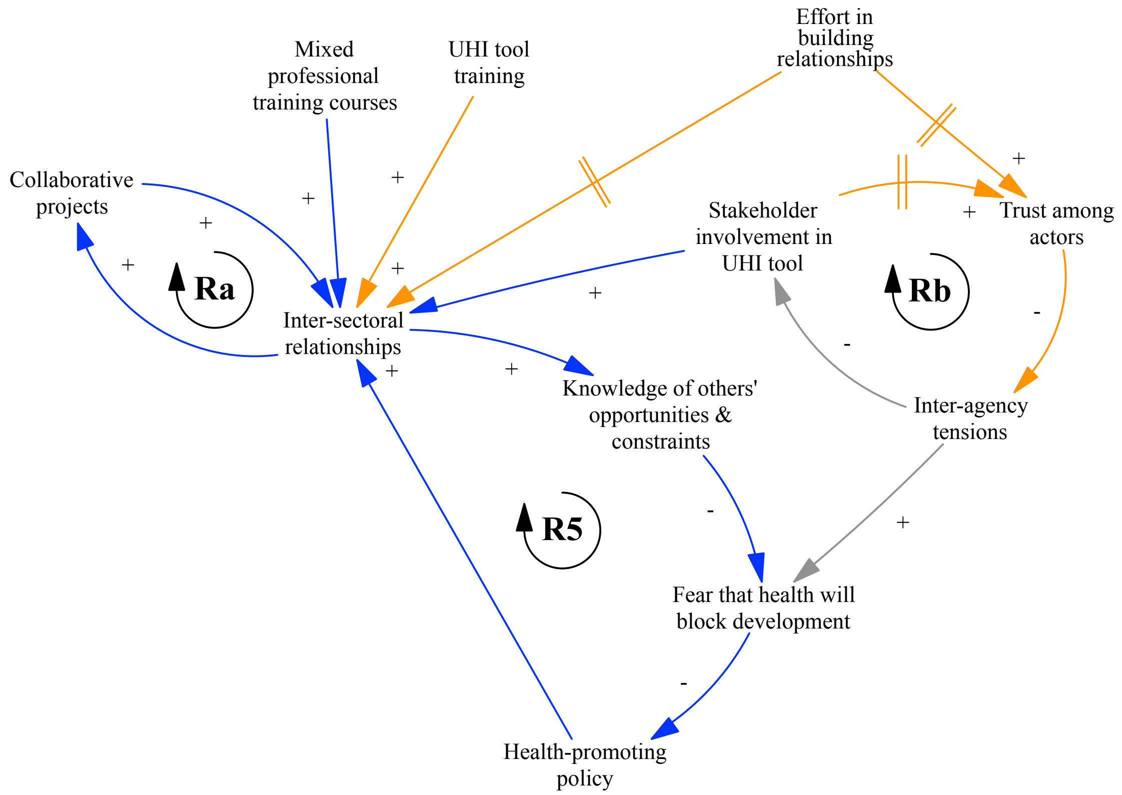

Figure 7-6 Detailed view of the causes and effects of inter-sectoral relationships not shown in the high-level CLD (Arrow colour: blue for both, orange for producers, green for users, grey for the researcher)

Table 7-7 Description of variables in Figure 7-6, excluding those previously defined

Variable name	**Description**
Collaborative projects	Research or policy projects involving health and built environment sector partners.
Effort in building relationships	The level of effort indicator producers exert to build relationships with non-health sector partners.
Fear that health will block development	The level of fear among policy-makers, politicians, developers or other stakeholders that health-related arguments (or health departments) will be used to oppose new development.
Inter-agency tensions	The level of tension between actors working across city departments and agencies.
Knowledge of others' opportunities & constraints	The extent to which actors working in different agencies/departments understand each other's policy-related opportunities and constraints.
Mixed professional training courses	Training courses related to urban health which are taught simultaneously to health and built environment university students or professionals.

Variable name	Description
Stakeholder involvement in UHI tool	Individuals beyond the health sector are involved in developing or using UHI tools, including built environment policy-makers and politicians.
Trust among actors	The level of trust between health and non-health actors across city agencies/departments.
UHI tool training	Training courses about how to use UHI tools, typically run by indicator producers.

7.3.2.2 *Policy implementation*

Looking at the policy development and implementation loops, B2 and R7, in more detail shows a number of unintended consequences or policy resistance mechanisms created by increased 'Health-promoting policy' and 'Misapplication of single indicator'. These mechanisms are shown in Figure 7-7, loops Rc, Rd and Re, and an exogenous influence. The new variables introduced in Figure 7-7 are defined in Table 7-8. The 'Misapplication of single indicator' and 'Knowledge of policy impacts' variables were also added after the participatory workshop, described later in this section.

Beginning with loop Rc, increased 'Health-promoting policy' leads to increased 'Developer's perceived cost of policy compliance' which reduces the 'Margin of development cost paid to impact fee'. This increases the 'Competition among policy objectives' resulting in an increased 'Health-promoting built environment gap'. One example of this from an indicator user was described as:

> *"And so they endorse [the policy], and then in the implementation, it becomes clear that it has a significant impact on affordability… And so the politicians pull back, and they expand the urban growth boundary, or they change, or they rezone, or they reduce the requirements for whatever, or they build in green wedges, or all of that stuff."*

Loop Rd shows that higher 'Developer's perceived cost of policy compliance' leads to higher 'Price of new property' which reduces the 'Affordable housing stock' and again, increases the 'Health-promoting built environment gap'.

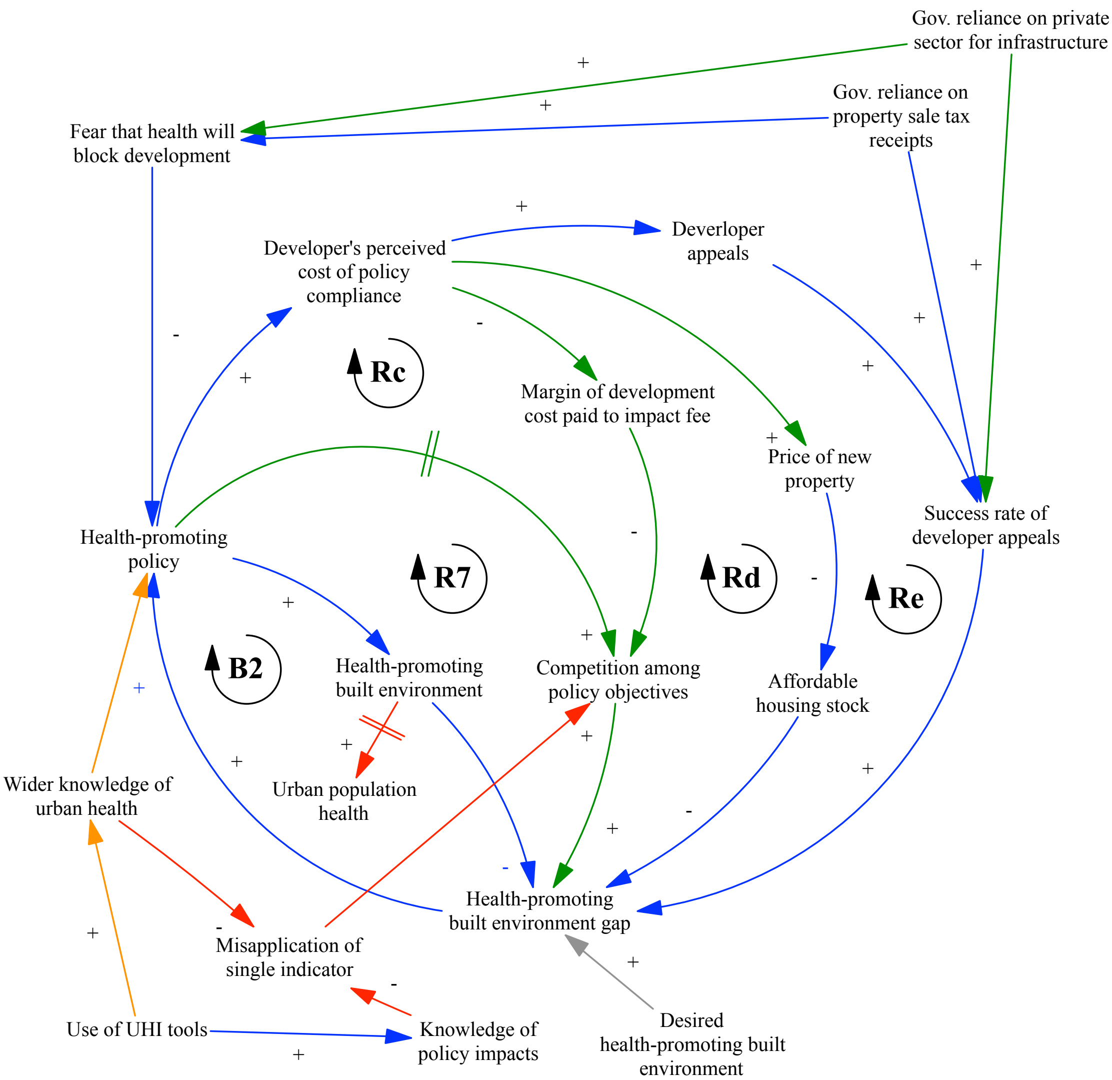

Figure 7-7 Detailed view of the unintended consequences and policy resistance mechanisms caused by health-promoting policy not shown in the high-level CLD (Arrow colour: blue for both, orange for producers, green for users, grey for the researcher and red for workshop participants)

In loop Re, the increased 'Developer's perceived cost of policy compliance' causes an increase in 'Developer appeals' which increases the 'Success rate of developer appeals', further increasing the 'Health-promoting built environment gap'. There are two exogenous variables which impact the 'Success rate of developer appeals' and the 'Fear that health will block development'. These relate to the governments reliance on both private sector developers for infrastructure and tax receipts from property. One indicator producer described the reliance on tax receipts from property as: 'We have an economy that's addicted to the growing population as a way to fund stuff, because people move here, they buy properties, the government collects stamp duty, and taxes, which then go to ... It's a Ponzi scheme, really.' Both indicator producers and users described government support of development as being detrimental to implementing health-promoting policies. In loop Re this is represented through the links from government reliance on tax receipts and the private sector to 'Success rate of developer appeals.

In this detailed CLD several exogenous variables increase 'Competition among policy objectives'. Low levels of 'Wider knowledge of urban health' and 'Knowledge of policy impact' could lead to 'Misapplication of single indicator', resulting in the unintended consequence of increased 'Competition among policy objectives'. These three exogenous variables (and some of their causes and effects) were added after the participatory workshop. The causal links and the two new variables are supported by the interview data where an indicator producer recounted that inappropriately devised indicators could "drive bad behaviour" or otherwise produce unintended consequences. Examples were given in relation to policies to control density and urban sprawl. In the workshop, participants emphasised that unintended consequences did not necessarily happen because the indicators were flawed, rather they were applied in an uninformed way (e.g. low 'Wider knowledge of urban health') to policy and decision-making, particularly by politicians who took a single issue out of context. This was consistent with the interview data example above in which the participant described how politicians were dismayed when targets to control density and urban sprawl failed. A poorly formed indicator created an unintended consequence because "the policy basis hasn't been carefully enough thought through", according to the participant. To capture this causal relation, the 'Knowledge of policy impacts' variable was inserted, which decreases 'Misapplication of single indicator'). This variable was in an earlier version of the model and it was called 'Knowledge of policy effectiveness'.

The wider role of indicators in this detailed view is shown through 'Use of UHI tools' which increases 'Knowledge of policy impacts' and 'Wider knowledge of urban health' (thus reducing 'Misapplication of single indicator'). Returning to Figure 7-1, it is also evident that the 'Ability to challenge business as usual' (in loops R3, R4 and B3) is a counter-mechanism to the implementation problems in R7, Rc, Rd and Re. Interview participants described how indicators were used to negotiate with developers about impact fees and other policy implementation matters.

Table 7-8 Description of variables in Figure 7-7, excluding those previously defined

Variable name	Description
Affordable housing stock	The number of homes which meet the definition of 'affordable housing'. This varies locally and may be calculated by a percentage reduction from the market rate or a portion of average incomes.
Competition among policy objectives	The extent to which policies within local urban planning policy documents cannot all be delivered in new development.
Developer appeals	The number of appeals against planning policy requirements or decisions filed by developers.
Developer's perceived cost of policy compliance	The amount of money which developers perceive is required to build development in compliance with planning policies.
Gov. reliance on property sale tax receipts	The extent to which any tier of government depends on tax receipts from property sales for a significant portion of its income.
Gov. reliance on private sector for infrastructure	The extent to which any tier of government depends on the private sector to (at least partly) finance and construct new infrastructure, including housing.
Knowledge of policy impacts	The level of knowledge about the various potential impacts of urban planning policies
Margin of development cost paid to impact fee	The percentage of the overall cost of new development which is paid to local government as an impact fee. Impact fees are used by government to pay for local infrastructure and amenities, which may include parks, schools and healthcare facilities. The amount of impact fee is set through local policy, but this is often negotiated for each project.
Misapplication of single indicator	The extent to which a single indicator is used to drive policy or decision-making that is inconsistent with the original intention of the indicator or otherwise results in unintended consequences.
Price of new property	The price of new property determined by a developer. This is set at a point which the developer calculates will result in a particular portion of profit, taking into account uncertainties in the process.
Success rate of developer appeals	The rate at which appeals (against policy requirements or decisions) are decided in favour of the developer.
Urban population health	The extent to which the urban population is healthy.

7.3.2.3 *Community involvement*

The community's involvement in urban governance and UHI tools impacts the level to which the built environment promotes health and wellbeing. Figure 7-8 shows the detailed view beneath loops B3 and R8, which also affect B2 and R7. Two additional feedback loops are evident, Rf and Ba. Table 7-9 defines the additional variables in this causal loop diagram.

In this detailed view, loop B3 contains two additional explanatory variables, one of which is viewed differently by indicator producers and users. The connections at the bottom of the diagram show that when there are higher 'Obstructions of development projects' this increases the 'Value of community knowledge in planning' and indicator users see this as increasing the 'Use of UHI tools based on community knowledge'. Indicator producers view higher 'Obstructions of development projects' as directly increasing the 'Use of UHI tools based on community knowledge'. In both cases this increases the 'Awareness of the community's unmet needs' which is used to challenge business as usual.

Loop Rf shows how 'Community involvement in UHI tool' increases the 'Community capacity to engage in urban governance' which increases the 'Community's perceived power in urban governance'. The researcher inserted an additional link to close this loop so that involvement in UHI tools is a positively reinforcing activity for the 'Community's perceived power in urban governance'.

Loop Ba explains that higher 'Community's perceived power in urban governance' leads to higher 'Community's satisfaction with built environment', again proposed by the researcher.

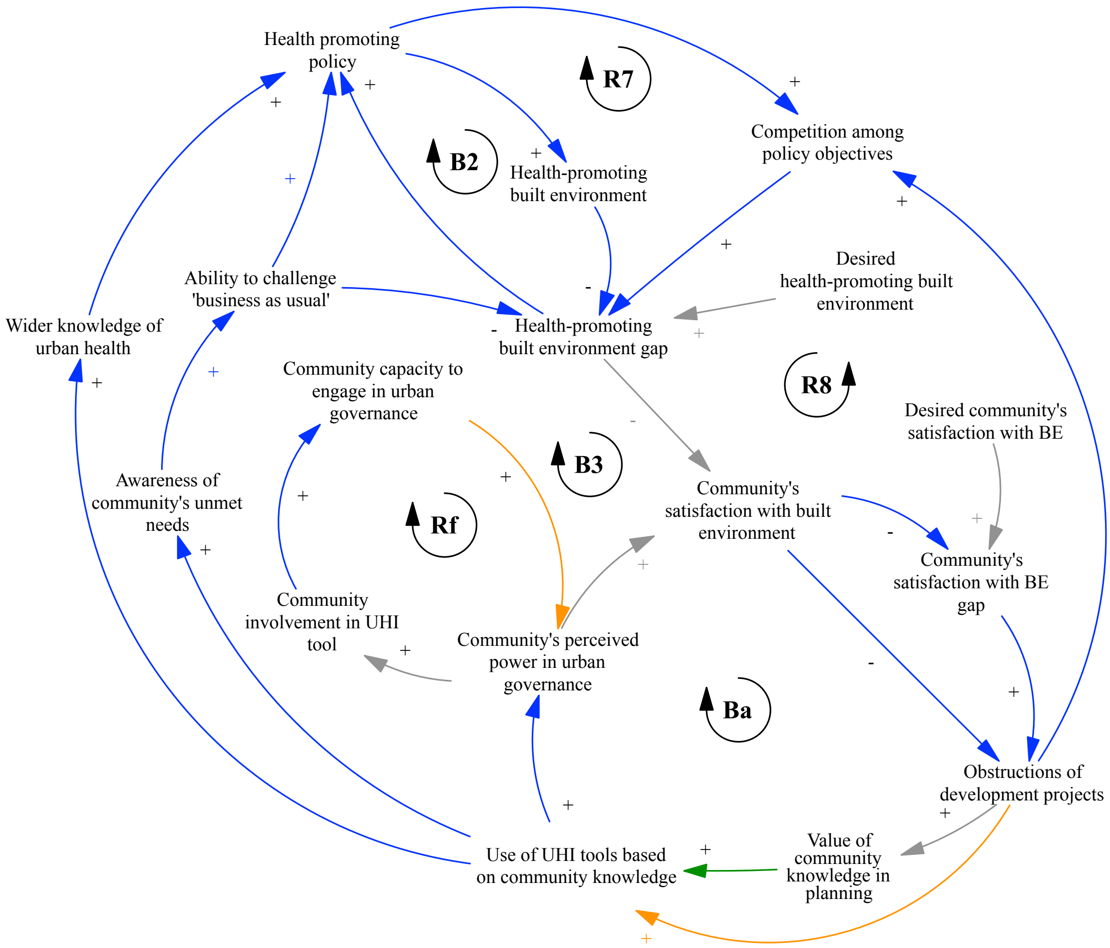

Figure 7-8 Detailed view of the causes and effects of the community's role in governance (Arrow colour: blue for both, orange for producers, green for users, grey for the researcher. BE: Built environment)

Table 7-9 Description of variables in Figure 7-8, excluding those previously defined

Variable name	Description
Awareness of community's unmet needs	The level of policy and decision-makers' awareness of the community's needs which are not currently met by the built environment, e.g. access to green space.
Community capacity to engage in urban governance	The extent to which the community has the knowledge and time to participate in urban governance such as co-development of policy.
Community involvement in UHI tool	The extent to which the community engages in the development and/or application of a UHI tool.
Community's perceived power in governance	The extent to which community groups or representatives feel that their needs are considered and addressed in policy and decisions.

Variable name	Description
Community's satisfaction with BE gap	The gap between the desired and current extent to which community groups or representatives feel that their needs are considered and addressed in policy and decisions.
Desired community's satisfaction with BE	The level at which community groups or representatives feel that their needs should be considered and addressed in policy and decisions.
Value of community knowledge in planning	The extent to which policy and decision-makers value using the community's knowledge in planning activities.

7.3.2.4 *Stability of UHI tools*

The stability, or fragility, of UHI tools is determined by a number of factors which do not appear in the high-level CLD. Figure 7-9 shows the feedback relations among UHI tools and urban actors (with new variables described in Table 7-10).

The role of politicians is highlighted in this detailed view. Loop R2 shows that when 'Politicians' agenda aligns with urban health' is higher, it positively influences both 'Stability of UHI tools' and 'Inter-sectoral relationships', which in turn reduce the 'Production of new UHI tools' (in loops Ri and Rj/R2 respectively), eventually increasing the 'Perceived relevance and influence of UHI tools.' For example, an indicator user said:

> *"And the simplification is really helpful for political action...when you have those very clear benchmarks, it gives something for everyone to work towards, and [that's] a very good example because it has inspired a lot of inter-agency work and all of that."*

The politicians' agenda can be more aligned with urban health if 'Performance in UHI tool' is higher. Conversely, if performance is lower 'Political fear of accountability' is increased, reducing the 'Stability of UHI tools'.

The stability of UHI tools is influenced by organisational memory. Indicator users referred to the difficulty within their organisation of keeping attention on such tools. One user said: "I suppose the metrics help, but the problem that I see is short term memory of these things."

In loop Rh, only indicator producers identified the value of inter-sectoral relationships to increase resources for UHI tools. However both groups recognised the importance of resources for 'Stability of UHI tools' which increased 'Institutionalised UHI tools' and further increased 'Inter-sectoral relationships'.

Following workshop participants' feedback, the variable 'Culture of health-promotion' was noted as an effect of increased 'Institutionalised UHI tools'.

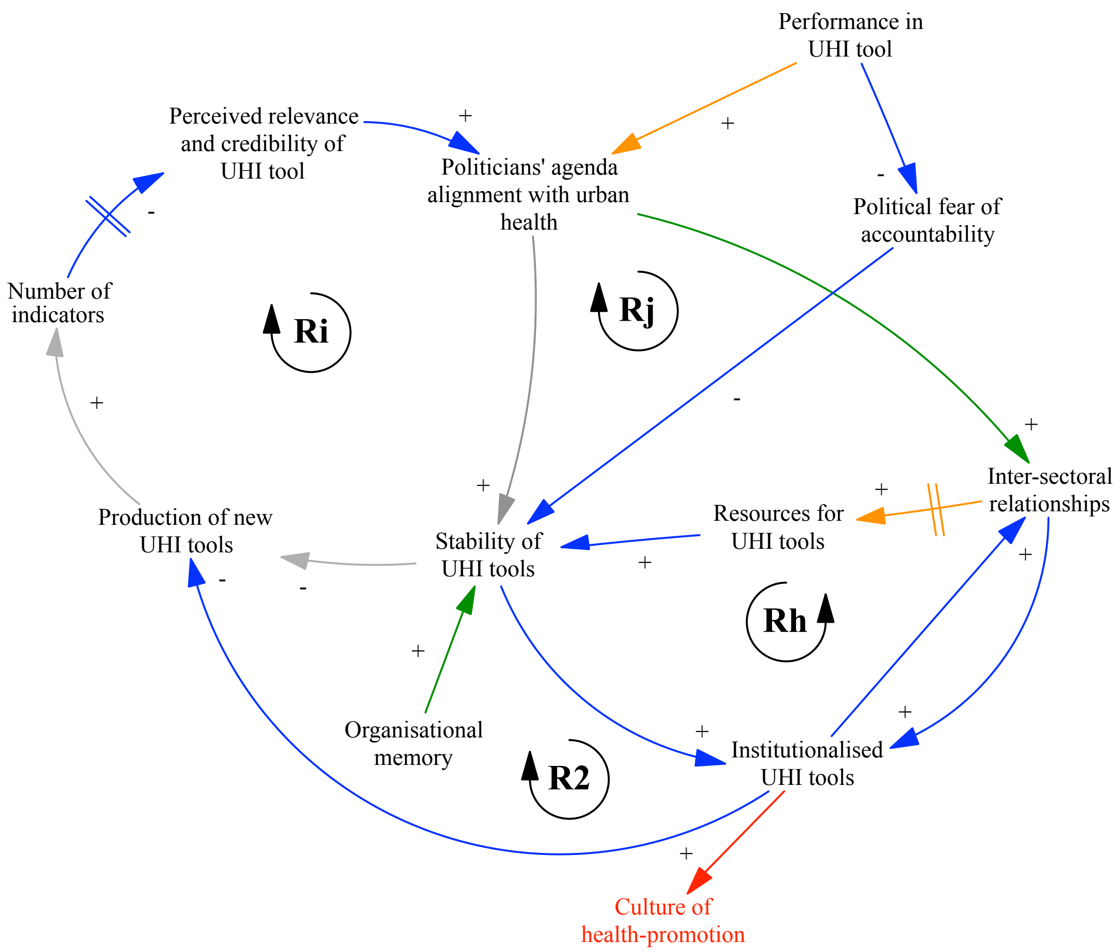

Figure 7-9 Detailed view of the causes and effects of the stability of UHI tools (Arrow colour: blue for both, orange for producers, green for users, grey for the researcher and red for workshop participants)

Table 7-10 Description of variables in Figure 7-9, excluding those previously defined

Variable name	**Description**
Culture of health-promotion	The level of culture within an organisation geared toward promoting health through policies, programmes and activities.
Organisational memory	The level of shared knowledge within an institution of previous programmes and initiatives, alongside their successes and failures.
Performance in UHI tool	The level of performance against indicators within the UHI tool (possibly compared over time, geographically or to an evidence-based threshold).

Variable name	Description
Political fear of accountability	The extent to which politicians fear having a public record of the impact of policies and decisions.
Politicians' agenda aligns with urban health	The extent to which the issues on politicians' agenda would support urban health, e.g. reducing traffic speeds.
Resources for UHI tools	The level of funding to support UHI tool data collection, publication and application.
Stability of UHI tools	The extent to which UHI tools have secure funding over time for data collection, publication and application.

7.3.2.5 *Design of UHI tool*

There were a number of characteristics that influenced 'Perceived relevance and authority of UHI tools' which were recognised differently by indicator producers and users (Figure 7-10). Table 7-11 provides a description for these characteristics. These characteristics were introduced in section 6.6.6. Indicator users identified 'Quantifying urban health in UHI tools' and 'Age of UHI tool data' as increasing and decreasing the 'Perceived relevance and authority of UHI tools'. Indicator producers found 'Spatial data presentation', 'Data presentation at multiple spatial scales', 'Problem-driven analysis of indicator data' and 'Credibility of UHI tool producers' as increasing Perceived relevance and authority of UHI tools'. And both producers and users found that 'Producers' awareness of political context', Attractiveness of data presentation' and 'Data at small spatial scales' increase 'Perceived relevance and authority of UHI tools', while 'Number of indicators' decreases the former.

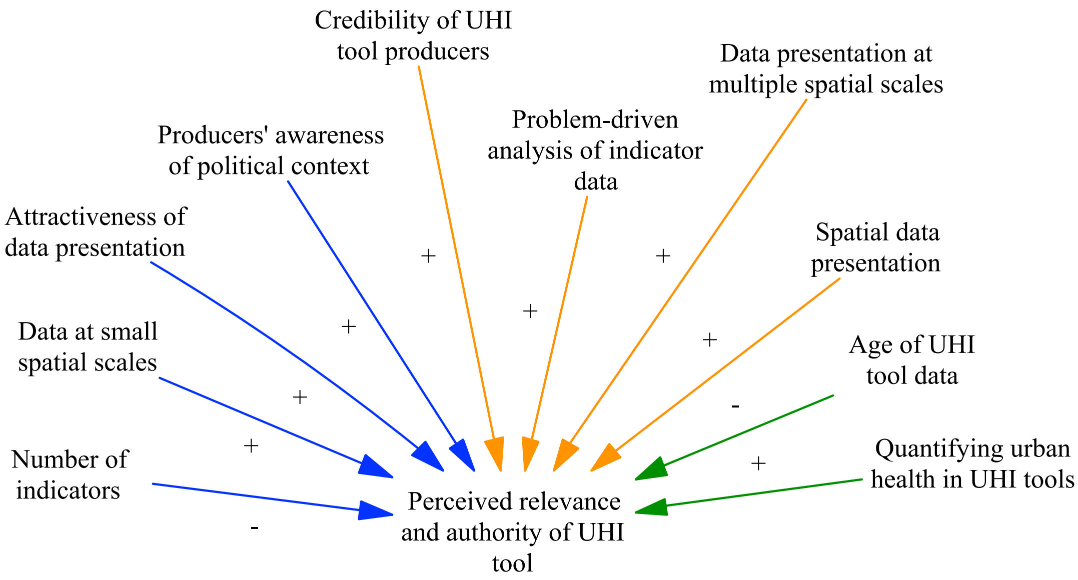

Figure 7-10 Detailed view of the causes of perceived relevance and authority of UHI tools. Arrow colour: blue for both, orange for producers, and green for users.

Table 7-11 Description of variables in Figure 7-10, excluding those previously defined

Variable name	**Description**
Age of UHI tool data	The age of data sources (high indicates more years passed since data collection) used in the UHI tool.
Attractiveness of data presentation	The level of attractiveness of data presentation in the UHI tool, e.g. displayed through easy to interpret graphs or infographics.
Credibility of UHI tool producers	The level of credibility, judged by indicator users and other actors, of UHI tool producers.
Data at small spatial scales	The extent to which UHI tool data is reported at smaller than city spatial scales, e.g. district and neighbourhood.
Data presentation at multiple spatial scales	The extent to which UHI tool data is reported at multiple data scales, e.g. state, neighbourhood and city.
Problem-driven analysis of indicator data	The extent to which indicator analysis is driven by urban health and policy problems (rather than being restricted to available data or producing indicators because data are available).
Producers' awareness of political context	The extent to which indicator producers understand the political context in which UHI tools operate.

Variable name	Description
Spatial data presentation	The extent to which UHI tool data are presented via maps.
Quantifying urban health in UHI tools	The extent to which UHI tools quantify the state of urban health and/or its determinants (as opposed to providing qualitative data about urban health).

7.3.3 Model evaluation: feedback from participatory modelling workshop

The overall impression of workshop participants was that the model was useful and it represented their general view of how UHI tools influence urban planning policy and decision-making. In particular, an indicator producer said that it was helpful to know more about how UHI tools influenced policy-making because this was not something their organisation understood well. In addition, an indicator user said that it was helpful to explore the policy implementation section of the model, specifically to identify possible interventions for improvement. There was substantial consensus about the interconnections and feedback relations within the model. Participants identified (through discussion and drawing on copies of the model) five additional causal relations; however, they were also in agreement that adding more causal links could reduce the comprehensibility of the model. There were six topics raised which participants felt were missing in the model or could be explored through further research. Summary results of the workshop are reported below with a description of how suggested changes were incorporated or left out of the final model.

7.3.3.1 *Agreement with the model structure*

There were several specific references to model structure that participants viewed as plausible and accurate. First, workshop participants said that loops B1 and R1 resonated with their experience, specifically in relation to the increased ‘Number of indicators’ decreasing the ‘Perceived relevance and authority of UHI tools’. One group referred to this phenomenon as “indicator fatigue”. The group also felt that indicators are likely to continue increasing as more research about urban health becomes available alongside increased data, further exacerbating this problem. Second, in relation to the impact of ‘Use of UHI tools based on community knowledge’ participants did agree that this variable could increase ‘Wider knowledge of urban health’ and ‘Ability to challenge business as usual'. Furthermore, they agreed that 'Wider knowledge of urban health' increased 'Health-promoting policy'. Third, participants agreed that 'Inter-sectoral relationships' and 'Advocacy effectiveness' were key outcomes of creating UHI tools.

Finally, the 'Obstructions of development projects' variable received significant attention (as directed by the facilitator) and overall participants felt that the effects of this variable were accurate. They spoke about how obstructions could either promote or detract from health depending on the proposed development. Participants questioned whether there was an implicit bias represented in the mental model that new development was bad. In the San Francisco context they reported that opposition to new development (caused by fear of gentrification) has had a very significant effect on the availability and quality of affordable housing. Participants felt that this phenomenon was represented in the model where 'Obstructions of development projects' led to increased 'Competition among policy objectives.' They could also think of examples where increased 'Community satisfaction with built environment' could lead to increased 'Obstructions of development projects' in the case of "NIMBYism" (meaning 'not in my backyard' opposition to new development in an area). Nevertheless, they agreed that low community satisfaction could also lead to obstructions.

7.3.3.2 *Suggested additional causal relations*

There were five suggested additional causal relations which were added to the model (two) or not (three) for the reasons set out below.

The following two suggestions were added to the high-level (Figure 7-1) and detailed (Figure 7-9) versions of the model respectively.

1 Participants felt that although there are many indicators available, they are not always the right indicators. Therefore, one group suggested adding a negative arrow from 'Perceived relevance and authority of UHI tools' to 'Production of new UHI tools'. Adding this arrow created feedback loop R9 (Figure 7-1). This was identified in the interview data, yet it was not included in the preliminary high-level model because there were contradictions among indicator users' perspectives, even within the views expressed by a single person. Although indicator users (interview participants) felt that having too many indicators was confusing and overwhelming, they also felt that the existing set of indicators were not necessarily the right set and therefore advocated the production of additional indicators. Given the identification of this feedback relation in both the workshop and interview data, this loop was added to the final model.

2 Workshop participants viewed the process of UHI tool institutionalisation as a key factor that led to culture shifts within organisations and wider knowledge which changed conversations and policy about urban health over time. This causal link was supported by the interview data and therefore an arrow with positive polarity was added between 'Institutionalised UHI tools' and a new variable 'Culture of health-promotion' in Figure 7-9.

Participants suggested three additions to the model that were not incorporated in the final model for the reasons set out below:

3 One participant suggested that 'Wider knowledge of urban health' among the community could decrease 'Community's satisfaction with built environment' if they gained new knowledge of detrimental environmental health effects.

4 Another participant believed that the 'Number of advocates' could increase the 'Number of indicators' because advocates might use indicators as a way to insert their cause into the policy agenda through creation of new indicators. Although both of these (numbers three and four) were viewed as possible by other participants, these causal relations were not discussed in the interview data and participants recognised that adding these arrows may decrease the comprehensibility of the high-level model.

5 One group suggested further representation of the motivations for the 'Production of new UHI tools', perhaps through a 'zoom-in section' of the model. Although the modeller agreed this would be useful, the interviews did not contain sufficient discussion of the motivation for new UHI tools. Interview participants frequently mentioned their desire to increase understanding and action to address health inequities as a reason for producing and using UHI tools. This motivation is currently encompassed in the variable 'Desired urban health knowledge' (Figure 7-1). The workshop discussion challenged the idea that UHI tools are created by urban health researchers or experts to inform policy-makers. The systematic review analysis of existing UHI tools and narrative synthesis identified that their stated purpose and motivation was often about informing policy-makers. However, some workshop participants felt that there could be underlying hidden motivations that really drove UHI tool production, such as the leaders of UHI tool producer organisations desiring to be seen as thought-leaders, raising their organisation's status to potential clients. This is an area for further research.

7.3.3.3 *Missing variables and structure*

Participants identified six factors that they viewed as missing from the model, although they recognised that the model was representative of interview participants' views and needed to balance simplicity and usefulness in the high-level CLD. Three of these factors were added to the model and three were not, as described below.

The following three accounts of missing variables and structure were added to the model in Figure 7-7:

1 Participants asked whether it was possible to include a variable on actual health outcomes within the model to indicate whether UHI tools improve health. An early iteration of the model did contain such a variable called 'Urban health' that was affected by two variables: 'Control over health-promoting policy implementation' and 'Policies informed by evidence' (neither of which were included in the final model). In keeping with the interview data, the 'Urban health' variable was re-introduced to a detailed section of the model in Figure 7-7 as 'Urban population health' with a positive polarity arrow from 'health-promoting built environment'.

2 One indicator user cautioned that the model did not show the potential danger of applying single indicators out of context. They said that this can lead to oversimplification of problems which can cause unintended consequences. In other words, if policy-makers get very fixated on a particular indicator they may ignore the other factors that impact that issue, resulting in poor policies or decisions. The researcher considered this view in relation to the interview data which contained another account of this phenomenon regarding residential density and urban growth boundary (to prevent urban sprawl) indicators. Structure was therefore added to a detailed CLD (Figure 7-7) in the form of two additional variables 'Misapplication of single indicator' and 'Knowledge of policy impact', with links to existing variables from the high-level CLD 'Wider knowledge of urban health' and 'Use of UHI tools', as described in section 7.3.2.2.

3 One indicator producer felt that the different potential uses of UHI tools, such as baseline assessment or policy-monitoring, were not represented in the model. Early versions of the model contained variables such as 'Monitoring of urban health' and

‘Knowledge of policy effectiveness’. During the iterative modelling process the former was combined into the latter. The latter appeared in early versions of the model as an effect of ‘Use of UHI tools’ that led to ‘Targeted health promoting policies’ (Appendix A3.1, Figure 3). Later versions of the model removed this variable to increase clarity in the model. However, following the previously discussed topic of ‘Misapplication of single indicator’, the ‘Knowledge of policy effectiveness’ variable was reintroduced as ‘Knowledge of policy impact’.

The following three factors were not incorporated in the final version of the model:

4 There were several discussions about the actors in the model, including government, the community and developers. There was recognition of the significant power dynamics among these groups and acknowledgement that actors within these groups change over time. ‘Community’ was seen as a problematic label within the model because it was too simplistic to cover the broad set of interests represented by different community groups. In San Francisco, community representation was described as dominated by very established community groups who often opposed development and were “weaponising the data” (through UHI tools) to achieve their goal. However, the resulting impact on the affordable housing stock was detrimental to other community groups who are underrepresented in the city’s governance. In summary, one participant said: “I would love to see more about the actors themselves and a reflection of their diversity and imbalances in the agency and authority that they have in different situations.” The interview data did not describe these diverse community interests and therefore this was not possible to add to the model. This is an area for further research.

5 An indicator user said that there was far more complexity in the policy-implementation and policy-making section of the model than was currently represented in terms of political cycles and agendas. The detailed sections of the model do contain some of this detail. For example, Figure 7-9 contains variables about political agendas including ‘Politicians’ agenda alignment with urban health’ and ‘Political fear of accountability’, while Figure 7-7 includes variables about government reliance on development for sales tax receipts and financing of infrastructure. These detailed sections of the model were provided to workshop participants in the second small group discussion, however they were not described in detail. The researcher took the view that without explicit reference to missing variables no further changes were possible.

6 One of the small groups felt that new data, media and technology were changing local governance. This partly related to the ability of certain groups to "weaponise" data to achieve their aims. But it was also a wider point about governance activities occurring outside of 'official channels' through new media such as Nextdoor, a social media platform for neighbourhoods started in San Francisco ("Nextdoor," 2019). These relations could be represented through the 'Advocacy effectiveness' variable (Figure 7-1, loops R3 and R4) which increases when there is increased 'Use of UHI tools'. This causal link would be consistent with governance activities occurring outside 'official channels' as many urban actors are involved in health-promotion activities in a whole-of-society approach. However, there was an impression among workshop participants that these activities were not transparent and therefore could be problematic. The use of UHI tool data in new technology and social media is an area for further research that was not covered in the interview data.

7.4 Discussion

This chapter presented the first causal model for UHI tool influence on urban planning policy and decision-making in which UHI tools were an endogenous element in the model. The systems thinking approach has facilitated a detailed exploration of the cause and effect relations underpinning the themes outlined in chapter six. This section outlines the strengths and weaknesses of the qualitative modelling approach. Then the researcher reflects on the findings of the participatory workshop and implications for further research. The findings are fully discussed in chapter eight through the lens of the study's conceptual framework and wider literature.

7.4.1 Strengths

There are multiple strengths to this study in terms of the study design and conduct and the usefulness of the resulting model. The overall strengths of the PhD study are described in chapter eight. In relation to the causal loop diagram specifically, it is a strength that the model development process is fully documented (Sterman, 2000). The workshop with UHI tool experts provided an opportunity to test the research findings with a group of 'members of the social world who were studied' supporting Lincoln and Guba's (1985) credibility criterion (in Bryman, 2004, p.275). Furthermore, group discussions in the workshop allowed participants to 'share and compare mental models' providing an opportunity for learning and exploration of assumptions (Ford and Sterman, 1998, p.331). The workshop demonstrated that UHI tool experts in San Francisco found the model useful to explore UHI tool use. Participants highlighted a number of feedback relations that matched their experience that they had not previously considered in causal relation terms. Finally, the process of model development distinguished between interview participant groups allowing dynamics to be seen from different perspectives (and highlighting areas of consensus).

7.4.2 Limitations

There were a number of limitations in the systems thinking analysis. First, balancing the desire to provide detailed causal relations and comprehensibility of the model by policy-makers requires decisions about which feedback relations are included in the high-level model. There is uncertainty about whether the high-level CLD includes the most important feedback relations or whether these are present in the more detailed versions (or were excluded from the model entirely). The level of detail was partly confirmed as appropriate by workshop participants, however they were also unsure when adding detail to the high-level CLD would be justified. Second, the participant modelling workshop was only conducted in one of the interview settings (San Francisco) for cost and logistical reasons. Additional workshops in Melbourne and Sydney may have produced contradictory or further confirmatory findings. Third, although there is value in involving stakeholders in group model building at earlier stages (Eker and Zimmermann, 2016), this was not viewed as feasible due to stakeholders' lack of availability to attend a longer model building workshop. Fourth, having a single facilitator leading a participatory modelling workshop can create potential role conflicts or result in less critical feedback from participants (Richardson and Andersen, 1995). The researcher sought to mitigate this through the workshop design. For example, most of the conversation took place in small group discussions in which the facilitator deliberately left participants to converse among themselves (although they were being audio-recorded). Finally, the success of the workshop is partly reliant on the 'thoughts and agendas' that participants bring to the table (ibid, p.133).

Richardson (1986) outlined several limitations of causal loop diagrams which could lead to misinterpretation, although he acknowledged their value for presenting complex systems to non-expert audiences. The key limitation of CLDs is that they do not distinguish between 'information links' and 'rate-to-level' links (ibid, p.159). The latter would typically be represented in quantitative system dynamics models through stock and flow diagrams, underpinned by specific values and rates. Without this information, the polarity of arrows connecting variables within CLDs may become false, leading to false conclusions when tracing behaviour around the model. Richardson proposed new definitions for the polarity in CLDs, later adopted by Sterman (2000), where he specified that polarity links between causes and effects denote an increase or decrease 'above [or below] what it would otherwise have been' (p.139). Richardson also proposed visual techniques to distinguish links between rate-to-level connections and information links, such as straight/curved or solid/dotted lines respectively. Sterman (2000) emphasised that CLDs represent structure, not behaviour. They can only state what might happen based on the feedback structure, not what has actually happened. There is a balance to achieve between specificity and communicating the structure to non-expert audiences. In the study's model, stocks were not denoted. However, this results in unclear dynamics, for example where 'Institutionalised UHI tools' reduces 'Production of new UHI tools', thereby reducing the 'Number of indicators' (Figure 7-1, loop R2). In reality, reducing the 'Production of new UHI tools' (a flow) will not reduce the existing 'Number of UHI tools' (a stock). Yet these limitations were not seen to be problematic for the policy-maker and indicator producer audience of this model.

7.4.3 Reflections on the participatory modelling process

The participatory modelling workshop demonstrated the usefulness of the model and general agreement with the variables, interconnections and feedback relations. This was a valuable method to test the model's usefulness and the plausibility of individual elements of the model. The workshop did not identify specific interventions to improve policy implementation, community involvement or UHI tool use. However, participants provided five other suggestions that were changed in the final model, one of which related to policy implementation (i.e. 'Misapplication of single indicator'). The workshop discussion also showed a number of areas for further research, as discussed below.

The workshop discussion demonstrated the importance of further research on the community's (or communities') perspective(s) of the value and use of UHI tools. A suggestion from one workshop participant that 'Wider knowledge of urban health' among the community could decrease 'Community's satisfaction with built environment' was broadly consistent with the dynamic hypothesis in chapter five (Figure 5-3). The hypothesis was derived from the systematic review data and showed how an increase in 'Community engagement in UHI tools' led to an increase in 'Community knowledge of urban health' and finally increased 'Community concern about urban health' (which further increased community engagement). This phenomenon was not discussed in the interviews even though literature from the San Francisco Indicators Project influenced this hypothesis. This may relate to the diverse experiences of this study's interview participants compared with the individuals involved in producing the SFIP case studies, Bhatia (2014) and Farhang et al. (2008). Data regarding the causes and effects of the community's knowledge (or concern) about urban health would ideally be gathered by interviewing members of the community. As workshop participants highlighted, there are likely to be multiple views among diverse community groups, not all of which are represented in UHI tool processes and subsequently in policy and decision-making. This is more fully discussed and identified as an area for further investigation in chapters eight and nine.

The commonly stated motivation of UHI tools to inform policy and decision-makers was questioned by some workshop participants. Two participants felt that there could be underlying hidden motivations that really drove UHI tool production, such as the leaders of UHI tool producer organisations desiring to be seen as thought-leaders, raising their organisation's status to potential clients. This was described in the context of UHI tools that were produced by commercial organisations. Another perspective was provided by two interview participants (indicator producers) who described producing a set of indicators because it was a requirement of their research funder. They were sceptical about the UHI tool's potential policy impact, although this was the aim of the tool. The Pastille Consortium (2002) suggested that indicator producers use indicators as a means to further establish their role as experts. Further research could investigate the underlying motivations of indicator producers and explore whether diverse motivations affect the use and value of UHI tools.

Finally, the workshop identified concerns that some groups could use UHI tool data in a way that would disadvantage other communities. There were new data, (social) media and technology that participants viewed as changing local governance and occurring outside of 'official channels' in a way that was not transparent. This emerging challenge is an important area for further investigation.

7.5 Conclusion

The key findings from the modelling portion of the study are summarised here and fully elaborated in chapter eight. The model provides the following:

- an endogenous explanation of UHI tool influence on urban planning policy and decision-making building on similar findings from the Pastille Consortium (2002) which reject the idea that indicators are external tools that are inserted into a linear policy process;
- several explanations for the fragility (or conversely, stability) of UHI tools and their proclivity for failure to inform policy-making;
- demonstration of the importance of relationships among governance actors and UHI tool producers in relation to advocacy, policy-making and the ability to challenge status quo urban planning, which study participants generally believed was not sufficient to create healthy built environments;
- novel exploration of the causal relations resulting in policy resistance of health-promoting built environment policies and how these can be overcome through the use of UHI tools and relationships among actors;
- demonstration of the potentially powerful role of community groups in contributing to or overcoming policy implementation challenges, including through the use of UHI tools; and
- highlighting the relative importance of the 'perceived relevance and credibility of UHI tools' in determining their value without focusing exclusively on the factors that contribute to this variable, as is often done in the indicator literature.

In conclusion, this chapter presented the methods used to build a causal representation of indicator producers' and users' mental models of UHI tool use. Sterman (2000) cautions that CLDs are 'never final, but always provisional' and would need to evolve as understanding of the problem and the purpose of modelling improves (p.166). The proposed model was useful for workshop participants who identified different ways of understanding the value and use of UHI tools. The model also helped to expose areas of uncertainty for further research. The next chapter will bring together the findings from the entire study and reflect on their meaning and impact in relation to the conceptual framework and wider indicator literature.

CHAPTER 8

Discussion

8.1 Introduction

The thesis has presented how secondary data were gathered and analysed to develop new knowledge and conceptualise mental models of UHI tools use in chapters four and five. The theory of change in chapter four provided a model of the use and value of UHI tools based on the existing literature. Then chapters six and seven reported how interview data were gathered and analysed to develop themes and causal loop diagrams depicting mental models of the value and use of UHI tools. Key findings were briefly summarised at the end of the systematic review and empirical chapters. In this chapter, the key study findings are elaborated, discussed in relation to the study's conceptual framework and put into context of the wider literature. The strengths and weaknesses of the approach are also outlined.

8.2 Summary research findings

The research findings address the study's three research questions (see below), comprising nine objectives, through the collection and analysis of primary and secondary data, informed by a conceptual framework of wider research and theory. Table 8-1 summarises the key findings from chapters four to seven for each research objective set out in chapter one. The research questions are mapped across the objectives and findings in Table 8-1 and repeated (from chapter one) as follows:

1 How do UHI tools present and measure the impact of the urban environment on health, especially in relation to complexity?

2 What mental model(s) do indicator producers and users have regarding the use of UHI tools in urban planning policy and decision-making?

3 What is the potential value of UHI tools for health promotion in the planning policy and decision-making process, particularly in relation to the complexity of this process?

A key finding is that UHI tools do influence local urban planning policy and decision-making, but not typically as an 'exogenous' entity, to adopt the language of the Pastille Consortium (2002, p.12). In other words, UHI tools were not conceived separately and then inserted into local policy processes to create impact. UHI tools that had policy impact in this study were well-resourced over many years allowing them to be embedded in and responsive to local policy processes, networks and institutions. This allowed individuals to develop relationships and trust across a number of city agencies and community organisations, promoting health through HiAP and whole-of-society approaches, among other benefits. UHI tools were used to overcome a number of constraints to healthy urban planning that arose through legal, political and economic systems. They were also used to legitimise community concerns in policy terms and spur action on urban health inequities. This chapter explains the significance of these findings in relation to the conceptual framework and wider indicator literature grouped by three key arguments. The three arguments address the three research questions holistically and they were selected by grouping important findings from across the study through the lens of the conceptual framework. These arguments add new knowledge to the literature of indicators and evidence use in policy-making.

The key arguments are summarised as follows:

1 **UHI tools influence urban policy and decision-making endogenously:** Contrary to the typical portrayal of indicator use in the urban health literature, the thesis contends that UHI tools are an endogenous element of urban planning policy and decision-making and this has implications for indicator users and producers. This argument contains three sub-arguments building on findings from the Pastille Consortium (2002) and Sébastien et al. (2014) which both argued that sustainability indicators did not influence local decision-making directly; however they did influence: 1) local institutions and governance, 2) legitimisation of policy and 3) knowledge translation and negotiation. The final point reflects on the use of UHI tools to represent both scientific and community knowledge (gathered through community involvement in UHI tools) in policy processes. The thesis argues that community involvement in UHI tool development and application could result in urban planning policies and decisions that genuinely respond to diverse communities' needs. However, managing the expectations of diverse community representatives is

a significant undertaking and will require diverse skills and funding to those which are applied in the analysis of indicator data. The study findings further support claims by Innes (1998) about the important role of 'gradually embedded' information that influences policy actors' mental models (p.53). This requires researchers to reconceptualise the role of evidence and means that UHI tools can influence policy and decision-making when certain conditions are met.

2 **Stability of UHI tools and complexity in urban health and policy-making:** Drawing on the research findings and previous literature, the researcher argues that stable UHI tools (defined in section 8.4) exhibit many qualities to support urban governance actors with the complexity of urban health policy-making. Stable UHI tools are comparable to Innes and Booher's (2010) collaboratively rational processes and this helps to explain their value for addressing complexity. In addition, other characteristics of stable UHI tools support indicator users with complexity, such as: 1) allowing longitudinal assessment of how interconnected factors change over time addressing the counterintuitive and dynamic nature of the complex urban health system and 2) supporting policy-makers with the identification of unintended consequences and policy resistance as these effects emerge over time.

3 **Relative importance of UHI tool design:** The researcher confronts the claim that the collaborative process of developing indicators is more important than indicators themselves and the associated argument that indicator producers have overly focused on the design of indicators rather than their role in the policy process. The thesis argues that although there is some truth to both of these claims, research on technical indicator development is warranted for four reasons: 1) indicators may influence policy outside of collaborative processes, 2) indicator users and producers do not necessarily have the same perception about the important characteristics of indicators to influence policy, 3) scholars have identified under-represented groups in typical indicator data and 4) there may be unintended consequences of oversimplifying complex issues through indicators.

Table 8-1 Key findings mapped against research objectives, thesis chapters and research questions (RQs)

Obj.	Objective, thesis chapter and relevant RQ	Key findings
1	To create a census and taxonomy of UHI tools (Ch.4, RQ1)	● The proportion of tools with data aggregation/measurement at the neighbourhood and lower scale and presentation of data via digital interactive maps have both increased over time. ● The majority of UHI tools intend to inform policy and decision-making, yet it is unclear whether a significant number achieve this aim. ● The majority of UHI tools are evidence-based and therefore provide a potential route from research through to policy. ● There is a degree of similarity in the domains measured across UHI tool topics particularly among health and wellbeing, quality of life, and liveability. ● A taxonomy of UHI tools was proposed with five classes comprising 17 sub-classes which demonstrates the importance of considering users' needs when developing indicator tools to ensure they can be used to support built environment practitioners.
2	To understand how UHI tools are used in the policy and decision-making process, including facilitators/barriers to use (Ch.4, RQ2, RQ3)	● Both expert-led and participatory indicator projects can be underpinned by research evidence and community knowledge; providing a middle ground for debates about the opposing epistemological bases of indicators. ● The facilitators and barriers identified in the synthesis contradict the dominant view of indicator use by policy-makers as a simplistic linear process.
3	To explore the perceived impact of UHI tools on policy and decision-making (Ch.4, RQ3)	● The process of UHI tool development brings about useful outcomes for urban environment policy and decision-makers; however, this is not the only route to implementation of indicators. ● Participatory UHI tools were more effective at achieving uses and benefits that would support 'health in all policies' and 'whole-of-society' approaches to governing healthy cities. ● A theory of change of UHI tool use was presented which differentiated between expert-led and participatory indicator development approaches. The ToC provided an alternative to the typical linear model of indicator use in the literature, highlighting the range of inputs and activities that are affected by many contextual factors to produce outputs and outcomes.

Obj.	Objective, thesis chapter and relevant RQ	Key findings
4	To investigate the value of UHI tools in relation to simplifying, representing or addressing complexity for urban planning policy and decision-making (Ch.4, RQ1, RQ3)	● Complexity was recognised by UHI tool producers as a feature of both policy-making and urban health systems, among other factors. However, few producers specified how UHI tools represented or addressed the complexity of urban health. ● Some studies found that UHI tools were not effective at influencing the complex policy and decision-making process, primarily due to political and economic constraints. ● Seven characteristics of complexity in urban health systems were outlined and paired with strategies to address the complexity of both urban health and the policy and decision-making process using UHI tools. Such strategies built on the census and narrative synthesis.
5	To conceptualise a model of indicator users' and producers' mental models of the use of UHI tools & their value in relation to complex systems (Ch.5, RQ2, RQ3)	● Three dynamic hypotheses (expressed in CLDs) were proposed showing how 1) community engagement in UHI tools leads to municipal action, 2) UHI tool engagement leads to dispersed knowledge and 3) poor performance in UHI tools leads to political action.
6	To investigate the feedback relations influencing the use of UHI tools in the planning policy and decision-making process (Ch.6, RQ2)	● UHI tools were used to re-frame knowledge about urban health, although they did not necessarily result in new or expanded knowledge. Re-framing knowledge encompassed the use of indicators to see: a richer picture, interconnections across built environment exposures, new perspectives of a problem, or community perspectives. These new ways of looking at challenges also opened up different solutions. ● Indicators were used as evidence to disrupt urban economic constraints to healthy planning in negotiations with developers, policy development and determining the allocation of development impact fees. ● Indicators were used by some politicians to rally effort, focus attention or highlight inequity related to health urban planning issues. ● The planning legal system posed a barrier to healthy urban planning in some cases. Indicators were used by advocacy and lobbying groups in campaigns to change or introduce new legislation or policy. ● Indicator producers identified a number of characteristics of UHI tools which they perceived as supporting or hindering the potential influence of indicators on policy and decision-making. Supportive characteristics included: creating ownership among indicator users, building relationships with users, presenting and communicating data to match users' requirements and focusing on users' policy-making issues. Hindering characteristics included: poor data quality, too many indicators and the fragility of indicator tools.

Obj.	Objective, thesis chapter and relevant RQ	Key findings
7	To explore participants' perceptions of the value of UHI tools for health promotion in the complex policy process, and in relation to the complexity of urban health (Ch.6, RQ3)	● UHI tools were used to develop inter-sectoral relationships through which UHI tool producers spread knowledge about the wider determinants of health, resulting in cross-sectoral advocates. Relationship building also supported: building trust and credibility, supporting funding applications, creating positive relationships in the contentious planning environment, understanding other actors' constraints and opportunities and spreading ownership of UHI tools across multiple organisations. ● Equity was a core driver for producers and users. Participants used UHI tools to challenge powerful interests, tell difficult truths to politicians or community representatives, legitimise community concerns within the planning system and mitigate the impact of new development on disadvantaged communities. ● UHI tools were identified as a means to help address the complexity of urban health through: showing multiple interconnected variables and domains, identifying unintended consequences and investigating policy resistance. However, none of these benefits were without limitation and participants identified further risks associated with the inherent simplification of complex issues through production of indicators.

Obj.	Objective, thesis chapter and relevant RQ	Key findings
8	To develop a preliminary CLD of indicator users and producers' mental models of the use of UHI tools & their value in promoting health and addressing complexity (Ch.7, RQ2, RQ3)	● The high-level CLD explains UHI tool influence through their development and application as an integral part of policy and decision-making (and governance more widely) rather than positioning indicators an exogenous entity inserted into these processes. ● Inter-sectoral relationships were key to the institutionalisation and influence of UHI tools on policy and decision-making. Relationships were created through the development and application of UHI tools over long periods of time, requiring well-resourced tools and some continuity of staff. ● A number of healthy urban planning policy implementation challenges were disrupted through the use of UHI tools. This was achieved through feedback relations involving health-promoting policy, advocacy, wider knowledge of urban health, and community involvement in UHI tools. ● Community involvement in UHI tools was used to overcome policy implementation problems, in some cases by highlighting urban health inequities. Such involvement also increased community capacity to engage in urban governance, increasing the community's satisfaction with the built environment and reducing obstructions of development (if it was deemed to satisfy community needs). ● The fragility (or stability) of UHI tools and their proclivity to fail to inform policy-making was influenced by several feedback relations, including: the continual production of new indicators, their perceived relevance and credibility, politicians' agendas, organisational memory, resources, institutionalisation of UHI tools and inter-sectoral relationships. ● The mental models of indicator producers and users did not completely align, however there was a great degree of similarity across these two groups.
9	To test and further develop the preliminary CLD with indicator users and producers (Ch.7, RQ2, RQ3)	● There was strong consensus on the model structure and boundaries. Although some missing variables and structure were discussed, participants agreed that the balance of information in the high-level diagram was important to maintain (i.e. adding detail may be counterproductive). ● Two suggested additions to the high-level and detailed CLDs were supported by interview data: 1) a negative arrow from 'Perceived relevance and authority of UHI tools' to 'Production of new UHI tools' and 2) a positive arrow from 'Institutionalised UHI tools' to a 'Culture of health-promotion'. ● Participants' identification of missing variables and structure provided rich areas for future research, particularly in relation to 1) the motivation for UHI tool production, 2) power dynamics among actors, 3) the variability and representation of community needs and 4) oversimplification of complex topics.

8.3 UHI tools as endogenous factors in policy and decision-making

The systems thinking analysis resulted in a closed causal (endogenous) explanation of how UHI tools play an integral role to building and sustaining cross-sectoral relationships and knowledge sharing to influence policies and decisions. This causal model is the first of its kind (to the researcher's knowledge), although components of the model align with other research findings, strengthening its potential to be useful beyond the case studies examined in this study. The Pastille Consortium (2002) also considered indicators as integral to local governance systems, providing a basis for the language of endogenous and exogenous influence adopted in this thesis. They argued that 'indicators function **inside** the governance process they are not exogenous factors parachuted in…' (ibid, p.90). Endogenous explanations or theories use the variables within a closed causal loop diagram to account for behaviour (Sterman, 2000). Using endogenous explanations, this section shows how collaborative development and application of UHI tools helped actors: 1) work effectively across diverse institutions and governance arrangements, 2) legitimate health promotion at policy agenda and policy network levels and 3) influence policy-makers with scientific and community knowledge.

Findings from two European studies on the use of indicators by policy and decision-makers support and contextualise the arguments in this section. Both the Pastille Consortium (2002) and Policy Influence of Indicators (POINT) project (Sébastien et al., 2014) argued that sustainability indicators were not directly used in policy and decision-making, despite rhetoric from international organisations and governments which claim otherwise. The Pastille Consortium argued that indicators are not 'tools' that can be optimised to influence decision-making, but rather are integral to change within local institutions (and governance), relationships between policy actors, the legitimation of policy, and the construction and presentation of new knowledge to inform policy (ibid, p.15). Issues of power and the contested nature of urban policy were highlighted in the study's findings. The POINT project conceptualised indicators as boundary objects that can help to bridge or mediate between different policy actors, building on Jasanoff (1987) and Turnhout (2009). The POINT scholars distinguished between the *use* and *influence* of indicators and found that the latter was evident through advocacy, legitimisation (legitimisation and legitimation are used analogously in the Pastille and POINT studies) of particular policy positions, and framing worldviews and knowledge (Sébastien et al., 2014). These findings are well-aligned with the results of this study and they are considered in three sub-sections below.

8.3.1 Local institutions and governance

This study demonstrated the importance of local institutions (characterised by shared norms, values and cultures) and governance arrangements (the role of different groups in decision-making) in determining how indicators were perceived and used. The Pastille Consortium (2002) argued that understanding local institutions and governance was necessary to identify how indicators might need to be developed and used to make a difference. Similarly, the POINT study found that the design of indicators was of secondary importance to indicator producers' understanding of the 'repertoires' of indicator users, described as 'stabilised ways of thinking and acting' (van Der Meer, 1999, p.390, in Sébastien et al. 2014). This section describes how indicator producers developed an understanding of institutions and governance arrangements over time through building trusted relationships during the development and application of UHI tools. Using this new understanding, producers were able to modify their strategies to influence policy-making through UHI tool data or otherwise.

The causal model and thematic analysis showed how the development of inter-sectoral relationships helped actors to understand and bridge across diverse institutional cultures, norms and values to promote health through urban planning. Collaboratively developing and applying indicators helped producers and users understand each other's circumstances, opportunities and constraints (shown through the causal diagram in Figure 7-6). There are diverse norms, values and cultures across sectors and agencies that would impact health-related policies and activities, outlined in the conceptual framework. Furthermore, interview participants had diverse understandings of how policy-making and governance processes functioned across policy sectors (i.e. planning and public health). Building relationships across these sectors helped actors to understand or acknowledge differences and identify shared goals. In learning the institutional and governance arrangements of indicator users, producers sought to alter indicators, or the way in which indicators were communicated, to influence policy and decision-making. For example, indicator producers were surprised to encounter fear that health would be used as an argument to block economic growth or new development. Understanding this institutional view of health as a blockage of development allowed indicator producers to modify their communication and interaction with other departments to address this potential misunderstanding. Indicator users and producers were able to identify the shared goal of minimising harm to the public's health, whilst still proceeding with particular development projects. These processes likely benefited from the stability of the UHI tools in San Francisco and Melbourne. Over time, indicator producers and users developed an understanding of governance processes and tested and applied different strategies with different stakeholders and institutions to successfully influence urban planning.

8.3.2 Legitimation of policy

UHI tools were used as a means of legitimating policy positions by particular actors in the case study cities, a finding that resonates with Pastille Consortium (2002) and Sébastien et al. (2014). The Consortium (2002) summarised policy legitimation as the justification of actions, decisions and behavior within institutions to some widely agreed premises. The process of legitimation involves referencing an agreed 'norm, value or routine in order to avoid criticism and provide generalised support' for particular positions or actions in the process of policy debates (ibid, p.60). Legitimation can be used to argue for or against 'business as usual' approaches (ibid). Furthermore, they identified legitimation occurring at both policy agenda (national or international) and policy network levels (among policy actors). Similarly, Sébastien et al. (2014) found that sustainable development composite indicators were 'used politically as ammunition in the efforts of policy actors to legitimize their positions, worldviews, and visions of sustainability' (p.325). This study found multiple examples where UHI tools were employed as part of an argument to legitimate policy positions, particularly those that went against the status quo, at policy agenda and network levels.

At the policy agenda level, UHI tool producers successfully changed the discourse about sustainable development, inserting a health lens where it had not previously existed at city, state or national levels. In one case this involved advocates in multiple organisations pushing the message of the UHI tool, either using the indicators or the socio-ecological model that the UHI tool represented, to raise awareness of the impact of urban built environment policy on health, wellbeing and liveability. This occurred over a period of at least ten years, demonstrating that the stability of UHI tools may support their use in policy legitimation because the message of the UHI tool (i.e. a socio-ecological model of health determinants) becomes more accepted by policy actors over time. As Innes and

Booher (2000) said '[a]s the ideas become taken for granted they have their strongest impact on action' (p.177).

At the policy network level, the impact of inserting health into the urban planning process for specific developments was achieved through case-by-case use of the UHI tool. This involved policy actors and other stakeholders (such as community representatives) negotiating UHI tool application. There were debates about how the results of particular indicator analyses should be interpreted and translated into design requirements for new development. Community representatives relied on the perception that indicators would have an elevated status in the decision-making process in comparison to their own views, which was reinforced by the indicator producers helping them to apply indicators, exemplified by one interview participant as:

> *"That was the result of the authority of health… the power of the value of health, the currency of health, with evidence, into the political process…"*

Again, the stability of UHI tools could support this type of policy legitimation as the weight of indicators in the decision-making process could increase over time as knowledge about health and the built environment becomes embedded. However, not all stakeholders perceived health evidence as having the elevated status placed on it by some study participants. Thus, the legitimation of planning-related decisions on these grounds may change over time as actors reassess the role of health, wellbeing and liveability in wider sustainable development discourses.

8.3.3 Indicators as knowledge sharing tools

This section argues that UHI tools represent and support multi-directional sharing of diverse types of knowledge, including scientific and community knowledge. This is achieved through the development of relationships and ongoing interaction among indicator producers and users. There are two key arguments in this section. First, UHI tools are an endogenous part of local scientific knowledge translation processes, providing a different explanation to the typical models in the knowledge translation and indicator literature where indicators are inserted into policy processes. Second, inclusion of community knowledge in UHI tools could result in urban planning policies and decisions which genuinely respond to diverse communities' health and place needs and address the complexities of urban health challenges. Before arguing these points, the section provides a brief definition of the diverse knowledge claims represented by indicators.

The Pastille Consortium (2002) proposed that indicators must be considered in relation to diverse knowledge claims and their impact on the power of different groups to influence policy agendas. They outlined three classifications of knowledge claims pertaining to indicators: socially accredited (e.g. technical and scientific), experiential (e.g. local and gathered over time) and policy process/governance (i.e. how urban governance works) (ibid; p.70). Socially accredited and experiential knowledge together made up 'expert' knowledge, which typically determined the content of indicators as a way to influence local policy agendas. The Pastille Consortium's 'experiential knowledge' and Innes and Booher's (2010) 'lay knowledge' (p.5) are analogous and equally acknowledged by both sources as being: 1) essential for addressing complex sustainability challenges and 2) potentially powerful in influencing policy-makers. In this thesis, these knowledge claims have been described as community views or knowledge. Community knowledge was either embedded in UHI tools or gathered using UHI tools. In other words, indicator producers may have been involved in disseminating 'socially accredited' and/or 'experiential' knowledge (using the Pastille classification) to indicator users and other actors. This section discusses the sharing of such knowledge types in turn.

8.3.3.1 *Scientific knowledge translation*

The translation of scientific knowledge to influence policy-making did not occur in a linear manner in this study, but rather it was an iterative and embedded process in local urban governance. Indicators have been described as forms of evidence that can help translate scientific knowledge to policy-making (Davern et al., 2011, 2017). This section first summarises how evidence and indicators are understood to influence policy-making in the literature, and then builds on Innes (1998) to argue that linear knowledge translation models are insufficient to describe the influence of indicators.

According to the policy studies literature, scientific knowledge and evidence are usually conceived outside of policy systems and then brokered or disseminated into the policy process, with varying degrees of success (Cairney and Oliver, 2017). Explanations for failed translation include epistemological, disciplinary, political, and professional differences, and interactions across these categories (Smith and Joyce, 2012) and a range of 'barriers' (see Innvaer et al., 2002; Oliver et al., 2014a) identified under the assumption that evidence-based policy models are accurate (Cairney and Oliver, 2017, p.2). Policy-making is complex and irrational (Cairney, 2012b; Cairney and Oliver, 2017); yet it is widely understood as a linear process with discrete stages in which evidence is a key factor (Turner and Hulme, 1997; Hallsworth et al., 2011). Innes and Booher (2000) suggested that indicators fail to inform policy because indicator producers' lack knowledge about how evidence informs policy, which is supported by others in the indicator literature (e.g. Pastille Consortium, 2002; Decoville, 2018). In line with this view, indicators have been conceptualised as: 1) boundary objects that help bridge or translate knowledge among diverse policy actors (Turnhout, 2009; Sébastien et al., 2014) and 2) framing indicators that 'shape visions and frameworks of thought' (Sébastien et al., 2014, p.325). Vagueness about the precise nature of the knowledge represented by indicators is seen as an attribute enabling their role as boundary objects to bridge different types of policy actors (Sébastien et al., 2014). Innes (1998) rejected linear models of evidence translation and argued that as policy actors 'agree on new meanings of issues and data, their actions change, often without any moment of conscious decision' (p.53). She argued further that this conceptualisation of information in policy and decision-making is far more important than the rational instrumental model of evidence use, yet 'it is also far more difficult to isolate and describe' (ibid). The results in this thesis support Innes's claim that as information becomes 'gradually embedded' (ibid) it can have significant impacts on local policy and this is shown through the causal model in chapter seven, described below.

Inter-sectoral relationships were integral to knowledge sharing among indicator producers and users (Chapter 7, Figures 7-1 and 7-6). As opposed to traditional knowledge translation and indicator models, producers in this study created relationships with diverse governance actors to collaboratively develop and apply indicators, thereby ensuring UHI tools influenced urban policy and decision-making. Indicator producers analysed data in relation to the needs of indicator users, specifically to influence policy. This co-production and co-application approach kept indicator producers working closely with users over time, further reinforcing positive benefits of UHI tools. This also allowed information to become 'gradually embedded' to influence the mental models of urban policy-makers about wider determinants of health (Innes, 1998, p.53). The high-level CLD (Figure 7-1) showed that inter-sectoral relationships increased: the institutionalisation of UHI tools (which increased their stability, loop R2), health-promoting policy (loop R5) and the number and effectiveness of advocates (loop R4). Inter-sectoral relationships were also part of a causal chain that increased use of UHI tools and wider knowledge of urban health (R1-R6).

The dynamic and interconnected view of knowledge translation through UHI tools described above provides an additional perspective to the Pastille Consortium's (2002) 'self-reinforcing dynamic' whereby experts created indicator sets to legitimise their roles within organisations, the process of which reinforced the definition of an expert, which then further legitimised the role of the expert (ibid; p.73). This feedback relation was partially evident in the UHI tools investigated in this study, although this was less about experts' roles within organisations than their role in distributing knowledge through inter-sectoral collaboration. Inter-sectoral relationships were partially formed through ongoing communication over the use of UHI tools, typically because indicator producers had knowledge about how to interpret or analyse indicator data that was not held outside of their organisation. The limited usability or interpretability of a UHI tool had the (perhaps unintended) benefit of encouraging ongoing collaboration between indicator producers and users. This meant that relationships continued to be formed and maintained, with associated benefits for knowledge sharing. This could be seen as a similar self-reinforcing dynamic to that proposed by the Pastille Consortium, but with greater emphasis on inter-sectoral knowledge translation. The continuous nature of the knowledge exchange found in this research broadens Innes and Booher's (2000) assertion, that the process of developing and agreeing indicators is more important than the resulting indicator set, to include the collaborative process of indicator application, in line with contributions from Corburn and Cohen (2012). In summary, UHI tools did not simply deliver scientific information to users, rather they were part of governance processes in which knowledge of urban health was exchanged among diverse parties and co-produced for different purposes over time.

8.3.3.2 *Community knowledge and UHI tool influence*

The thesis argues that incorporation of experiential knowledge through community involvement in UHI tools can result in urban planning policies and decisions that respond to diverse communities' needs. However, managing the expectations of diverse community representatives is a complex undertaking and would require diverse skills and funding to that which is applied in the analysis of indicator data. It is widely established that community involvement in indicator projects can support collaborative governance models that incorporate a wide diversity of knowledge and interest (Innes and Booher, 2000; Holden, 2001, 2007, 2009; Pastille Consortium, 2002). The representation of community knowledge through UHI tools was highlighted throughout the study results. This section begins by reviewing how experiential knowledge was represented through UHI tools and how this is classified in the literature. Then the value of authentic dialogue to elicit and act on community knowledge is described and the extent to which UHI tools achieved this is considered. Finally, the benefits and challenges of including community knowledge in UHI tools are described.

There are many methods through which UHI tools may seek to reflect community knowledge and the resulting tools cannot be described dichotomously as community-driven or expert-driven (as outlined in section 4.6.5.3). The community may be directly involved in selecting indicators or they may be consulted using a pre-determined indicator set. Davern et al. (2017) state that most community indicator systems can be 'classified according to a 'bottom up' or 'top down' approach to development'; where the former are community driven and the latter are 'driven by government policy and planning officials with a lack of community involvement' (p.570). In contrast, Holden (2001) claim that many indicator projects cannot be 'described as discretely government- or citizen-led' (p.4). The UHI tools identified in the systematic review were conceptualised as being on a spectrum between expert-led and participatory approaches, in line with Holden's view. Future research could analyse the varying forms of community involvement in UHI tool development and application to explore the benefits of different models.

The communicative planning literature offers up *authentic dialogue* as a means of eliciting and using a wide range of knowledge in governance. The origins of authentic dialogue go back to Habermas (1984, 1987) who argued that because knowledge is socially constructed, debates about public action should not follow a single form of reasoning; a principle basis for his theory of communicative action (Healey, 1997). Habermas's argument is summarised by Healey as 'the appeal to science, the appeal to moral value, and the appeal to emotional response should be given an equivalent status in debate' (ibid, p.52). In support of this, Innes and Booher (2010) state that planners should engage with a wide range of actors in authentic dialogue, defined as:

- actors engage with each other on a shared task in which there is mutual recognition that claims are genuine;

- all parties have equal access to information and the ability to speak and be heard;
- participants bring experiential and scientific knowledge and jointly construct knowledge through interaction (pp.36–37).

A participatory process of indicator use could achieve authentic dialogue because it encourages integration of different types of knowledge, situated within a particular historical and geographical context (Healey, 1992). Such a process would include the views of deprived communities as these are fundamental to the development of policy that will produce 'workable and societally desirable outcomes' (Innes and Booher, 2010, p.170). Given the variation in community involvement in the UHI tools explored in this study, it is not clear that generalisations about the extent to which they achieved authentic dialogue could be made. In section 8.4, authentic dialogue is described in more detail and SFIP is proposed as the UHI tool which most closely met the conditions required to represent community interests.

Notwithstanding the potential lack of authentic dialogue in the studied UHI tools, the analysis found that community involvement led to both the inclusion of diverse knowledge and increased sense of power among participants, and these effects are interrelated. In chapter six both the 're-framing knowledge to change norms' and 'representing community interests and inequity' themes brought together multiple examples where community-informed UHI tools influenced urban planning by representing community needs. These themes were also evidenced in the results of the narrative synthesis (Chapter 4) where community involvement resulted in: 1) increased participation and sense of power in governance, 2) increased balancing of expert and lay knowledge, 3) increased negotiation and consensus building among actors and 4) promotion of HiAP and whole-of-society approaches. Finally, the causal model (Chapter 7) showed feedback relations between community involvement in UHI tools and policy implementation. Figure 7-8 showed that the 'Use of UHI tools based on community knowledge' increased the 'Community's perceived power in urban governance' with further benefits to community satisfaction and capacity to engage in urban governance (loops Ba and Rf). Increased 'Community satisfaction with the built environment' then reduced 'Obstructions of development projects', thereby reducing 'Competition among policy objectives' (loops Ba and R8), highlighting the importance of including community knowledge.

In this study, interactions between community representatives and other actors resulted in or highlighted tensions and competing interests, however this conflict may have created opportunities for debate and identification of agreeable solutions that may not have happened otherwise. Balancing conflicting knowledge claims may be an unanticipated challenges that is difficult to resolve through indicator projects. Scholars have identified multiple cases where community knowledge about health and place was contradictory to expert knowledge (e.g. Dennis et al., 2009; Lusk et al., 2019). Healey (1997) claims that greater recognition of diverse views within a community could 'lead to more informed local planning and more capacity to resist the dominatory [sic] tendencies of the abstract structures and systems associated with the economy and the state' (p.55). This Habermasian idea of pushing against system structures aligns with the theme from chapter six regarding 'disrupting problematic constraints to healthy planning' which was partially achieved through community informed UHI tools. As described in chapter three, Rydin (2007) argues that planners should distinguish between knowledge claims and other claims that actors make, such as ethical claims, and not all claims should be equally weighted. She provides a typology of planning knowledge claims and argues that planners should be involved in 'opening-up' and 'closing-down' knowledge claims through debate and testing, which may involve supporting actors who are less powerful to express their knowledge (ibid, p.58). Yet it is unclear whether indicator producers would typically have the capacity to engage in such deliberative governance activities. Holden (2001), Innes and Booher (2010), and the Pastille Consortium (2002) describe participatory indicator projects in Seattle (USA), Oakland (USA) and London (UK) respectively, where the development of indicators involved significant power dynamics among actors. A recommendation from the results of this study, supported by the wider literature, would therefore be that indicator producers should be aware of the contested landscape of urban health governance into which they attempt to insert a process of UHI tool development and consider whether they have the skills and intention to support such an undertaking.

In summary, this research argues that the multi-directional sharing and negotiating of knowledge claims across diverse actors involved in the ongoing development and application of UHI tools is a significant factor in their ability to influence policy and implementation. The causal model proposed by this thesis shows how UHI tools are shaped by people, politics and institutions over time and these interactions determine UHI tool influence on knowledge sharing, as well as, policy and decision-making and implementation. This marks a new perspective in the urban health indicator literature which has tended to focus on indicator development, assuming a linear process of knowledge translation into policy. Yet this perspective is in line with research on sustainability indicators which rejects the rational linear models of knowledge translation and urban policy-making (e.g. Innes and Booher, 2000; Pastille Consortium, 2002; Sébastien et al., 2014). Finally, there may not be a *blueprint* (Healey, 1992) or ideal way to develop UHI tools which represent community needs whilst negotiating competing knowledge claims, uneven power among actors and pre-existing tensions. Yet the collaboratively rational processes proposed by Innes and Booher (2010) provide a good guide for the conditions of success: diversity of interests, interdependence of actors and authentic dialogue (discussed in the next section).

8.4 UHI tool stability supporting the complexity of urban health policy-making

The thesis argues that the stability of UHI tools is a key characteristic underpinning their utility in supporting policy-makers to address the complexity of urban health. This section uses Innes and Booher's (2010) DIAD theory of collaborative rationality to examine the success of stable UHI tools in supporting indicator users with the complexity of urban health policy-making, for which traditional governance approaches have not been successful. Stable UHI tools achieve many of the benefits of collaboratively rational processes, although they do not necessarily meet all of its conditions. This discussion therefore identifies ways to further improve the benefits of stable UHI tools. The section briefly defines UHI tool stability and its effects before considering similarities to collaboratively rational processes.

The concept of stable UHI tools emerged from the interviews in which participants described fragile tools (characterised by losing funding, being forgotten and not being supported by politicians) and stable tools which had the financial and political support to enable long-term relationships and impact. Study participants' views were represented in Figure 7-9 which shows the causes and effects of the variable 'Stability of UHI tools' (defined in Table 7-10 as 'The extent to which UHI tools have secure funding over time for data collection, publication and application'). Figure 7-9 demonstrated that increased 'Institutionalised UHI tools' led to increased 'Inter-sectoral relationships' and 'Culture of health-promotion'. The high-level CLD in Figure 7-1 shows that 'Inter-sectoral relationships' is part of two feedback loops that increase 'Health-promoting policy' (R5 and R4). Thus the benefits of UHI tools for healthy urban governance described thus far (such as legitimation at policy agenda and network levels) partly depended on the long-term stability of UHI tools, exemplified by SFIP and CIV. In San Francisco and Victoria, actors involved in developing and using indicators shared knowledge and developed relationships over a period of at least ten years. Producers adapted their strategies to influence policy-making as they learned about other stakeholders' opportunities and constraints. Likewise, policy-makers were able to request analyses of the health-related impacts of policies and propose adjustments. These benefits align with the approaches for managing complex urban health systems (outlined in chapter two) such as: adaptive management, co-producing knowledge, participatory governance, integrated planning, and the use of monitoring systems (Corburn and Cohen, 2012; Rydin et al., 2012; Corburn, 2013, 2015; Gatzweiler et al., 2018).

The thesis contends that the use of stable UHI tools (SFIP and CIV) met most of the conditions for collaborative rationality. The DIAD theory outlines three conditions of collaboratively rational processes: diversity of interests among participants, interdependence of actors (who could not independently have their needs met), and authentic dialogue that adheres to Habermas' (1984) ideal speech conditions (Innes and Booher, 2010, p.35). Each of these conditions is considered in relation to the interview data and secondary literature for both projects below (Bhatia, 2007, 2014; Corburn and Bhatia, 2007; Farhang et al., 2008; Bhatia and Corburn, 2011; Davern et al., 2011, 2017; Lowe et al., 2015):

- **Diversity of interests** and knowledge, including both stakeholders with power and those affected by urban development, were involved and represented in the collaborative development and use of both UHI tools. However, the secondary literature showed a much more collaborative approach to indicator development in SFIP than CIV, which is why the latter was referred to as expert-led in the systematic review.
- **Interdependence of actors** was evidenced in both SFIP and CIV where decision-makers needed support from local communities to progress urban development that would promote health. The high-level CLD showed that the community and policy-makers were interdependent in achieving a health-promoting built environment (Figure 7-1, loops B2, B3, R7 and R8).

- **Authentic dialogue** could be seen as occurring through the SFIP Community Council's activities (described in Chapter 4) in which a wide range of actors jointly constructed indicators using socially accredited and experiential knowledge. Yet there were power imbalance in terms of how the resulting UHI tool was used; the planning authority and developers were reported to have used it only in-part and reluctantly (Bhatia, 2014; Farhang et al., 2008). It is less clear from the CIV literature or interviews whether authentic dialogue was part of the UHI tool production or application.

The four key results of collaborative rationality 'emerge in the dynamics of interaction' (Innes and Booher, 2010, p.37). This closely aligns to the research results where relationships among actors over time were essential to health-promoting policy development and implementation. The results of collaborative rationality are:

1. 'agents discover the reciprocal nature of their interests'
2. 'stakeholders also develop new relationships which often survive the conclusion of the collaborative process'
3. 'single loop and double loop learning emerge… as agents discover both new means to achieve their interests and come to [re-examine] and reframe the interests they previously held'
4. 'participants start to develop shared meanings…and identities' and 'they develop new heuristics' for future engagements such as 'listening, challenging assumptions, and seeking mutual gains' (ibid, pp.37–38).

Each of these results is considered briefly in relation to the study findings, demonstrating the alignment between stable UHI tool processes and collaboratively rational processes.

First, the research found that actors learned about each other's opportunities and constraints. In a collaboratively rational process this leads to actors exploring opportunities which are mutually beneficial. In the case studies, public health actors learned (through long-term interaction) to help urban planners identify design measures that reduced negative impacts, such as air pollution and concentration of cheap alcohol outlets. Public health actors had to adjust their understanding of how the planning system could be used to reduce negative impacts. In other words, rather than stopping development they looked for ways to shape development or mitigate harmful impacts. Furthermore, public health actors framed urban health issues widely, demonstrating alignment with other planning objectives such as economic and environmental sustainability.

Second, the research has heavily emphasised the important role of inter-sectoral relationships that were built through development and application of UHI tools. Even after engagement over UHI tools was finished, actors maintained relationships, continually sharing knowledge and developing further joint projects. In line with collaborative rationality, these relationships often 'engendered trust' (ibid, p.37) which study participants described as building over time with other actors. As previously described, these ongoing relationships had multiple benefits to support health-promoting policy and implementation.

Third, single and double loop learning could be described as emerging from the use of UHI tools when actors change their mental models. Sterman (2000) describes single loop learning as information being processed using existing mental models and applying existing decision rules, cultures or institutional norms. Whereas double loop learning involves changing those mental models leading to new decision rules and strategies. In this study mental models were changed when indicator producers interacted with policy-makers and re-examined their understanding of how evidence impacts policy. Similarly, in using UHI tools indicator users reframed their knowledge of how the built environment impacts health, learning of wider determinants of health than they were previously aware. Double loop learning was evident in the process of using UHI tools, and this was referred to as 'reframing knowledge' or gaining 'wider knowledge of urban health' in chapters six and seven respectively.

Finally, the results of a collaboratively rational process result in new ways of working together, shared meanings and potentially shared identities. In the stable UHI tool examples, indicator producers identified the ongoing importance of listening to policy-makers. Indicator producers recognised that they did not always understand policy-makers circumstances and at each encounter it was essential to actively listen to their current needs to understand how the provision of knowledge or indicator data could help to achieve a mutually beneficial outcome (i.e. a health-promoting built environment policy or decision). Further research would be needed to evaluate whether these benefits extend beyond indicator producers and policy-makers to members of the community.

This discussion has so far established that stable UHI tools resemble many of the conditions and results of collaboratively rational processes. The discussion will now briefly describe how this supports actors with addressing complexity. As described in chapter three, bounded rationality limits the cognitive ability to understand the interconnectedness of causes and effects in the world. Systems thinking scholars argue that people's limited mental models prevent them from understanding why undesirable effects occur and how they can be avoided in the future (Sterman, 2000). Thus the double loop learning resulting from collaborative rationality (and stable UHI tools) is one way that actors may expand their mental models of how the urban environment impacts health and wellbeing and the mechanisms through which this can be optimised in urban policy and decision-making. Stable UHI tools provide actors with information and opportunities to share diverse knowledge over time (and co-produce knowledge), allowing mental models to continually be re-evaluated and reformed to accommodate and act on new knowledge as a system adapts. This aligns with the approaches for managing complex urban health systems (outlined in chapter two) regarding inclusion of diverse knowledge in participatory governance processes and monitoring impacts over time (Corburn and Cohen, 2012; Rydin et al., 2012; Corburn, 2015, 2013; Gatzweiler et al., 2018). Innes and Booher (2000, 2010) also argue that distributed knowledge allows multiple actors to make changes to improve a system. This recognises that urban health challenges cannot be fixed by any single stakeholder and require cross-sectoral action, in line with HiAP and whole-of-society approaches (Kickbusch and Gleicher, 2012).

In conclusion, stable UHI tools share many characteristics of collaboratively rational processes and aid actors to address the complexity of urban health and planning process, but stable UHI tools may fall short of meeting all of the DIAD conditions. The causal loop diagrams in chapter seven described several factors which affect UHI tool stability such as political support, financial resources and organisational memory. Looking beyond SFIP and CIV, the systematic review did not identify other stable UHI tools partly because the initial and ongoing funding models for indicator systems were rarely mentioned in the documents analysed, perhaps with the exception of Bristol's Quality of Life Indicators (Shepherd and McMahon, 2009). Davern et al. (2017) note that the importance of funding is not often mentioned in the indicator literature, despite it's crucial role in the 'long term sustainability and impact of the system' (p.574). Both Davern et al. (2017) and Innes and Booher (2000) agreed that it probably takes five to ten years for indicators to be used by communities and influence governance. Therefore, the factors which influence UHI tool stability may be an important area for further research.

8.5 Relative importance of UHI tool design

Critics of a technical focus on indicator development argue that the collaborative process of developing indicators may be more important than indicators themselves (e.g. Innes and Booher, 2000) and that indicator producers have overly focused on the design of indicators rather than their role in the policy process (Pastille Consortium, 2002). This thesis confronts these two arguments whilst recognising that there is some truth to both of these claims. It is argued here that in the face of continued growth of new UHI tools (established in chapter four) and the value placed on such tools by some policy and decision-makers in this study, there is still a role for research which seeks to understand the characteristics of effective indicator sets. Continued research on technical indicator development is warranted for four reasons: 1) indicators may influence policy outside of collaborative processes, 2) indicator users and producers do not necessarily have the same perception about the important characteristics of indicators to influence policy, 3) scholars have identified under-represented groups in typical indicator data and 4) there may be unintended consequences of oversimplifying complex issues through indicators.

First, although collaborative processes of indicator development were highlighted as important in the theory of change and interview analysis, this was not the only way that UHI tools achieved change. There were a number of cases in both the primary and secondary data where indicators were used as evidence, in the form of simple facts, to argue a particular case or rally effort. For example, a dynamic hypothesis in chapter five (Section 5.3.4.3, Figure 5-5) outlined how poor performance in indicators was successful at raising awareness and political will, which led to policy and decision-making. In these cases, indicators could be seen as influencing policy-making without any collaboration or understanding of local context. The Pastille Consortium (2002) viewed this explanation of indicator influence as potentially dangerous because it inappropriately puts the emphasis on designing indicators to increase impact rather than understanding how they fit within wider processes, as discussed in section 8.3.1. They highlighted Owens and Cowell's (2001) caution that overly focusing on the development and refinement of tools comes at the risk of ignoring more fundamental barriers to sustainable development. The author agrees that viewing indicators as exogenous technical tools and focusing excessively on their development could be counterproductive. However, the data analysed in this study found several examples which provide the counterargument. The thesis argues that there should be a re-alignment of attention in the urban health indicator literature toward much more focus on the factors which influence the use of indicators; whilst recognising that there may be rare cases where indicators shift political and public agendas regardless of how they were produced and applied.

Second, the global growth of UHI tools identified in the systematic review would appear to demonstrate that the 'market' is not yet saturated and new tools should meet the information needs of those they intend to inform. In the case of urban planners this would involve the provision of data at neighbourhood scale; however, the systematic review found that a sizeable portion of new UHI tools do not contain this scale of data (although some of those UHI tools may not have intended to influence urban planners). The causal model in chapter seven showed the importance of UHI tool design represented by the 'perceived relevance and authority of UHI tool' variable. This variable was influenced by a number of characteristics of UHI tools that urban planning policy and decision-makers found to be important, including: quantifying urban health in UHI tools, inclusion of up-to-date data, reduced number of indicators, data at small spatial scales, attractive data presentation, and the indicator producer's awareness of the political context. In contrast, indicator producers identified additional design characteristics including: credibility of UHI tool producers, problem-driven analysis of indicator data, data presentation at multiple spatial scales, and data presentation via maps. The diversity of perceptions found in this analysis suggests that indicator producers may not be aware of the important factors to influence policy and decision-making. However, other scholars (e.g. Lowe et al., 2015) have found more crossover in perceptions of the importance of these factors across producers and users. A key point is that some indicator users identified UHI tool design factors as essential (e.g. age of UHI tool data and data at small spatial scales) and stated that indicators without these characteristics would not be useful for policy and decision-making. This is an important area for further research which prioritises the view of indicator users to avoid the production of new indicator sets which do not meet users' needs.

Third, policy-making using indicators that are not representative of local contexts is problematic and serves to reinforce the importance of ongoing research on indicator development. A significant criticism of the rational urban planning methodologies applied in the 1960s was that they disenfranchised particular groups within society such as women, ethnic groups, the elderly and disabled people (Healey, 1992) by not accurately representing their needs. Similarly, scholars have argued that inappropriate indicator measures fail to depict gender differences, local experiential knowledge (Parnell and Poyser, 2002) and inequity (Prasad et al., 2014). Urban planning's communicative turn responded to the failures of rational methods by recognising the socially constructed nature of knowledge and questioning the power structures and subordination of interests involved in moving from knowledge to action (Healey, 1997). Criticisms about the representation of diverse community needs within indicators can be interpreted through this lens. This would require indicator producers to consider the accuracy and representativeness of indicator measures for all population sub-groups, and that failure to do so would subordinate some interests. This introduces a dilemma for urban health indicator producers who may want to balance validated metrics of exposure and outcome alongside metrics that represent diverse community needs. These different types of indicators may be contradictory (although not necessarily) and may result in a large number of indicators, potentially reducing the perceived relevance of UHI tools as described in the causal model in this thesis. Challenges of incompatibility among indicator requirements are not new to indicator producers (Briggs, 1999); however they require ongoing research, particularly in relation to how indicators are used by policy-makers to better inform the development of new indicators that do not further disenfranchise particular communities.

A final note on the limitations of indicators and requirement for ongoing research relates to the unintended consequences that may emerge from misapplication of a single indicator or oversimplified metrics. Interview and workshop participants observed circumstances in which indicators had been misapplied or resulted in unintended consequences because a particular figure was taken out of context, as represented in Figure 7-7. The causes of indicator misapplication were represented as decreased 'Wider knowledge of urban health' and decreased 'Knowledge of policy impacts'. This explanation is supported by Sterman's (2006) assertion that '[p]olicy resistance arises from a narrow, reductionist worldview' (p.505). Oversimplification of complex issues through indicators was explored in the urban planning context by Decoville (2018) in relation to an EU 'land take' indicator. This metric sought to describe the loss of agricultural and semi-natural surfaces, comparing performance across the EU. Decoville argued that oversimplification of the land take phenomena through a single indicator led to misinterpretation and political manipulation. He rejects the conceptualisation of urban planning as a rational process and claims that indicators cannot be seen as 'guarantors of objective and factual knowledge' precisely because the planning process and planning outcomes are complex and socially constructed (ibid). In light of this study's findings and the wider literature, the researcher argues that the oversimplification of complex challenges, such as urban health, via indicators could be problematic and should be further investigated to understand the potential unintended consequences in terms of policy and decision-making.

In summary, the thesis supports scholars who highlight the importance of collaboratively developing UHI tools to achieve a range of benefits (e.g. Innes and Booher, 2000, 2010), however, there are still challenges about the nature of how indicators are constructed and used that require further research and attention from indicator producers and scholars.

8.6 Strengths of the approach

There are multiple strengths to this study in terms of the study design, conduct and usefulness of results for indicator producers, users and policy-makers. Bryman (2004) highlights the value of Lincoln and Guba's (1985) and Guba and Lincoln's (1994) trustworthiness and authenticity criteria for assessing the quality of research, as opposed to the traditional reliability and validity criteria applied to quantitative research. Trustworthiness encompasses credibility, transferability, dependability and confirmability (Bryman, 2004, p.273). While authenticity involves fairness, ontological authenticity, educative authenticity, catalytic authenticity and tactical authenticity (ibid; p.276). The authenticity criteria are controversial (ibid) in social research but they are particularly relevant to the practical outcomes found in this research. This section describes how the study meets these criteria.

The study was **credible** because it was 'carried out according to the canons of good practice' and findings were submitted and confirmed by 'members of the social world who were studied' (ibid, p.275). The systematic review, thematic analysis and systems thinking analysis were all conducted according to protocols or guidance established in relevant literature with detailed reporting of the process. The findings were reported to a group of indicator producer and experts in one of the case study cities in a workshop and participants conveyed general agreement with the findings, whilst highlighting areas for further research.

The study was **transferable** because through provision of a 'thick description' or 'rich accounts of the details' of the case studies readers can decide whether the findings could be transferred to other indicator projects (ibid; p.275). Chapters four and six provide detailed background information about the two main case studies (SFIP and CIV) and other indicator projects evaluated in the study. The narrative synthesis and thematic analysis also included participant quotes to provide additional 'rich accounts' of the dynamics in each example of UHI tool development and application. The researcher acknowledges that the stable UHI tools (SFIP and CIV) are unusual examples within the full range of published UHI tools, however the findings demonstrate why fragile UHI tools in wider contexts may fail to inform policy and decision-making.

The study was **dependable** because records were maintained through the research phases of 'problem formulation, selection of research participants, fieldwork notes, interview transcripts, data analysis decisions and so on' and these were submitted to peers or supervisors for auditing at various stages of the process (ibid; p.275). The thesis provides details for all of the above-mentioned decisions and documentation including: transparency of systematic review search criteria and results, detailed problem formulation in chapters three and five, selection of research participants in chapter six, and data analysis decisions in chapters six, seven and the appendices. For ethical reasons, the fieldwork notes and interview transcripts have not been published. However, the thesis and appendices provide relevant excerpts of interview data to confirm dependability. Furthermore, an electronic research log was kept by the researcher to document detailed decisions during the systematic review, thematic analysis and systems thinking analysis.

The study was **confirmable** because it can be argued that the researcher 'acted in good faith' and was not 'manifestly swayed' by 'personal values or theoretical inclinations' (ibid, p.276). The research was conducted using a clear conceptual framework tied to the literature (Chapter 3) which established the assumptions, beliefs, values and theory that were applied in the study design and conduct. The documentation of data analysis and decisions further allow peers to audit the confirmability of the findings.

Regarding the authenticity criteria, the study was **fair** because it represented 'different viewpoints among members of the social setting' (ibid, p.276). This was done by categorising participants as indicator producers or users and further considering their professional role (e.g. public health professional, academic or planning policy-maker) in the thematic analysis. Furthermore, diverse views were represented in the systems thinking analysis through colour-coded CLDs. The study was **ontologically authentic** because it helped 'members to arrive at a better understanding of their social' environment (ibid, p.276). This was demonstrated through the participatory modelling workshop where participants said that the CLDs helped them to consider the use and value of UHI tools in ways that they had not understood previously, and this was useful for their work. The study was **educatively authentic** because it helped 'members to appreciate better the perspectives of other members of their social setting' (ibid, p.276). Again, this can be demonstrated through the participatory modelling workshop where participants said that it was interesting to consider the diverse views represented in the colour-coded detailed CLDs. Publication of the findings will further aid with both ontological and educative authenticity. The final two authenticity criteria relate to whether members of the social setting under study will be motivated to 'engage in action to change their circumstances' (catalytic authenticity) or will be supported to do so through the research (tactical authenticity). These criteria would be better evaluated after the findings have been published, but it is anticipated that the research will help indicator producers and users with the selection, development and application of UHI tools which promote health through planning policy and decision-making. Initial results from the participatory workshop showed that participants found that the causal loop diagrams were useful in explaining how UHI tools influenced policy and decision-making in ways that they had not previously understood. This could result in changes to the way UHI tool producers and users collaboratively develop and apply indicators.

Additional study strengths relate to the mixed-methods research approach and the application of systems thinking theory and methods. First, the study design involved the use of more than one method to triangulate or cross-check findings (Bryman, 2004). Secondary data were analysed in the systematic review allowing comparison with findings from the primary data collected in semi-structured interviews. The interview data were then analysed using thematic analysis and a systems thinking approach, highlighting overlapping findings across these two methods. Finally, the workshop with UHI tool producers, users and experts allowed further checking of results. Thus triangulation of results occurred at multiple stages, strengthening the overall study design.

Second, the PRISMA-P compliant systematic review was a mixed-methods review of sequential explanatory design. This approach produced new quantitative data about 145

UHI tools and 8006 indicators. These data were then combined with and interpreted in relation to synthesised qualitative data about the use of UHI tools by urban planning policy and decision-makers. Therefore the mixed-methods approach produced findings that would not have been identified independently by the constituent parts of the review.

Finally, the application of a systems thinking approach to explore and model the use of UHI tools responds to criticisms in health and policy research fields that complexity is often cited as a challenge in such research but not adequately addressed (Cairney, 2012b; Rutter et al., 2017; Greenhalgh and Papoutsi, 2018). The resulting CLD representing study participants' combined mental model is the first causal explanation for how UHI tools influence policy, implementation and health-promotion. The systematic review and interview data demonstrated a number of ways that the characteristics of UHI tools may help indicator users understand the complexity of urban health, such as identification of interconnected variables, policy resistance and unintended consequences. The thematic analysis and CLD also showed how UHI tool development and application supported the development of health-promoting policies for the complex urban health system, including: inter-sectoral relationships, health promotion advocates across sectors, and wider knowledge of urban health.

8.7 Limitations of the approach

Detailed study limitations have previously been described in the discussion sections of chapters four to seven as they pertain to the research methods applied. A general limitation relates to the PhD research having been conducted by a single researcher, which can introduce bias in data collection, analysis and reporting. This was mitigated through detailed reporting, checking results through internal and external workshops, discussing approaches and findings with supervisors and including a second reviewer during the systematic review screening stages.

Limiting the interviews to indicator producers and users meant that community representatives' views were excluded from the study data. During the thematic analysis process it became clear that additional interviews with this stakeholder group would be beneficial to better understand the ways in which the community were involved in UHI tool development and the impact of such involvement on health-promoting policy and implementation. However, it was not feasible within the scope of the study to return to the USA and Australia to conduct these interviews. Rather than describing this strictly as a limitation, it is seen as a rich area for further research.

8.8 Conclusion

This chapter has described four summary themes that emerged from the study findings. Each theme introduced key claims made by the research and situated these in the context of the conceptual framework and wider literature. The chapter then described the overall strengths and limitations of the study. This provided a summary assessment of the research that built on more detailed strengths and limitations described in chapters four to seven. The final chapter summarises the research and outlines the contributions to knowledge. It also provides recommendations for practice and research before reflecting on the research process and finishing with suggested future research.

CHAPTER 9

Conclusions

9.1 Introduction

Building on the interpretation and discussion of the research findings in the last chapter, this chapter will outline the contributions to knowledge (theoretical and methodological), provide recommendations for researchers and practitioners, reflect on the research process and suggest future research priorities.

9.2 Summary of research

This research involved a progression of stages that incrementally built on each other to arrive at a final causal loop diagram representing indicator users and producers' mental models of UHI tool use and value in urban planning policy and decision-making. Each stage in the research (the systematic review, theory of change, model conceptualisation, thematic analysis of interviews and systems thinking approach) had discrete findings that were considered independently in the respective chapters and holistically in chapter eight. The topic of this research is an under-explored topic that relates to larger research themes such as the use of evidence in policy-making and urban governance.

9.3 Contributions to knowledge

This study has contributed the following knowledge to the fields of urban health indicators and urban health policy studies.

- The first census and taxonomy of UHI tools, including 145 UHI tools comprising 8006 indicators, classifying the scope and characteristics of health and wellbeing, quality of life, liveability, wellbeing and walkability/physical activity indicator sets. *As described in chapter four and Pineo et al. (2017a, 2017b, 2018a).*
- The first narrative synthesis of studies on the use of UHI tools by built environment policy and decision-makers, identifying facilitators/barriers to UHI tool use, the values and uses of UHI tools and the important role of community involvement in UHI tool development and application. *As described in chapter four.*

- A theory of change of the value of UHI tools for health-promotion developed through a narrative synthesis of ten studies, outlining key inputs, activities, outputs and outcomes and wider contextual factors. *As described in chapter four.*
- Research filling a knowledge gap about the use of UHI tools in urban planning policy and decision-making, outlining the importance of inter-sectoral relationships, advocacy, knowledge re-framing, stability of UHI tools, representation of community interests and the use of UHI tools to disrupt constraints to healthy urban planning. *As described in chapters six and eight.*
- The first causal model of UHI tool influence on urban policy, implementation and health promotion, making explicit the endogenous role of UHI tools in this complex process. *As described in chapters seven and eight.*
- Research filling a knowledge gap about how UHI tools represent the complexity of urban health systems and how they are used in the complex urban planning process to promote health. *As described in chapters, four, six and eight*.
- Applying the collaborative rationality theory (Innes and Booher, 2010) to stable UHI tool processes and considering the value of such approaches to address complexity characteristics in urban health and planning. *As described in chapter eight*.

9.4 Contributions to methods

- Development of the systematic review method by conducting a mixed-methods systematic review of sequential explanatory design in this topic area, collecting and analysing both quantitative and qualitative data and combining the data to reveal additional insights. *As described in chapter four.*
- Development of the application of the thematic analysis method to analyse interview data in development of causal loop diagrams (where grounded theory has typically been used), including detailed description of theme development and the modelling process and reflections on the process (which have not typically been described). *As described in chapters six and seven*.

9.5 Recommendations

This research has identified a number of recommendations for indicator producers and users and those who research urban health indicators.

1 New indicator projects should consider how diverse knowledge claims will be represented in UHI tools and develop a stakeholder engagement plan, including consideration of the required skillset to accomplish this plan. This research has provided significant insights into the process through which indicators influence policy that are not currently reflected in the urban health indicator literature. Indicator producers should be aware of the contested landscape of urban health governance into which they attempt to promote a process of UHI tool development. Given that many UHI tool producers come from a public health background, they may not have experience or appropriate skills to address these dynamics. Even urban planners may lack the appropriate facilitation and mediation skills to manage highly contested public debates, although these are a key part of a planner's skillset (Bolan, 2017). Furthermore, many UHI tool producers identified urban health equity as a key motivator for developing new indicator tools. This information may be represented through routinely collected data showing diverse exposures or health outcomes. If community engagement is part of the producers' plan to represent health equity issues, this will need to feature in the above-mentioned engagement plan. UHI tool producers should also consider the expectations that such activities will raise among community representatives and whether these can be met within the scope of any indicator project.

2 Before creating new indicators, decision-support tools and sophisticated dashboards, producers should engage with stakeholders to understand their information needs and consider co-producing any desired tools with a range of urban governance actors. Indicators are one method to make sense of increased data from the smart cities movement (e.g. Townsend, 2013) such as data from government departments, sensors (stationary or wearable), and the internet of things (e.g. smart phones, thermostats or street lights). Increased data from these sources may provide valuable information about built environment exposures, health-related behaviours or even health outcomes at small spatial scales. However, data analysists need to carefully consider how such data will influence policy-making before expending effort in analysis and presentation. The findings in this research and the wider literature would suggest that many UHI tools do not appear to influence policy-makers and producers should also consider the historical perspective that rational planning approaches and decision-support tools have been criticised for under-representing the needs and perspectives of some groups in society (such as women and low socio-economic status groups).

3 Producers may want to consider the policy solutions that particular indicators would support (or reject) and whether these potential applications meet the original objectives of producing the indicator. Several research participants identified a potential risk of indicators that are taken out of context and deployed by some politicians to achieve goals that were not necessarily the original purpose of the indicator. This risk was elaborated by Decoville (2018) in relation to the EU's land take indicator and is further described in section 9.7. The risk relates to (over)simplifying complex issues with metrics which is paradoxically a highly rated benefit of indicators, as described previously. Indicator producers and users may have trouble foreseeing how specific indicators could be taken out of context.

9.6 Reflections on research process

Throughout the process of conducting this research there were many choices and opportunities to reflect on the selection of theory and methods. This section briefly describes the researcher's reflections on some of these choices leading in to a final discussion on suggested future research.

In the process of upgrading from the MPhil to PhD programme the researcher considered the value of producing a quantitative causal model of UHI tool use, but this was rejected. There are many arguments for quantitative modelling. Ford and Sterman (1998) hypothesised that expert knowledge elicitation leading to a formal simulation model helps experts 'to clarify and specify their knowledge more than they would if we worked at a more abstract level using tools such as causal loop diagrams' (p.313). Furthermore, they highlighted the previously made claim that a formal modelling process 'almost always yields additional insights into problem simulations' (ibid; p.314). Notwithstanding these arguments and the limitations of CLDs (e.g. Richardson, 1986), the researcher remains convinced that a qualitative model of UHI tool use and value for health-promotion in urban planning is useful for policy-makers and the indicator community. The researcher was most interested in understanding and visually representing (i.e. making explicit for readers) interconnections and feedback relations, both of which can be achieved in CLDs. The researcher is satisfied that the application of qualitative system dynamics approaches was appropriate to show the likely UHI tool influence on policy-making and implementation.

During the modelling process the researcher found very little guidance in the system dynamics literature regarding model development and simplification, particularly regarding the identification of causality in interview data. The literature provides very little detail on moving from hundreds of word-and-arrow diagrams to a concise model for policy-makers' consumption. The researcher identified only one feedback loop after modelling the connections explicitly made from the interview data. However, the narrative description of the thematic analysis results clearly contained more feedback relations. The initial lack of feedback relations produced by modelling the word-and-arrow diagrams may reflect the modeller's lack of experience with this method. There may also be a role for more detail in the system dynamics literature about uncovering feedback relations from interviews. These issues sparked a number of reflections about current research of mental models related to complex systems. The researcher's master's thesis (Pineo, 2007) explored theories about cognition and communication building on bounded rationality (Simon, 1976) decision-making with heuristics (Gigerenzer and Selten, 2002) and inferential communication (Sperber and Wilson, 1995). There may be exciting opportunities to expand methods for eliciting mental models from experts by applying methods and theory from psychology, linguistics and other fields. Although these opportunities were outside the scope of this research project, they point toward the potential for new transdisciplinary approaches to understanding cognition and decision-making in contexts characterised by complexity such as urban health and policy-making.

At the outset of this research project the author had never previously considered scientific paradigms, let alone the implications of diverse worldviews and paradigm wars for policy and decision-making. During the study period there were two significant political events – the election of US President Donald Trump and the UK referendum result to leave the European Union. Academic discussions about epistemology have rather swiftly become central to understanding today's political discourse as evidenced by recent headlines: *Donald Trump and the rise of tribal epistemology* (Roberts, 2017) and *What populists and anti-vaxxers have in common* (The Economist and S.D., 2018). The nature of how society collectively agrees what is or is not true are being deeply questioned and this has many implications for local debates about the health impact of the built environment. If popular opinion is swayed by vested interests that cast doubt on evidence-based associations about the environment and health, indicators may lose their 'darling position' among policy-makers (Wong, 2006, p.3). This shaping of public dialogue for economic or political gain certainly threatens the position of academic experts but may also further obscure the needs of the most vulnerable groups in society who would be adversely impacted by poor urban environments and the impacts of climate change. This further highlights the imperative to better understand 1) how evidence informs policy, 2) how evidence represents community interests and 3) what other processes are required to produce health-promoting built environment policies that will address health inequities in today's political context.

9.7 Suggested future research

This research has identified a number of future research priorities related to urban health governance and indicators. The previous section provided support for some of these research directions in relation to theory or debates that were not otherwise covered within the thesis.

1 The power of different actors within health and planning governance processes was discussed in the research and partially represented in the high-level causal loop diagram. However, workshop participants highlighted the circumstances in San Francisco where indicators could be conceptualised as "weaponising" data to fight for a particular (anti-development) position. Similarly, Sébastien et al., (2014) spoke of 'the use of indicators as "ammunition" in political debates' (p.334). The use of indicator data to legitimise the needs of particular groups is an area for further research, particularly in relation to changing governance mechanisms and new technologies (such as social media). Further exploration of such power dynamics and how UHI tools mediate or contribute to which actors have power within urban planning processes and decision-making (Forester, 1982, 1989) would help uncover areas of leverage to create healthier urban environments. Future research could explore the views of community groups, developers and other actors.

2 Building on the previous point, there were concerns from the participatory modelling workshop participants about whether the perspectives represented in UHI tools are representative of under-served and deprived communities in relation to health equity. Although there is significant literature on the value of UHI tools in representing health equity concerns (Corburn and Cohen, 2012; Corburn et al., 2014; Prasad et al.,

2014) more research could explore how such tools are used in the policy and decision-making process to accurately represent diverse community needs and whether they result in policy, development or funding that remedies inequities.

3 The research explored the potential risks of having too few indicators. This topic was raised by study participants and discussed in relation to Decoville's (2018) assertion that oversimplification through a single indicator led to misinterpretation and political manipulation in the case of the EU land take indicator. Further research could usefully investigate the potential unintended consequences of indicators in terms of policy and decision-making and how these could be avoided through indicator design and/or use.

4 The indicator literature often refers to various stages of policy-making for which indicators may be useful such as baseline assessments and monitoring of interventions. Yet this research did not find that indicator users and producers conceptualised UHI tool influence in this way. Study participants widely acknowledged that evaluation of built environment policy impact almost never happens, a problem that spreads more widely that urban planning policy (Weiss (1998). Yet scholars highlight the importance of evaluating health-related policy impacts given the need for policy innovation and the complexities of urban health (e.g. Rydin et al., 2012). Future research could further investigate why built environment policy and design impacts are not evaluated (at multiple spatial scales) and the implications of this for urban health policy approaches.

5 UHI tool stability was proposed as an important factor to support policy and decision-makers with complex policy problems. Furthermore, Davern et al. (2017) and Innes and Booher (2000) note the funding and time required for ensure indicators can have impact. Further research could explore the factors that support UHI tool stability beyond funding. Short-term funding for the production of UHI tools may have occurred because funders misunderstood the value of indicators in governance processes. In other words, they did not see that the data may not be as important as the relationships and wider knowledge sharing activities that UHI tool development and application support.

6 Finally, additional research could explore why UHI tool producers are motivated to create new indicators. A clearer understanding of motivations would result in better research on the effectiveness of indicators. In addition, further research could analyse the characteristics of UHI tools which policy-makers most value. These characteristics are covered widely in the indicator best practice literature but it is unclear whether those characteristics were identified following research with policy-makers.

9.8 Conclusions

In concluding this study, the researcher reflects that indicators can influence policy and decision-making through a number of routes, yet these mechanisms are not those typically discussed in the urban health indicator literature. This thesis has contributed new knowledge about the characteristics of UHI tools and their use and value in health-promoting urban governance processes in the USA and Australia. The research has also shown how stable UHI tools can support policy-makers with complex policy problems. The thesis has also contributed to methods developments including: a mixed-methods sequential explanatory systematic review and the use of thematic analysis to code interview data for qualitative system dynamics models. The findings of this research will be of value to indicator users and producers and the researcher has already presented findings to these audiences at invited talks and the participatory modelling workshop. Finally, areas of further research have been identified, partly supported by discussions from indicator users and producers.

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APPENDIX 1 SUPPLEMENTARY MATERIAL FOR CHAPTER 4

A1.1 Published systematic review protocol

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Systematic Reviews

PROTOCOL Open Access

Characteristics and use of urban health indicator tools by municipal built environment policy and decision-makers: a systematic review protocol

Helen Pineo[1*], Ketevan Glonti[2], Harry Rutter[2], Nicole Zimmermann[1], Paul Wilkinson[3] and Michael Davies[1]

Abstract

Background: There is wide agreement that there is a lack of attention to health in municipal environmental policy-making, such as urban planning and regeneration. Explanations for this include differing professional norms between health and urban environment professionals, system complexity and limited evidence for causality between attributes of the built environment and health outcomes. Data from urban health indicator (UHI) tools are potentially a valuable form of evidence for local government policy and decision-makers. Although many UHI tools have been specifically developed to inform policy, there is poor understanding of how they are used. This study aims to identify the nature and characteristics of UHI tools and their use by municipal built environment policy and decision-makers.

Methods: Health and social sciences databases (ASSIA, Campbell Library, EMBASE, MEDLINE, Scopus, Social Policy and Practice and Web of Science Core Collection) will be searched for studies using UHI tools alongside hand-searching of key journals and citation searches of included studies. Advanced searches of practitioner websites and Google will also be used to find grey literature. Search results will be screened for UHI tools, and for studies which report on or evaluate the use of such tools. Data about UHI tools will be extracted to compile a census and taxonomy of existing tools based on their specific characteristics and purpose. In addition, qualitative and quantitative studies about the use of these tools will be appraised using quality appraisal tools produced by the UK National Institute for Health and Care Excellence (NICE) and synthesised in order to gain insight into the perceptions, value and use of UHI tools in the municipal built environment policy and decision-making process. This review is not registered with PROSPERO.

Discussion: This systematic review focuses specifically on UHI tools that assess the physical environment's impact on health (such as transport, housing, air quality and greenspace). This study will help indicator producers understand whether this form of evidence is of value to built environment policy and decision-makers and how such tools should be tailored for this audience.

Systematic review registration: N/A.

Keywords: Urban metrics, Built environment, Indicator, Indices, Policy, Urban health, Evidence, Urban, Social determinants of health

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Background

The impact of the urban environment on health outcomes has been widely documented [1–3], but there remains a lack of attention to health in municipal environmental policy-making, such as urban planning and regeneration [4, 5]. Researchers point to several potential explanations for the perceived lack of action from policy-makers, including differing professional norms, system complexity and limited evidence for causality between attributes of the built environment and health outcomes [2, 5, 6]. Urban health indicators are a resource which could help overcome some of these challenges and inform evidence-based municipal policies on the social determinants of health. The WHO Healthy Cities projects and a variety of other research and policy programmes have used data from urban health indicators (UHIs) as evidence to inform strategies and policies [7–10].

The use of evidence to inform policy and decision-making in municipal services that impact the wider determinants of health is an under-researched area [11, 12]. Recent studies have found that built environment professionals value data and expertise about the local context over academic evidence [12, 13]. Many indicator tools claim to be evidence-based and are underpinned by research evidence and expert involvement. Therefore urban health indicators may be one route through which research evidence informs policy, if they are used in the policy-making process [10]. Several recent reviews of urban health indicators have focused on describing the nature of indicators and challenges with their development—none have evaluated studies on their use by policy and decision-makers [7, 9, 14, 15]. It is therefore unclear whether this form of evidence is reaching its intended audience and aiding with the process of policy and decision-making.

Urban health and environmental health indicators have traditionally focused on health outcomes and environmental risks such as pollution [16]. The rise of non-communicable diseases and links to urban form and development patterns have broadened the scope and purpose of urban health indicators [17]. There have been recent attempts to conceptualise the interconnections and complex relations between the environmental determinants of health and other related policy objectives such as liveability, quality of life, wellbeing and sustainability [2, 5, 7]. A number of recent indicator tools are attempting to make these relations more explicit with the intention of informing and shaping policies and decisions that meet these aligned objectives.[1] These tools provide indicators on multiple aspects of the urban environment simultaneously, therefore recognising and highlighting the complexity of the system. Examples of urban health indicators include access to recreational facilities (measured by the San Francisco Indicator Project as 'proportion of population within 1/4 mile of a public recreation facility') and access to public transport (measured by the Community Indicators Victoria tool as 'average distance to nearest public transport stop including tram, bus and train stops (kilometers)'. It is these tools which could be of most use to urban planners and other municipal built environment policy and decision-makers who need to balance multiple sustainability objectives with competing interests, such as economic viability and local acceptability [18]. Although researchers argue that indicators can be used to help policy-makers understand and respond to complex systems, this claim is not supported by research evidence on the use of indicators for this purpose [9, 19].

Defining urban health indicator tools

A number of concepts were explored in the health and urban planning literature to develop a definition for 'urban health indicator tool' for this review. Galea and Vlahov define urban health as 'the determinants of health and diseases in urban areas and with the urban context itself as the exposure of interest' [1]. There are numerous definitions for an 'indicator' which vary by the policy fields for which they were created. Kotval describes an indicator as 'a measure or a set of measures that describes a complex social, economic or physical reality' [20]. While Pencheon refers to indicators as 'succinct measures that aim to describe as much about a system as possible in as few points as possible' [21]. This review defines an 'urban health indicator tool' as a collection of summary measures about the physical urban environment's contribution to human health and wellbeing. This definition broadens the scope of 'health' to include related concepts of quality of life, liveability and wellbeing.

Aims/objectives

This study aims to investigate the nature and characteristics of urban health indicator tools and their perceived value and use by municipal built environment policy and decision-makers. The specific objectives are the following:

1. To create a census and taxonomy of urban health indicator tools
2. To understand how UHI tools are used in the policy and decision-making process
3. To explore the perceived impact of UHI tools on policy and decision-making
4. To investigate the value of UHI tools in relation to simplifying, representing or addressing complex systems

Method

This systematic review will include studies and grey literature to identify UHI tools and investigate their use by policy and decision-makers. The PRISMA-P guidelines have been followed, and the checklist is available in Additional file 1. The protocol was developed iteratively following a scoping review of relevant studies and urban health indicator tools. It was informed by similar social sciences systematic reviews regarding the relevant population of policy-makers [13, 22]. Draft iterations of the protocol were shared with an advisory group of senior researchers across health, policy and built environment fields and subsequently improved. This review is not registered with PROSPERO.

Eligibility criteria

There are two parts to this systematic review, with each part having distinct criteria. The first part (part A) is a census of urban health indicator tools. Any UHI tool referred to in peer-reviewed or grey literature documents will be eligible for inclusion if it meets the definition of an urban health indicator tool outlined above and is published in English. Non-English language publications are excluded due to resource constraints and this is recognised as a limitation in the review which will be considered during analysis and reporting of results. UHI tools which only regard one aspect of the physical urban environment (such as air quality) are too narrow to meet the definition provided in this protocol and will therefore be excluded.

The second part of the review (part B) relates to studies about the use of UHI tools and includes any study design (including case studies). Studies will be included if they meet the following criteria:

- Reports substantive data on views, attitudes or knowledge about the use of an urban health indicator tool in the policy-making or decision-making process, or about the implementation of specific policies, interventions or programmes informed by these (modified from [13])
- Includes policy and/or decision-makers from one of the following policy fields in local government: housing, transport, urban planning and regeneration
- Reports qualitative or quantitative data
- Published in English

Studies reported in any country will be included initially. It may be necessary to limit studies to those that are similar to a UK context if the cultures of practise appear to be sufficiently different. There are no date restrictions.

Information sources

Two University College London (UCL) librarians specialising in systematic reviews have helped to identify the search strategy and appropriate bibliographic databases for the review. The following health and social sciences databases will be searched: Applied Social Sciences Index and Abstracts (ASSIA), Campbell Library, EMBASE, MEDLINE, Scopus, Social Policy and Practice and Web of Science Core Collection (includes Social Sciences Citation Index). In addition, a hand-search of the following key journals will be conducted: Annual Review of Public Health, Social Science and Medicine, BMC Public Health and Social Indicators Research. Citation searches of included studies will be performed. Following advice from the UCL librarian, Google Advanced Search will be used to systematically search using specified search terms, including a focus on the following practitioner websites: Town and Country Planning Association (UK), Royal Town Planning Institute (UK), Planning Institute of Australia, American Planning Association, Built Environment and Public Health Clearinghouse and the World Health Organization Europe.

Search strategy

The search terms and MeSH subject headings were identified through a scoping study of urban health indicator publications. Search terms and indicators identified in similar reviews were also examined and trialled to identify the key terms [7, 9, 15]. The key terms for the inclusion criteria were related to the urban environment (e.g. urban, metropolitan, city, environment, neighbourhood, community), health and related concepts (e.g. determinant, public, health, wellbeing, wellness, quality, liveability) and indicator terms (e.g. benchmark, tool, indicator, index, indices, measure, metric, profile, assessment, score, standard). In Scopus, Web of Science and Ovid (EMBASE and MEDLINE), subject areas were limited to refine results (e.g. subjects such as pharmacology and dentistry were excluded). Boolean and adjacency operators were also used to construct the search and refine results. An example of the Ovid MEDLINE search is included in Additional file 2.

Data management and selection

All records will be imported into EppiReviewer, specialist systematic review software, and duplicates will be removed. A second reviewer (KG) will screen a randomly selected sample of 10% of titles and abstracts. Inter-rater agreement percentages will be reported for both screening stages. Conflicts will be discussed and agreed upon with a third researcher (HR). Records will be removed at this stage if they do not meet the inclusion criteria for part A (i.e. they do not mention an urban health indicator tool or are not published in English). The second reviewer will screen a randomly selected sample of 10% of full papers. This pool of studies will include records for part A and part B. Full papers will be screened simultaneously for the inclusion criteria in part A and part B. The result will be a set of included urban health indicator tools and a set of included studies about the use of these tools.

Data extraction

For each included urban health indicator tool (identified in part A), we will use the provided references or a Google search to determine if there is a stand-alone website and/or further documentation about the indicator and its methodology. The data will be extracted from the indicator tool website or other documentation by the indicator tool producer where possible. The preference is to find information about the indicator tool directly from its producer rather than third-party summaries or evaluations. If the information is only available through the included study, then the data will be extracted from there. The information source will be logged as part of the data extraction. A draft data extraction form in Excel has been developed (see Additional file 3). The form was iteratively developed using information from the scoping review. The data extraction will include the following categories (developed from the scoping review):

- Scale—At what scales can the system be applied or measured? (e.g. neighbourhood or city)
- Geography—Which areas can this system be applied in (e.g. specific cities or nations)?
- Scope—What aspects are analysed (e.g. built environment, health outcomes, demographics)?
- Producer—Which organisation developed the system? What type of organisation?
- Funders—Which organisations funded the indicator system?
- Purpose—What is the stated purpose? (e.g. research and/or informing policy)
- Methodology—Is there a published methodology and what are its characteristics?
- Evidence base—Does the methodology refer to evidence which was used to inform the system? What is the nature of this evidence?
- Weighting—Is there a weighting system and what are its characteristics?
- Complexity—Does the methodology refer to complexity and, if so, in what context?
- Uncertainty—Does the methodology refer to uncertainty and, if so, in what context?
- Maps—Is there an option to view the data on maps?
- Publication date—When was the system published?
- Source—Where was this information found?
- Indicators—Which indicators are reported?

Studies that meet inclusion criteria for part B will be included in a narrative synthesis. The following data will be extracted in an Excel sheet (see Additional file 4) for each study included in part B (informed by [13, 22]):

- Author, year
- Country
- Year that study was carried out
- Urban health indicator tool being evaluated
- Policy field
- Research parameters
- Data collection methods
- Population and sample selection
- Outcomes
- Analysis methods
- Limitations
- Funding source
- Conflicts of interest

A data extraction form has been created in Excel and any quantitative data will be analysed using Excel. Qualitative data will be synthesised using NVivo qualitative data analysis Software (QSR International Pty Ltd., Version 11, 2015). Data will be coded using an open code set. These will be updated in an iterative process as new factors regarding the perceptions and use of urban health indicator tools are identified.

Quality appraisal

Studies about the use of UHI tools (part B) will be appraised using the quality appraisal tools for qualitative and quantitative studies produced by the UK National Institute for Health and Care Excellence (NICE) [23]. A modified version of the NICE tool for quantitative studies reporting correlations and associations will be used as there is no suitable version for study designs reporting quantitative data on participants' perceptions. For qualitative studies, the NICE appraisal checklist includes assessment of the following: theoretical approach, study design, data collection, trustworthiness, analysis and ethics. For quantitative studies, the following topics are appraised: population, method of selection, outcomes, analyses and summary. A copy of the completed checklists will be published with the review results as an additional file.

Data synthesis

There will be two components to the data synthesis. Data about the UHI tools will be analysed to create a taxonomy of the types of tools available to municipal built environment policy and decision-makers. This will include quantitative analysis of the physical urban environment features being measured, such as the percentage of UHI tools measuring particular features. The analysis will also assess the proportion of tools operating in particular geographic scales, the number of tools published each year, the proportion of UHI tools which mention complexity and the proportion of tools developed by different organisation types. The narrative synthesis of qualitative data from part B of this review will identify any recurrent themes across the studies regarding the perceptions and value of urban health indicator tools by policy and decision-makers.

Discussion

Many urban health indicator tools are created with the goal of informing policy- and decision-makers who influence the social determinants of health in urban environments. However, there is little clarity about what type of evidence this audience uses and whether urban health indicator tools form part of their evidence toolbox. This review focuses specifically on municipal built environment policy and decision-makers and their perceptions of UHI tools. The findings will be of value to UHI tool producers who wish to target their tools to this audience with the aim of improving the health impact of urban environments.

Complexity is emphasised as a key challenge in relation to policy-making for health and the built environment, in response to which indicators have been promoted as a solution. This review will seek to understand whether and how UHI tools aim to address the complexity of the systems they measure. An initial scoping review showed that this topic is not widely addressed in indicator methodology documents. This review will seek to understand whether UHI tools are perceived as assisting with complexity in the policy and decision-making process. However, it is recognised that studies identified for this review may not address this topic. Therefore, this review will also help to establish the current research evidence supporting the claim that indicators are a tool to support policy and decision-makers operating in this complex system.

Endnotes

[1] For example, see the San Francisco Indicator Project developed by the SF Department of Public Health and the City and County of San Francisco (http://www.sfindicatorproject.org/ accessed 29 Mar 2016) and the Community Indicators Victoria tool developed by McCaughey Centre, VicHealth and the University of Melbourne (http://www.communityindicators.net.au/ accessed 17 Feb 2016).

Additional files

Additional file 1: PRISMA-P Checklist. Completed PRISMA-P Checklist. (DOCX 37 kb)

Additional file 2: Title of data: MEDLINE search. MEDLINE (Ovid) search strategy. (DOCX 12 kb)

Additional file 3: Data extraction form part A. Data extraction form part A. (XLS 33 kb)

Additional file 4: Data extraction form part B. Data extraction form part B. (XLS 22 kb)

Abbreviations

ASSIA: Applied Social Sciences Index and Abstracts; MeSH: Medical Subject Headings; NICE: National Institute for Health and Care Excellence; PRISMA-P: Preferred Reporting Items for Systematic review and Meta-Analysis Protocols; UCL: University College London; UHI: Urban health indicator

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Availability of data and materials

Not applicable.

Authors' contributions

HP designed the study, undertook the scoping review, performed the searches, imported results into EppiReviewer, screened results and wrote the protocol. NZ, KG, HR, PW and MD advised on the study design and contributed to the writing of this protocol. All authors read and approved the final manuscript.

Competing interests

HP is a PhD student funded by the Building Research Establishment Ltd. The other authors declare that they have no competing interests.

Consent for publication

Not applicable.

Ethics approval and consent to participate

Not applicable.

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A1.2 Published completed PRISMA-P checklist

Table 1 shows the completed PRISMA-P checklist as recommended by Shamseer et al. (2015). This was published as an appendix with the protocol.

Table 1 Completed PRISMA-P (Preferred Reporting Items for Systematic review and Meta-Analysis Protocols) 2015 checklist

Section and topic	Item No	Checklist item	Information from protocol
ADMINISTRATIVE INFORMATION			
Title:			
Identification	1a	Identify the report as a protocol of a systematic review	Protocol titled 'Characteristics and use of urban health indicator tools by municipal built environment policy and decision-makers: a systematic review protocol'
Update	1b	If the protocol is for an update of a previous systematic review, identify as such	N/A
Registration	2	If registered, provide the name of the registry (such as PROSPERO) and registration number	N/A
Authors:			
Contact	3a	Provide name, institutional affiliation, e-mail address of all protocol authors; provide physical mailing address of corresponding author	Helen Pineo[1], Ketevan Glonti[2], Harry Rutter[2], Nicole Zimmermann[1], Paul Wilkinson[3], Michael Davies[1] [1]Institute of Environmental Design and Engineering, Bartlett School of Environment, Energy and Resources, University College London, Central House, 14 Upper Woburn Place, London, WC1H 0NN, helen.pineo.15@ucl.ac.uk, n.zimmermann@ucl.ac.uk, michael.davies@ucl.ac.uk [2]ECOHOST – The Centre for Health and Social Change, London School of Hygiene and Tropical Medicine, 15-17 Tavistock Place, London, WC1H 9SH, ketevan.glonti@lshtm.ac.uk, harry.rutter@lshtm.ac.uk [3]Department of Social and Environmental Health Research, London School of Hygiene and Tropical Medicine, Keppel Street, London, WC1E 7HT, paul.wilkinson@lshtm.ac.uk
Contributions	3b	Describe contributions of protocol authors and identify the guarantor of the review	NZ, KG, HR, PW, MD advised on the study design. HP designed the study, performed the searches, imported results into EppiReviewer, performed deduplication and wrote the protocol. HP will screen records, perform quality appraisal, extract data and analyse data. KG will screen a randomly sampled selection of titles, abstracts and full papers. All authors read and approved the protocol. All authors will read the final systematic review paper. The guarantor of the review is Helen Pineo.

Section and topic	Item No	Checklist item	Information from protocol
Amendments	4	If the protocol represents an amendment of a previously completed or published protocol, identify as such and list changes; otherwise, state plan for documenting important protocol amendments	The protocol was developed iteratively during the scoping review process. Any changes to the final published version will be noted and appended to the systematic review publication.
Support:			
Sources	5a	Indicate sources of financial or other support for the review	The Building Research Establishment Ltd. (BRE) is funding the review via HP's PhD sponsorship.
Sponsor	5b	Provide name for the review funder and/or sponsor	Same as above.
Role of sponsor or funder	5c	Describe roles of funder(s), sponsor(s), and/or institution(s), if any, in developing the protocol	The funder was not involved in developing the protocol apart from HP's role as a part-time PhD student employed by the BRE.
INTRODUCTION			
Rationale	6	Describe the rationale for the review in the context of what is already known	Previous reviews of urban metrics and urban health indicators (UHIs) have not evaluated the use of these tools by built environment policy and decision-makers. It is not clear whether this policy audience is using UHIs and how they are perceived and valued in professional practice. See 'background' for more information.
Objectives	7	Provide an explicit statement of the question(s) the review will address with reference to participants, interventions, comparators, and outcomes (PICO)	This study aims to investigate the nature and characteristics of urban health indicator tools and their perceived value and use by municipal built environment policy and decision-making. The specific objectives are: 1. To create a census and taxonomy of urban health indicator tools. 2. To understand how UHI tools are used in the policy and decision-making process 3. To explore the perceived impact of UHI tools on policy and decision-making. 4. To investigate the value of UHI tools in relation to simplifying, representing or addressing complex systems. Population: Built environment policy and decision-makers in local government: urban planners, transport planners, housing officers, regeneration officers and elected members in these policy areas. Intervention: Use of urban health indicators in the policy and decision-making process Comparison: N/A

Section and topic	Item No	Checklist item	Information from protocol
			Outcome: views, attitudes or knowledge about the use of an urban health indicator tool in the policy-making or decision-making process, or about the implementation of specific policies, interventions or programmes informed by UHI tools
METHODS			
Eligibility criteria	8	Specify the study characteristics (such as PICO, study design, setting, time frame) and report characteristics (such as years considered, language, publication status) to be used as criteria for eligibility for the review	There are two parts to this systematic review, with each part having distinct criteria. The first part (Part A) aims to establish a census of urban health indicator tools. Any reference to UHI tools in peer-reviewed or grey literature documents will be eligible. The included UHI tools for Part A must meet the definition of an urban health indicator tool outlined above and be published in English. UHI tools which only regard one aspect of the physical urban environment (such as air quality) are too narrow to meet the definition provided in this protocol and will therefore be excluded. The second part of the review (Part B) relates to studies about the use of UHI tools and includes any study design (including case studies). The studies are included if they meet the following criteria: • Reports substantive data on views, attitudes or knowledge about the use of an urban health indicator tool in the policy-making or decision-making process, or about the implementation of specific policies, interventions or programmes informed by these (modified from [13]). • Includes policy and/or decision-makers from one of the following policy fields in local government: housing; transport; urban planning and regeneration. • Reports qualitative or quantitative data. • Published in English. Studies reported in any country will be included initially. It may be necessary to limit studies to those that are similar to a UK context if the cultures of practice appear to be sufficiently different. There are no date restrictions.
Information sources	9	Describe all intended information sources (such as electronic databases, contact with study authors, trial registers or other grey literature sources) with planned dates of coverage	Two University College London (UCL) librarians specialising in systematic reviews have helped to identify the search strategy and appropriate bibliographic databases for the review (RM and TV). The following health and social sciences databases will be searched: Applied Social Sciences Index and Abstracts (ASSIA), Campbell Library, EMBASE, MEDLINE, Scopus, Social Policy and Practice, and Web of Science Core Collection (includes Social Sciences Citation Index). In addition, a hand-search of the following key journals will be conducted: Annual Review of Public Health, Social Science and Medicine, BMC Public Health, and Social Indicators Research. Citation searches of included studies will be performed. Following advice from the UCL librarian, Advanced Google Searches will be used to systematically search practitioner websites and

Section and topic	Item No	Checklist item	Information from protocol
			Google using specified search terms. In addition to two focused Google searches (using multiple terms and Boolean operators), the following specific websites were explored through Advanced Google searches: Town and Country Planning Association (UK), Royal Town Planning Institute (UK), Planning Institute of Australia, American Planning Association, Built Environment and Public Health Clearinghouse, World Health Organization Europe. There are no date limitations beyond those imposed by the bibliographic databases.
Search strategy	10	Present draft of search strategy to be used for at least one electronic database, including planned limits, such that it could be repeated	Medline Ovid search: 1. city planning/ or environment design/ or urban renewal/ 2. Urban Health/ or Urban Population/ 3. (Urban or Metropolitan or City or Cities or Environment* or Neighbourhood or Neighborhood or Communit*).ti. 4. Cities/ 5. 1 or 2 or 3 or 4 6. ((Determinant* or Public or Health* or Wellbeing or well being or Quality of life or Liveab* or Livab*) adj2 (Benchmark* or Tool* or Indicator* or Index* or Indices or Measure* or Metric* or Profile* or Assessment* or Score* or Standard*)).m_titl. 7. ((Determinant* or Public or Health* or Wellbeing or well being or Quality of life or Liveab* or Livab*) adj2 (Benchmark* or Tool* or Indicator* or Index* or Indices or Measure* or Metric* or Profile* or Assessment* or Score* or Standard*)).tw. 8. exp Health Status/ 9. exp Health Status Indicators/ 10. 8 or 9 11. 5 and 7 and 10 12. 5 and 6

Section and topic	Item No	Checklist item	Information from protocol
			13. 11 or 12 14. limit 13 to english language 15. exp animals/ not humans/ 16. 14 not 15
Study records:			
Data management	11a	Describe the mechanism(s) that will be used to manage records and data throughout the review	EppiReviewer software will be used to manage all records and perform screening. Microsoft Excel will be used for data extraction and quantitative data analysis (if applicable). Qualitative data will be synthesised using NVivo qualitative data analysis Software; QSR International Pty Ltd. Version 11, 2015.
Selection process	11b	State the process that will be used for selecting studies (such as two independent reviewers) through each phase of the review (that is, screening, eligibility and inclusion in meta-analysis)	All records will be imported into EppiReviewer, specialist systematic review software, and duplicates will be removed. A second reviewer will screen a randomly selected sample of 10% of titles and abstracts. Inter-rater agreement percentages will be reported for both screening stages. Conflicts will be discussed and agreed upon with a third researcher. Records will be removed at this stage if they do not meet the inclusion criteria for Part A (i.e. they do not mention an urban health indicator tool or are not published in English). A second reviewer will screen a randomly selected sample 10% of full papers. This pool of studies will include records for Part A and Part B. Full papers will be screened simultaneously for the inclusion criteria in Part A and Part B. The result will be a set of included urban health indicator tools and a set of included studies about the use of these tools.
Data collection process	11c	Describe planned method of extracting data from reports (such as piloting forms, done independently, in duplicate), any processes for obtaining and confirming data from investigators	Data will be extracted in two separate Excel forms (for Part A and B respectively) independently.
Data items	12	List and define all variables for which data will be sought (such as PICO items, funding sources), any pre-planned data assumptions and simplifications	For Part A – the census of Urban Health Indicator Tools the following will be sought: • Scale – At what scales can the system be applied or measured? (e.g. neighbourhood or city) • Geography – Which areas can this system be applied in (e.g. specific cities or nations)? • Scope – What aspects are analysed (e.g. built environment, health outcomes, demographics)? • Producer – Which organisation developed the system? What type of organisation? • Funders – Which organisations funded the indicator system?

Section and topic	Item No	Checklist item	Information from protocol
			• Purpose – What is the stated purpose? (e.g. research and/or informing policy) • Methodology – Is there a published methodology and what are its characteristics? • Evidence-base – Does the methodology refer to evidence which was used to inform the system? What is the nature of this evidence? • Weighting – Is there a weighting system and what are its characteristics? • Complexity – Does the methodology refer to complexity and, if so, in what context? • Uncertainty – Does the methodology refer to uncertainty and, if so, in what context? • Maps – Is there an option to view the data on maps? • Publication date – When was the system published? • Source – Where was this information found? • Indicators – Which indicators are reported? For Part B the analysis of the use of UHI tools, the following will be extracted: • author, year • country • year that study was carried out • urban health indicator tool being evaluated • policy field • research parameters • data collection methods • population and sample selection • outcomes • analysis methods • limitations • funding source • conflicts of interest
Outcomes and prioritization	13	List and define all outcomes for which data will be sought, including prioritization of main and additional outcomes, with rationale	A narrative synthesis of outcomes (substantive data on views, attitudes or knowledge about the use of an urban health indicator tool in the policy-making or decision-making process, or about the implementation of specific policies, interventions or programmes informed by these) will use open coding.

Section and topic	Item No	Checklist item	Information from protocol
Risk of bias in individual studies	14	Describe anticipated methods for assessing risk of bias of individual studies, including whether this will be done at the outcome or study level, or both; state how this information will be used in data synthesis	Given the nature of this review, there will be no assessment of risk of bias. Bias will be addressed as a limitation of the included study types.
Data synthesis	15a	Describe criteria under which study data will be quantitatively synthesised	If quantitative data about views, attitudes and knowledge are obtained, these will be reported. It is unlikely that data from more than one study will be combined (if this is possible, it will be done in Excel).
	15b	If data are appropriate for quantitative synthesis, describe planned summary measures, methods of handling data and methods of combining data from studies, including any planned exploration of consistency (such as I^2, Kendall's τ)	Any quantitative data would likely be responses to surveys and these are not likely to be consistent across studies (and therefore not possible to combine).
	15c	Describe any proposed additional analyses (such as sensitivity or subgroup analyses, meta-regression)	N/A
	15d	If quantitative synthesis is not appropriate, describe the type of summary planned	There will be two components to the data synthesis. Data about the UHI tools will be analysed to create a taxonomy of the types of tools available to municipal built environment policy and decision-makers. This will include analysis of the physical urban environment features being measured, the scale at which they are measured and other observations on the nature of these tools. The narrative synthesis of qualitative data from Part B of this review will identify any recurrent themes across the studies regarding the perceptions and value of urban health indicator tools by policy and decision-makers. The qualitative data reported as the outcomes will be synthesised using NVivo. Data will be coded using an open code set. These will be updated in an iterative process as new factors regarding the perceptions and use of urban health indicator tools are identified.
Meta-bias(es)	16	Specify any planned assessment of meta-bias(es) (such as publication bias across studies, selective reporting within studies)	N/A

Section and topic	Item No	Checklist item	Information from protocol
Confidence in cumulative evidence	17	Describe how the strength of the body of evidence will be assessed (such as GRADE)	Studies about the use of UHI tools will be appraised independently using the quality appraisal tool produced by the UK National Institute for Health and Care Excellence (NICE). A copy of the completed checklists will be made available with the study results. There will not be an assessment of the confidence of cumulative evidence.

A1.3 Published systematic review Part A results

Note on page 626 in the second paragraph an error was identified when drafting the thesis. The number of UHI tools for which the researcher was unable to confirm whether they were used beyond research purposes should be 46/120 (38.3%) which was incorrectly reported as 45/120 (37.5%). Also note that the rate of growth in Figure 7 (page 621) was calculated using the cumulative number of UHI tools. In the thesis, the rate of growth is calculated using the number of new UHI tools.

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Abstract Urban health indicator (UHI) tools provide evidence about the health impacts of the physical urban environment which can be used in built environment policy and decision-making. Where UHI tools provide data at the neighborhood (and lower) scale they can provide valuable information about health inequalities and environmental deprivation. This review performs a census of UHI tools and explores their nature and characteristics (including how they represent, simplify or address complex systems) to increase understanding of their potential use by municipal built environment policy and decision-makers. We searched seven bibliographic databases, four key journals and six practitioner websites and conducted Google searches between January 27, 2016 and February 24, 2016 for UHI tools. We extracted data from primary studies and online indicator systems. We included 198 documents which identified 145 UHI tools comprising 8006 indicators, from which we developed a taxonomy. Our taxonomy classifies the significant diversity of UHI tools with respect to topic, spatial scale, format, scope and purpose. The proportions of UHI tools which measure data at the neighborhood and lower scale, and present data via interactive maps, have both increased over time. This is particularly relevant to built environment policy and decision-makers, reflects growing analytical capability and offers the potential for improved understanding of the complexity of influences on urban health (an aspect noted as a particular challenge by some indicator producers). The relation between urban health indicators and health

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impacts attributable to modifiable environmental characteristics is often indirect. Furthermore, the use of UHI tools in policy and decision-making appears to be limited, thus raising questions about the continued development of such tools by multiple organisations duplicating scarce resources. Further research is needed to understand the requirements of built environment policy and decision-makers, public health professionals and local communities regarding the form and presentation of indicators which support their varied objectives.

Keywords Urban metrics · Built environment · Indicator · Indices · Policy · Urban health · Evidence · Urban planning · Healthy cities · Social determinants of health

Introduction

Both the global increase in non-communicable diseases and improved understanding of the social determinants of health have contributed to an increased awareness of the influence of built environment policies on health and wellbeing [1–3]. Estimates vary, but recent research attributes 23% of global deaths to the environments in which people live [4]. The urban environment, including air pollution, noise, housing and transport, plays a significant role in people's health, and improvements should involve collaboration between health and built environment professionals [2, 5]. Other social determinants, such as employment and education, are also influenced by urban planners, increasing the importance of their work for population health [6]. Municipal built environment practitioners can improve health through policies and decisions which identify the need for and design of new infrastructure, development and regeneration programmes.

Urban health indicator (UHI) tools seek to provide built environment policy and decision-makers with information to develop policies, make decisions and monitor impacts. These metrics can demonstrate the impact of the built environment on health and expose health inequalities within cities. Urban health is a complex system with many interconnected parts [7–10] which UHI tools attempt to simplify for policy-makers [11]. The range of potential uses of indicators by municipal government is vast. Further to the above-mentioned uses, indicators are also employed to [12–18]:

- Benchmark progress at local, regional, national or international levels
- Set targets for improvement
- Demonstrate performance to residents
- Prioritise funding allocation/bid for funding
- Act as an 'early warning' of potential problems
- Involve the public in prioritisation and definition of policy goals
- Identify strengths and weaknesses in a community

The intended use of indicator tools is likely to inform their composition and characteristics, elements which are often represented in a taxonomy [19]. Taxonomies have been developed for mental health and ecological indicators by identifying and classifying user requirements such as spatial scale and decision-making context [20, 21]. Yet, research addressing how indicators are used and how they can be standardised is missing, providing two main reasons why an improved understanding of UHI tool characteristics and an associated taxonomy may help indicator producers and users.

First, indicator researchers have tended to focus on the development and validation of indicator tools, rather than investigating how such tools are used by policy- and decision-makers [15]. The production of new indicator tools is often a duplication of previous research efforts. However, there is recognition that locally developed tools may increase acceptability and allow for tailoring of indicators to local needs [19, 22, 23]. In fact, some have argued that the process of indicator development is at least as important in achieving change as the eventual use of indicators [16, 22]. Increased understanding of the characteristics of UHI tools which meet the needs of policy and decision-makers could reduce wasted efforts by indicator producers and increase usability for indicator users.

Second, despite the large amount of research on indicator development, there is still a lack of consensus on how to measure the urban environment's impact on health and related concepts. Standardising the development of urban health indicators is a topic of ongoing debate [23, 24]. Despite the large number of UHI tools already available, researchers continue to contribute new international indicator sets whilst implicitly supporting greater standardisation (see [25, 26]). Salvador-Carulla and colleagues argued that there is a lack of international consensus on indicators and that indicator tools 'lack adequate semantic interoperability' [20]. A taxonomy which describes the general characteristics of UHI tools would provide a useful step toward standardisation, resulting in reduction of duplicated efforts and easier identification of appropriate UHI tools.

To our knowledge, there exist three reviews of relevant indicators. The Prasad et al. systematic review of urban health metrics highlighted the lack of available data for metrics in low and middle income countries and questioned the translation of evidence gained through using such metrics into policy and decision-making [27]. Rothenberg et al. conducted a non-systematic review of urban health indicators and metrics which found that indicator sets focus on large-area comparisons (nations, states) and that small-area comparisons (cities, neighborhoods) are relatively underdeveloped [19]. They also observed similarity in the domains measured across compilations. The Badland et al. review of urban liveability indicators for the Australian urban planning policy context found inconsistency in how domains were measured, a relative lack of validated indicators and a lack of information on how to apply indicators to inform urban policy and practice [9].

This systematic review examines a specific type of indicator compilation which could inform municipal built environment policy and decision-makers about the social determinants of health, defined as 'urban health indicator tools'. The review has two distinct parts, as outlined in a previously published protocol [28, 29]. Part A seeks to conduct a census of UHI tools to describe their characteristics and develop a taxonomy of such tools. Part B seeks to explore the perceptions and use of UHI tools by built environment policy and decision-makers. Both parts examine how UHI tools address the complexity of urban health and how this complexity affects policy and decision-making. This paper reports the findings of Part A.

Methods

The protocol for this review was published in *Systematic Reviews* including a completed PRISMA-P checklist [28]. From January 27, 2016 to February 24, 2016, we searched seven bibliographic databases using search terms and MeSH subject headings related to (1) the urban environment, (2) health and related concepts and (3) indicators. We conducted Google Advanced searches on six practitioner websites and the internet using specified search terms in line with the search strategy for databases. There was no date restriction on database searches. We hand-searched four key journals with date restrictions of 3 to 5 years depending on the relevance of articles found and the number of volumes per year. Table 1 shows the sources searched for the review.

Eligibility Criteria

A UHI tool was defined as 'a collection of summary measures about the physical urban environment's contribution to human health and wellbeing' [28]. A combination of indicators can be referred to as a set, compilation, collection or tool [19, 30, 31]. We selected the term 'tool' because it reflects a utility or intention to support policy and decision-making. Tools which sought to measure the related concepts of quality of life (QOL), wellbeing and liveability were also included. During the screening stage, we decided to include tools which measured the impact of the physical urban environment on walkability/physical activity (PA) as this is an important contribution of the built environment toward promoting good health [32, 33]. Any UHI tool which met the definition was referred to in peer-reviewed or grey literature documents (including websites) and was published in English was included in the review. UHI tools needed to measure at least two different aspects of the physical urban environment to be included (e.g. housing and air quality).

All documents were screened by the principal investigator (HP) and a random sample of 10% of documents were screened by a second reviewer (KG) at the title and abstract and full paper screening stages. Differences were resolved through discussion. Eppi-Reviewer software was used to manage all documents and screening.

Data Extraction and Analysis

The name of each UHI tool was entered as a search term in Google to find additional information and sources. Data were extracted from the original source wherever possible. Characteristics of UHI tools were extracted and analysed in Excel. The characteristics extracted were informed by a scoping review (reported in the protocol) and included four additional points that were not listed in the protocol:

- Topic: concept that the UHI tool measured (e.g. health or liveability)

Table 1 Databases, websites and journals searched for the review, including years hand-searched for journals

Source type	Source
Bibliographic databases	Applied Social Sciences Index and Abstracts (ASSIA)
	Campbell Library
	Embase
	Medline
	Scopus
	Social Policy and Practice
	Web of Science Core Collection (includes the Social Sciences Citation Index)
Websites	Town and Country Planning Association (UK)
	Royal Town Planning Institute (UK)
	Planning Institute of Australia
	American Planning Association
	Built Environment and Public Health Clearinghouse (USA)
	World Health Organization Europe, Urban Health, Healthy Cities
Hand-searched journals	Annual Review of Public Health (5 years)
	Social Science and Medicine (3 years)
	BMC Public Health (1 year)
	Social Indicators Research (3 years)

- Main source of data (e.g. municipal datasets or resident surveys)
- Indicator type: subjective or objective (as defined in Lowe et al. [36 p. 136])
- Whether the tool had been used beyond research

The last point was informed by the Google search of each indicator tool. If this search produced evidence of case studies, policy documents or other uses beyond the original research paper, this was marked as 'used beyond research'. The others were marked as 'unknown'.

We modified approaches used by Salvador-Carulla et al. [20] and Wardrop et al. [21] to develop our taxonomy. Salvador-Carulla and colleagues developed key topics for their taxonomy by reviewing published literature and indicator lists. Then they discussed these topics with expert groups. Wardrop and colleagues developed their taxonomy on the basis of characteristics of environmental indicators which would be useful for environmental managers using a survey of government officials. We combined and modified these approaches. We used relevant literature [9, 19, 27] and the data gathered in the review to identify five key characteristics of UHI tools for built environment professionals: spatial scale, purpose, topic, scope and format. These became the highest level category within the taxonomy, denoted as 'class'. Data were extracted on each of the five classes. The second order in the taxonomy, 'sub-class', was developed during the analysis of data extracted in the review, noting differences within each class and categorising these in an iterative process. UHI tools may have characteristics from multiple sub-classes (they are not mutually exclusive). Indicator domains (listed as sub-classes under 'scope') were selected using a set of domains identified from previous reviews [9, 19]. For analysis purposes, all 8006 indicators were standardised to this list of domains. It is possible to divide these domains into smaller groups (e.g. chronic diseases and injuries could be sub-domains under the domain of health outcomes).

During data analysis the term neighborhood was grouped with other sub-city spatial scales including ward and district. Lower than neighborhood scales were also grouped together, representing street or household scale for example. Given variation in the meaning of terms like 'district' or 'post-code', scales were assigned on the basis of authors' descriptions.

UHI tools report data, and are available for use, at different spatial scales. These were reported using three terms: spatial scale, general geography and specific geography. Spatial scale referred to the level of data aggregation for which the tool reported indicator data.

General geography referred to the geographical scales in which a particular UHI tool could be accessed (such as a city, county or state). Specific geography added a place name to that general term. For example, the U.S. Centers for Disease Control and Prevention's 'Environmental Public Health Tracking Network' covered the whole country and allowed users to select indicator data at the county and zip code scales (with comparison of state averages as well) [34]. The data for this UHI tool was thus extracted as:

- Spatial scale: multiple (county, zip code)
- General geography: country
- Specific geography: USA

Results

The flow of documents through the review is shown in the PRISMA diagram (Fig 1). There were 9097 records identified in the database, internet and journal searches. After duplicates were removed, 6510 titles and abstracts were screened. Of these, 370 were included in a full-text review. Finally, 198 documents were included in the Part A census of UHI Tools. These documents referred to 145 separate urban health indicator tools (Appendix 1) which comprised 8006 indicators.

Taxonomy of UHI Tools

Figure 2 shows our taxonomy with five classes: spatial scale, purpose, topic, scope and format. In this section, we present the taxonomy and review each class and its sub-classes.

Spatial Scale

Of the UHI tools included in this review, 59.3% (86/145) measured data at the neighborhood

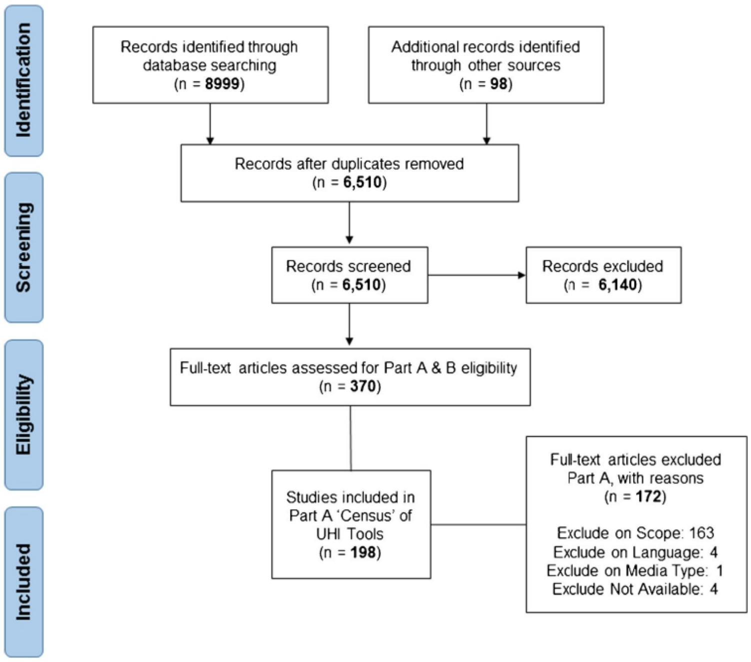

Fig. 1 Flow of documents through the review, following PRISMA reporting style [35]

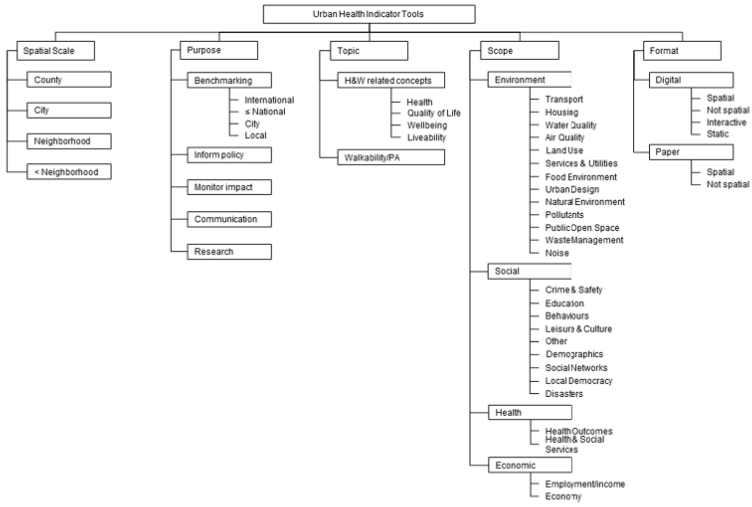

Fig. 2 Taxonomy of urban health indicator tools. H&W, health and wellbeing; PA, physical activity

scale or lower. Over time, the proportion and number of UHI tools which present data at the neighborhood scale and lower has increased (Figs. 3 and 4).

Purpose

Of UHI tools, 82.8% (120/145) stated that part of their purpose was to inform policy and decision-

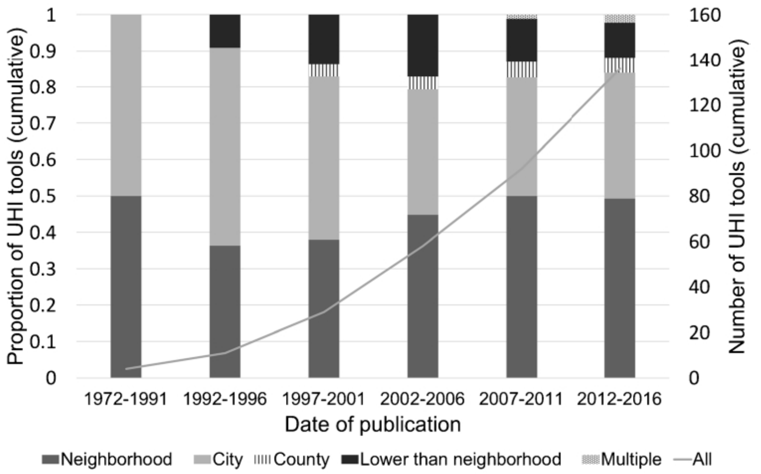

Fig. 3 Change over time of proportion of UHI tools by spatial scale compared with cumulative growth of UHI tools. N.B. Missing data for 9/145 UHI tools: 7 did not report a date of publication and 2 did not report spatial scale

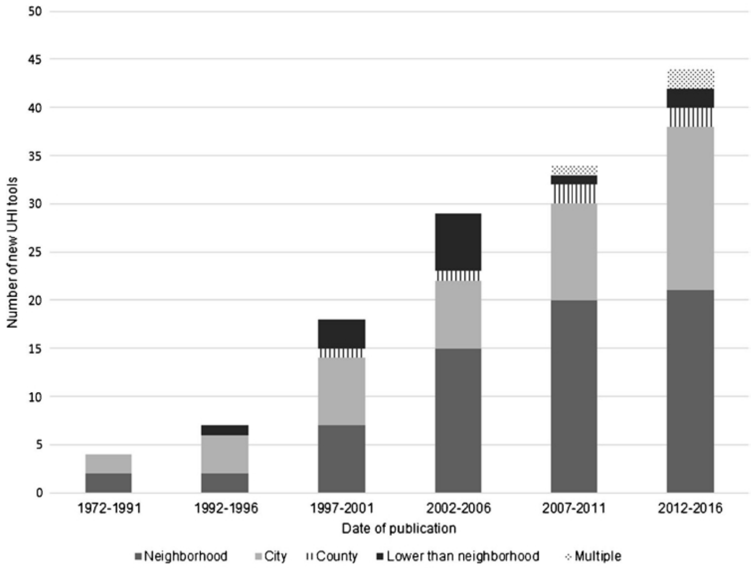

Fig. 4 Number of new UHI tools by spatial scale. N.B. Missing data for 9/145 UHI tools: 7 did not report a date of publication and 2 did not report spatial scale

making (Fig. 5). Monitoring and evaluation (45.5%, 66/145), research (41.4%, 60/145), local comparison/benchmarking (40.0%, 58/145) and communicating with non-specialists (35.9%, 52/

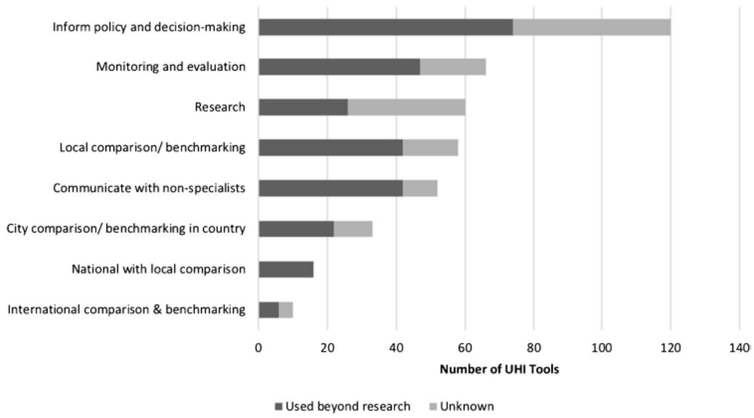

Fig. 5 Number of UHI tools in each stated purpose categorised by those which were used beyond research and 'unknown'

145) were also commonly stated goals of UHI tools. The majority of tools (54.5%, 79/145) were found to be used beyond research.

Topic

The concepts of QOL, wellbeing and liveability are closely related to human health and their definitions overlap significantly. Table 2 lists a selection of definitions or explanations of these concepts which were identified in the systematic review (or citations found therein) and demonstrates overlaps between the ways in which these concepts were defined.

Analysis of the indicator domains showed that there is some homogeneity of scope across tools which measure different health-related concepts, with the exception of walkability/PA tools (Fig. 6). Each topic area (excluding walkability/PA) measured a similar proportion of environmental (18.2– 44.1%), social (23.2– 41.8%), health (7.6–27.7%) and economic indicators (7.9– 13.5%). Given the significant difference of scope in the walkability/PA tools (75.1% environmental indicators), this topic area was noted as a separate subclass in the taxonomy to the more similar health-related concepts.

Health and wellbeing (H&W) (45.5%, 66/145) and QOL (22.1%, 32/145) were the most common topic areas across the tools. Walkability/PA tools (13.8%, 20/145) are a relatively recent addition in urban health metrics (Fig. 7). Bradshaw's Walkability Index from 1993 was the first example, with the remainder produced from 2002 [41]. There were only four UHI tools found between 1972 and 1991, with the number of new tools increasing 14 times by the end of 2006. The rate of growth was between 100 and 200% between 1972 and 2006 (Fig. 7). In the last decade, the growth rate has slowed to between 46.8 and 56.7%.

Table 3 shows a breakdown of domains across topic areas. Between four to seven of the top ten domains for health and wellbeing appear in the top ten for the other topic areas, illustrating the overlap of domains across each topic. The least similar topic is walkability/PA which only shares four domains with the H&W topic.

Scope

Indicators under the scope of environment made up the largest portion (41.9%, 3351/8006). Table 4 shows the four scopes with each of their composite domains and the number of indicators in each.

UHI tools measured between 3 and 286 individual indicators (average 56). Across the 145 UHI tools, 3 did not report the full list of indicators.

Table 2 Definitions and explanations of quality of life, liveability and wellbeing concepts from selected papers included in the systematic review or citations found therein

Concept	Definition
Quality of life	'The wellbeing of individuals within the context of their environment' [36]
	'An individual's happiness or satisfaction with life and environment including needs and desires and other tangible and intangible factors which determine overall wellbeing' [37, 38]
Liveability	'Closely aligned with the social determinants of health' [9]
	'The human requirement for social amenity, health and wellbeing and it includes both individual and community wellbeing' [39]
Wellbeing	"Associated with concepts such as happiness, life satisfaction and social capital, all of which fall under the rubric of a 'social quality of life'" [40]
Community wellbeing	'Reflect a community's health status and its basic quality of life' [40]

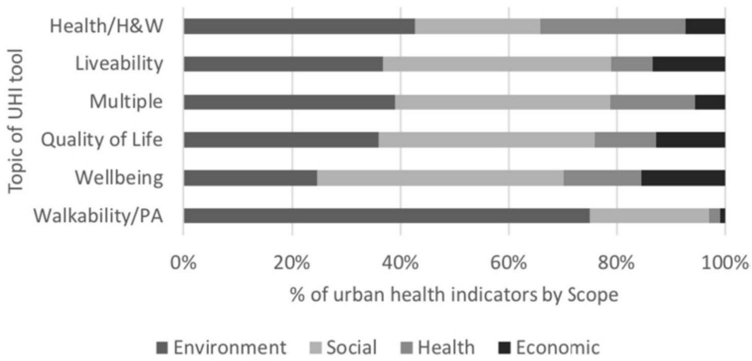

Fig. 6 Scope of indicators across UHI tool topics. PA, physical activity; H&W, health and wellbeing

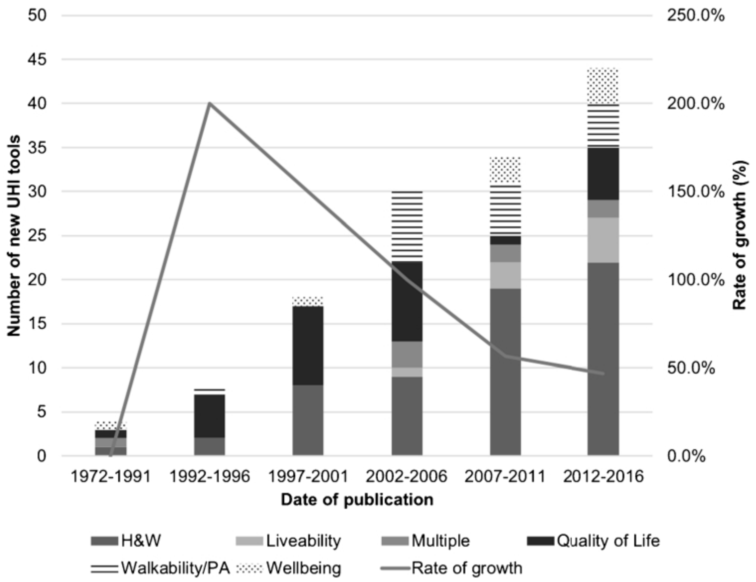

Fig. 7 Date of publication of UHI tools by topic area and rate of growth. N.B. Missing data for 7/145 UHI tools which did not report a date of publication

Table 3 Number of indicators in each domain across UHI tool topic areas, sorted by H&W

	Topics						
Domains	**H&W**	**Liveability**	**Multiple**	**Quality of Life**	**Walkability /PA**	**Wellbeing**	**Total**
health outcomes	862	15	33	139	11	60	1120
transport	394	81	18	163	293	35	984
employment and income	254	60	11	159	7	63	554
behaviours	229	29	41	43	15	28	385
water quality	211	6	1	20	1	1	240
housing	197	52	21	147	19	33	469
air quality	195	11	1	39	1	10	257
education	178	69	16	158	8	43	472
health and social services	177	41	17	69	3	19	326
crime and safety	155	54	30	157	53	58	507
land use	146	6	4	27	55	1	239
pollutants	105	5	4	6		3	123
food environment	103	7	37	11	38	3	199
demographics	100	22	7	71	19	19	238
services & utilities	93	29	7	83	2	7	221
leisure and culture	72	62	18	97	35	34	318
natural environment	65	21	13	38	13	6	156
public open space	62	30	6	46	13	10	167
social networks	62	12	6	37	2	37	156
economy	42	39	7	76		22	186
other	42	26	4	121	14	45	252
urban design	37	9	8	37	71	7	169
waste management	33	5	4	38		7	87
local democracy	29	29	2	44	1	20	125
noise	14	11	1	11	1	2	40
disasters	4	5	3	4			16
Grand Total	3861	736	320	1841	675	573	8006

Top 10 domains are highlighted in green for each UHI topic area

H&W health and wellbeing, *PA* physical activity

Format

Of UHI tools, 44.1% (64/145) displayed data on static or interactive maps, and from 1997, the number and proportion of these tools has grown (Fig. 8). Interactive maps allowed users to select indicators and/or locations to be mapped through an online dashboard. Nearly all (96.0%, 24/25) of the UHI tools which had an interactive mapping function intended to inform policy and decision-making. Examples include 'Peg Wellbeing Indicators' and the health profiles on the 'Plan for a Healthy Los Angeles' website [42, 43]. Three-quarters of these interactive UHI tools (76.0%, 19/25) displayed data at the neighborhood scale. Most of these tools (92.0%, 23/25) also allowed local comparison and benchmarking across other neighborhoods and counties.

Other Characteristics of UHI Tools

This portion of the results section presents additional characteristics of UHI tools which were not used to form the taxonomy. See the protocol for the full list of items extracted and the Supplementary Material section for additional details and results.

Of the tools, 37.9% (55/145) were available at the city-scale with national systems following closely behind (31.0%, 45/145). Many tools were available

Table 4 Indicator domains grouped by scope across all UHI tools (total of 8006 indicators)

Category	Domains	Number of indicators
Environment		
	Transport	984
	Housing	469
	Air quality	257
	Water quality	240
	Land use	239
	Services and utilities	221
	Food environment	199
	Urban design	169
	Public open space	167
	Natural environment	156
	Pollutants	123
	Waste management	87
	Noise	40
	Category total	**3351**
Social		
	Crime and safety	507
	Education	472
	Behaviours	385
	Leisure and culture	318
	Other	252
	Demographics	238
	Social networks	156
	Local democracy	125
	Disasters	16
	Category total	**2469**
Health		
	Health outcomes	1120
	Health and social services	326
	Category total	**1446**
Economic		
	Employment and income	554
	Economy	186
	Category total	**740**

internationally (19.3%, 28/145). Tools were found for 28 individual countries (Fig. 9). In addition, there were 28 international tools (i.e. could be used in any country) and 4 European tools.

Research institutions were the largest producer of UHI tools (54.5%, 79/145). Many of the tools produced by research institutions were not found to have been used beyond research (62.7%, 37/59). The funding source was often not stated (46%, 67/145). Where reported, the largest funder of UHI tools was government (17.9%, 26/145). Of the UHI tools, 86.9% (126/145) reported some information about the methodology. Evidence which informed the methodology or indicator selection was reported in 99/145 cases (68.3%). Peer-reviewed literature was the largest primary source of evidence used in 52.4% (76/145) of tools. The majority of tools (57.9%, 84/145) used existing datasets from multiple organisations to measure the indicators.

A significant number of tools referred to complexity in the methodology (43%, 63/145). The word complexity was mentioned in 128 instances covering multiple topics, including:

- Indicators/indices can simplify or mask the complexity of the concepts being measured
- The urban environment impact on health and behaviour is complex
- Measuring the urban environment's impact on health is complex
- The process of policy and decision-making is complex

Eleven UHI tools stated that indicators or composite indices can simplify the complexity of the concepts being measured. In relation to the City of Winnipeg Quality of Life Indicators, Hardi and Pintér explained: '[i]ndicators are used to simplify information about complex phenomena, such as sustainable development or, in this case, QOL, in order to make communication easier and quantification possible' [11]. This was contrasted by the opposing view that indicators/indices can mask complexity (two instances). The authors of the London Quality of Life Indicators stated: '[a]lthough the Commission have sought to identify and report on 20 headline indicators, to constitute a popular 'barometer' for London's quality of life, it is clear that single figure measures can mask a much more complex situation' [44].

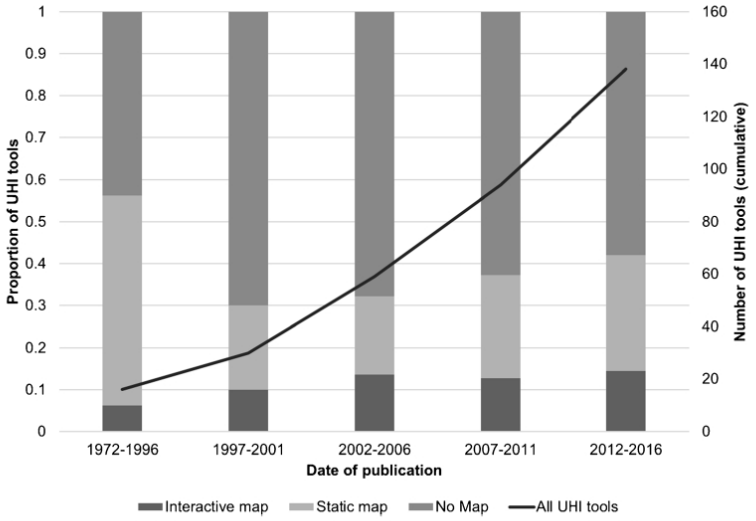

Fig. 8 Proportion of UHI tools which display data on static and interactive maps over time, compared with the cumulative growth of all UHI tools. N.B. Missing data for 7/145 UHI tools which did not report a date of publication

Three UHI tools referred to the complex process of policy and decision-making, sometimes in recognition that indicators may not inform policy due to this complexity. For example, Hunt and

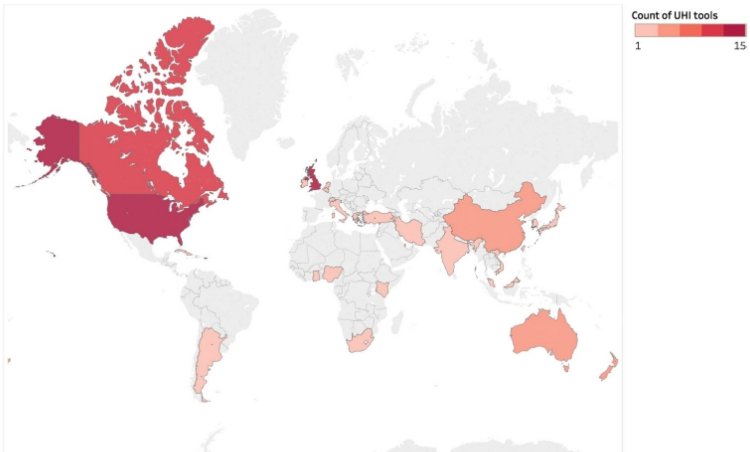

Fig. 9 Location of UHI tools internationally. N.B. Tools which apply in more than one country are not shaded

Lewin commented that 'policy action may not easily follow the identification of environmental health problems [through indicators], which is due both to the large numbers of other factors that also affect health and to the complexity of the policy process' [45].

UHI tools rarely explained strategies used to help account for complexity. Feneri et al. used Multi-criteria Decision Analysis to 'conceptualize the complex issue of evaluating quality of life' [46]. They specified the use of Analytical Hierarchy Process to prioritise indicators. The AARP Livability Index used a high number of indicators to address complexity, stating: '[s]imple questions about livability [sic] can have complex answers. This is why the index includes a large number of metrics' [47].

Discussion

This review identified great diversity in the purpose and characteristics of urban health indicator tools making it difficult to draw simple conclusions. However, the review generated novel findings about UHI tools as they relate to the needs of built environment policy and decision-makers. Our taxonomy demonstrates the importance of considering users' needs when developing indicator tools to ensure they can be used to support built environment practitioners. Our main findings are summarised here with implications discussed below. First, we found that the proportion of tools with data aggregation/measurement at the neighborhood and lower scale and presentation of data via digital interactive maps have both increased over time. Second, we highlighted that the majority of UHI tools *intend* to inform policy and decision-making, yet it is unclear whether a significant number achieve this aim. Third, we found that the majority of UHI tools are evidence-based and therefore provide a potential route from research through to policy. Fourth, we have explored the nature of how UHI tool methodologies address complexity, identifying specific strategies. Finally, we have shown that there is a degree of similarity in the domains measured across UHI tool topics.

In comparison to existing reviews of indicators which measure the urban environment's impact on health, this review casts a wider net by including measures of health, QOL, liveability, wellbeing, and walkability/physical activity. This has enabled a detailed analysis of a large number of indicator tools and their respective characteristics, including 8006 individual indicators. The review was limited to English language publications, potentially excluding many UHI tools from non-English language countries. The method used to classify whether a tool had been used beyond research was simplistic and may have underestimated those tools which were indeed used beyond research.

The increasing number of UHI tools with data aggregation at neighborhood or lower scale is of significance for built environment policy and decision-makers. In 2002, Talen questioned the usefulness of indicators to inform urban planning because the majority were comparing cities (inter-city) rather than neighborhoods (intra-city) [48]. Neighborhood and lower scale of measurement or data aggregation is more appropriate for identifying health inequalities and environmental deprivation which may contribute to poor health [49]. Indicators at this scale can be used to inform neighborhood development/regeneration policies and monitor the impact of these over time. Data visualisation is also frequently noted as a helpful feature of UHI tools for built environment policy and decision-makers, particularly in relation to displaying data on maps [19, 27]. The growing numbers of UHI tools which present data on interactive maps at the neighborhood or lower scale are likely to be a powerful source of information for built environment policy and decision-makers.

A number of tools (31.7%, 46/145) did not explain the evidence used for indicator selection, creating questions over the suitability of their use in policy and decision-making. Although the validity of individual indicators (association between exposure and outcome) was not assessed by this review, the range of methods for selecting indicators demonstrated that this process was not always informed by evidence about environmental exposures and health effects. Badland et al. called for further research about the validity of indicators within UHI tools (specifically in relation to liveability indicators) [9]. However, we would suggest that there is a large selection of validated indicators in the published literature and research efforts may be better directed toward understanding how existing indicators are used to guide the policy and decision-making process.

The distinction of whether UHI tools are used beyond research is of interest when considering transfer of research knowledge to practitioners. We were unable to confirm whether 45/120 tools (37.5%) which intended to inform policy/decision-making achieved this aim. There could be a delay between research and use or this may also point to other knowledge translation issues. UHI tool producers should consider the needs of their audience and may benefit from wider strategies to increase research use by policy and decision-makers (see [50]). The apparent low use of many UHI tools leads us to consider whether greater standardisation of indicators is required rather than development of new indicator tools.

Standardisation of UHI tools may be aided by our finding that there is significant overlap across domains measuring health-related topics such as QOL, liveability and wellbeing. Rothenberg et al. also found similarities in indicator domains across urban health indicator compilations [19]. Guidance on developing indicators of health and the determinants of health is supported by specific frameworks (e.g. DPSEEA) that emphasise the requirement for an evidence-based, often causal relationship between environmental exposures and specific health outcomes [24, 51]. This formality may increase the acceptability of a standardised set of indicators. However, lack of consensus over how to define and measure related topics like QOL, wellbeing and liveability (despite similarity in existing UHI tools) may mean that standardisation for these topics is harder to achieve.

A standardised set of global indicators would mean that rather than developing new UHI tools, researchers and practitioners could choose from an internationally published set of evidence-based indicators. Local selection of indicators would likely be based on data availability, health priorities and community opinion. The WHO's Urban Health Index provides methods for local public health data analysts to produce local indices (including instructions for mapping the results) [52, 53]. Such a tool is valuable to avoid duplicated effort when selecting appropriate indicator aggregation methods. However, we suggest that a set of global evidence-based indicators, which the WHO's Urban Health Index currently lacks, would be of great value to local indicator projects. Given that many global UHI tools are already available, a standardised set would need to be widely promoted and supported to achieve impact and avoid further duplication of effort. Further research is needed to determine whether a standardised set of urban health indicators could be promoted globally and accepted locally (such as the Sustainable Development Goals).

Whilst some indicator producers recognised that indicators could help explain complex phenomena, other authors noted that they may not be effective at influencing a complex policy and decision-making process. This topic will be explored further in a subsequent paper related to this systematic review which will synthesise qualitative data from studies exploring the use of UHI tools in the built environment policy and decision-making process.

Observing the similarity across indicator measures, there is a question about whether some data are included simply because they are easy to measure (or commonly measured as a part of routine statistics), whilst other more difficult topics are excluded. For example, although noise is known to impact multiple health outcomes [54], it is less frequently measured in UHI tools, reflecting the difficulty of measuring this exposure. This is an area for further investigation. The growth of city datasets emerging from open data initiatives may increase the need for indicators to help interpret and make sense of data. This may also support increased small-scale spatial comparisons, improving usability by built environment policy and decision-makers. New data from smartphones, social media and other sources are also likely to increase available datasets for UHI tools and may be a useful way to increase citizen participation in generating and evaluating indicator data.

Appendix 1

Table 5 All UHI tools identified in the review with their characteristics relating to the five classes in the taxonomy

Tool/index	Topic	Spatial Scale (of data aggregation)	Place (of tool availability)	Format		Scope (no. of indicators)			
				Interactive map	Static map	Economic	Environment	Health	Social
2011 Livable City Index [55]	H&W	City	China			8	73	5	33
Abbreviated Neighborhood Environment Walkability Scale (ANEWS) [56]	Walkability/PA	Neighborhood	International			0	33	0	21
Active Neighborhood Checklist [57]	Walkability/PA	<Neighborhood	USA			0	43	0	7
Active Transportation and Health Indicators [58]	H&W	City and neighborhood	Peterborough, Canada		Y	3	79	12	9
Activity-Friendly Index [59]	Walkability/PA	City and neighborhood	Toronto, Canada		Y	0	4	0	1
American Fitness Index [60]	Walkability/PA	City	USA			3	9	9	22
ANQoLHP Neighborhood Health Index [61]	H&W	City and neighborhood	Atlanta, GA, USA	Y		0	2	6	0
ANQoLHP Neighborhood Quality of Life Index [36]	Quality of life	City and neighborhood	Atlanta, GA, USA	Y	Y	1	7	1	2
Baltimore Neighborhood Indicators Alliance, Vital Signs [62]	Quality of life	City and neighborhood	Baltimore, MD, USA	Y		27	46	15	74
Border Observatory Project [63]	Quality of life	City	USA and Mexico			5	16	5	18
Bristol Quality of Life Indicators [64]	Quality of life	City and neighborhood	Bristol, UK	Y	Y	4	42	12	89
British Colombia Atlas of Wellness [65]	Multiple	Multiple	British Columbia, Canada		Y	7	22	33	64
Buffalo City QOL Survey [66]	Quality of life	City and neighborhood	Buffalo City, South Africa			6	27	3	21
Built Environment Assessment Tool [67]	H&W	<Neighborhood	International			0	71	0	6
Built Environment Site Survey Checklist, BESSC [68]	H&W	<Neighborhood	England			0	18	0	9
CANVAS (Computer-Assisted Neighborhood Visual Assessment System) [69]	H&W	<Neighborhood	International			0	134	1	27
Caya Hueso Urban Ecosystem Health Indicators [70]	H&W	Neighborhood	Habana, Cuba			5	17	11	16
Child Opportunity Index [71]	H&W	Neighborhood	USA	Y	Y	5	6	1	7
Childhood wellbeing indicators [72]	Wellbeing	Neighborhood	International			3	5	5	18
Children's Environmental Health Indicators [73]	H&W	Not specified	International			5	18	25	6

Table 5 (continued)

Tool/index	Topic	Spatial Scale (of data aggregation)	Place (of tool availability)	Format		Scope (no. of indicators)			
				Interactive map	Static map	Economic	Environment	Health	Social
Christchurch City Health and Wellbeing Profile [74]	H&W	City	Christchurch, New Zealand		Y	4	13	13	18
City Ecosystem Health Index [75]	H&W	City	Chongqing, China			4	11	2	2
City Livability Index [76]	Liveability	City	China			5	4	3	2
City of Melbourne Urban Health Profile metrics [77]	H&W	City and neighborhood	Melbourne, Australia			1	4	11	16
City of Winnipeg Quality-of-Life Indicators [11]	Quality of life	City	Winnipeg, Canada			14	25	6	15
Coalitions Linking Action and Science for Prevention (CLASP) Tool [78]	Walkability/PA	Neighborhood	Canada	Y	Y	4	31	2	19
Colorado Health Indicators [79]	H&W	County	Colorado, USA	Y	Y	13	23	91	60
Combined Environmental Stressor's Exposure (CENSE) Tool [80]	H&W	Neighborhood	International			0	7	0	0
Communities Count [81]	H&W	County	King County, WA, USA		Y	49	25	66	113
Community Health and Equity Index [82]	H&W	Neighborhood	Los Angeles, CA, USA		Y	3	16	7	3
Community Health Environment Scan Survey (CHESS) [83]	H&W	Neighborhood	International			0	28	0	24
Community Health Status Indicators [84]	H&W	County	USA	Y		2	6	28	7
Community Healthy Living Index [85]	H&W	Neighborhood	USA			0	23	1	12
Community Indicators Victoria [86]	H&W	≥ City	Victoria, Australia	Y		13	80	14	83
Community Well-Being Index (A) [87]	Wellbeing	City	Korea			14	11	12	47
Community Well-Being Index (B) [88]	Wellbeing	City	Flint, MI, USA			11	25	4	64
Community Wellbeing Questionnaire [13]	Wellbeing	Neighborhood	International			3	11	2	29
Core Environmental Health Indicators in Lucknow and Calcutta [45]	H&W	Neighborhood	India			0	9	0	1
County Health Rankings [89]	H&W	County	USA	Y		3	7	19	8
DECAMB Programme Indicators for the Urban Environment [90]	Quality of life	Not specified	Italy			0	6	1	4
Edmonton LIFE: Local Indicators For Excellence [91]	Quality of life	City	Edmonton, Canada			12	11	10	21
Environmental Index [92]	H&W	City	Netherlands		Y	0	4	0	0
	H&W	City	USA			3	55	9	4

Table 5 (continued)

Tool/index	Topic	Spatial Scale (of data aggregation)	Place (of tool availability)	Format		Scope (no. of indicators)			
				Interactive map	Static map	Economic	Environment	Health	Social
Environment Health Sustainability (EHS) Index [93]									
Environmental Health Basic Exposure Survey [94]	H&W	Neighborhood	Baltimore, MD, USA		Y	0	12	9	1
Environmental Health Indicators New Zealand (EHINZ) [95]	H&W	City and neighborhood	New Zealand	Y		1	32	16	7
Environmental Profile of a Community's Health (EPOCH 1) [96]	Walkability/PA	Neighborhood	International			0	26	3	9
Environmental Public Health Tracking Network Indicators [34]	H&W	≥ County	USA	Y		6	132	119	15
Environmental Quality Index [97]	Multiple	Neighborhood	Argentina		Y	1	15	0	7
Environmental Quality Index, EPA [98]	H&W	County	USA		Y	10	203	1	5
Environmental Supports for Physical Activity Questionnaire [99]	Walkability/PA	Neighborhood	USA			0	5	0	12
EPOCH Photo Neighborhood Evaluation Tool (EP-NET) [100]	Walkability/PA	Neighborhood	International			0	51	0	9
European Livable Cities Index [39]	Liveability	City	Europe			3	11	3	6
EURO-PREVOB Community Questionnaire [101]	Multiple	Neighborhood	International			0	28	1	2
EURO-URHIS Urban Health Indicators [102]	H&W	City	Europe			2	6	24	13
FireStar Neighborhood Stability Framework [103]	Multiple	Neighborhood	Maryvale Village, Phoenix, AZ, USA			2	4	4	8
Flemish City Monitor [104]	Liveability	City	Flanders, Belgium			49	97	9	131
Glasgow Indicators Project [105]	H&W	City	Glasgow, Scotland			15	16	9	41
Global City Indicators Facility - Your Health in the City Indicators [106]	H&W	City	International			Y	Y	Y	Y
Global Liveable Cities Index [107]	Liveability	City	International			26	22	7	30
Global Liveability Ranking [108]	Liveability	City	International			0	8	6	16
Happy City Index [109]	Wellbeing	City	England			6	18	15	22
Health and Environmental Sustainability Indicators [110]	H&W	Neighborhood	Vietnam			0	11	4	1
Health Determinants Indicators [111]	H&W	City	Japan			20	23	20	9
Health Indicators Dashboard [112]	H&W	≥ City	Racine, WI, USA			3	14	31	9
Healthy Chicago 2.0 [113]	H&W	City and neighborhood	Chicago, IL, USA	Y		Y	3	4	38	30

Table 5 (continued)

Tool/index	Topic	Spatial Scale (of data aggregation)	Place (of tool availability)	Format		Scope (no. of indicators)			
				Interactive map	Static map	Economic	Environment	Health	Social
Healthy City Noise-Air Index [114]	H&W	City	International			0	5	0	0
Healthy Communities Index [115]	H&W	City	USA			2	4	0	4
Healthy Community Council Assessment [116]	Multiple	≥ City	Harrisonburg and Rockingham, VA, USA			3	9	11	17
Healthy Resources Index [59]	H&W	City and neighborhood	Toronto, Canada		Y	0	3	0	1
Housing and Environmental Quality Indicators [117]	Multiple	Neighborhood	Benin, Nigeria			1	21	1	2
Indicators of Urban Ecosystem Health [118]	H&W	City and neighborhood	Canada			3	28	3	17
Intra-city Social Well-Being Indicators [119]	Wellbeing	Neighborhood	Tampa, FL, USA		Y	11	15	8	13
Irvine-Minnesota Inventory [120]	Walkability/PA	<Neighborhood	USA			0	60	0	10
ISO 37120 [121]	Quality of life	City	International			12	56	9	23
Kansas Health Matters [122]	H&W	County	Kansas, USA	Y	Y	15	24	76	23
Livability Index [47]	Liveability	Multiple	USA	Y		6	36	6	18
Livable Index System [123]	Liveability	Neighborhood	Tiexi District, Shenyang, China			0	18	1	13
Liveability Assessment Tool [124]	Liveability	Neighborhood	Hunter New England, Australia			4	62	20	81
Local Climate Change Environmental Public Health Indicators (EPHI) [125]	H&W	≥ Neighborhood	International	Y		U	U	U	U
Local Health [126]	H&W	≥ Neighborhood	England	Y		8	2	50	25
London Quality of Life Indicators [44]	Quality of life	City	London, UK			8	13	1	11
London Ward Well-Being Scores [127]	Wellbeing	Neighborhood	London, UK	Y		2	3	2	5
London's Health Strategy High Level Indicators [128]	H&W	City	London, UK			2	2	4	2
Maryland Inventory of Urban Design Quality (MIUDQ) [129]	Walkability/PA	<Neighborhood	USA			0	26	0	1
Multiple Environmental Deprivation Index (MEDIx) [130]	H&W	Neighborhood	UK		Y	0	8	0	0
Neighborhood Environment Walkability Scale (NEWS) [131]	Walkability/PA	Neighborhood	International			0	38	0	7
Neighborhood Health Profile Reports [132]	H&W	City and neighborhood	Baltimore, MD, USA		Y	2	11	6	11
	H&W	Neighborhood	England			0	22	0	2

Table 5 (continued)

Tool/index	Topic	Spatial Scale (of data aggregation)	Place (of tool availability)	Format		Scope (no. of indicators)			
				Interactive map	Static map	Economic	Environment	Health	Social
Neighborhood Design Characteristics Checklist (NeDeCC) [133]									
Neighborhood Environment Indices [134]	Walkability/PA	Neighborhood	Putrajaya, Malaysia			0	4	0	0
Neighborhood Quality Index [135]	H&W	Neighborhood	Taiwan			0	1	0	15
New Zealand Quality of Life Project [136]	Quality of life	City	New Zealand			41	58	27	87
New Zealand Systematic Pedestrian and Cycling Environmental Scan (NZ SPACES) [137]	Walkability/PA	<Neighborhood	New Zealand			0	47	0	7
Objective and Subjective Quality of Life Indicators for Taiwan [138]	Quality of life	≥ City	Taiwan			9	5	5	7
Ottawa Neighborhood Study Indicators [139]	H&W	Neighborhood	Ottawa, Canada	Y	Y	Y	Y	Y	Y
Pasadena Quality of Life Index [140]	Quality of life	City	Pasadena/Altadena, CA, USA		Y	7	20	26	18
Pedestrian Environment Data Scan (PEDS) [141]	Walkability/PA	<Neighborhood	USA		Y	0	36	0	1
Peg Well-being Indicators [42]	Wellbeing	City and neighborhood	Winnipeg, Canada	Y		20	23	17	28
Physical Activity Neighborhood Environment Scale (PANES) [142]	Walkability/PA	Neighborhood	International			0	14	0	3
Pilot Environmental Public Health Indicators [143]	H&W	County	USA			0	2	2	0
Places Rated Almanac [144]	Quality of life	City	USA		Y	1	15	7	21
Plan for a Healthy LA Health Atlas/Health Profiles [43]	H&W	City and neighborhood	Los Angeles, CA, USA	Y	Y	21	44	21	26
Proposed indicators linking health and sustainability [26]	H&W	City	International			0	15	5	4
Proxy Environmental Health Indicators for Accra [14]	H&W	Neighborhood	Accra, Ghana			1	69	22	13
Quality of Life Counts (Local) [10]	Quality of life	City	UK			5	17	1	7
Quality of Life in South East Queensland [145]	Quality of life	≥ City	South East Queensland, Australia			0	10	2	8
Quality of Life in the City of Florence [146]	Quality of life	City and neighborhood	Florence, Italy			2	9	0	8
Quality of Life Index for Urban Transitional Neighborhood [147]	Quality of life	Neighborhood	Darvazeshemiran, Tehran, Iran			7	22	4	21

Table 5 (continued)

Tool/index	Topic	Spatial Scale (of data aggregation)	Place (of tool availability)	Format		Scope (no. of indicators)			
				Interactive map	Static map	Economic	Environment	Health	Social
Quality of Life Index in Delhi [148]	Quality of life	City and neighborhood	Delhi, India		Y	2	24	1	5
Quality of Life Indicator Program for San Diego-Tijuana Metropolitan Region [149]	Quality of life	City	San Diego-Tijuana, USA and Mexico			2	17	9	8
Quality of Life Indicators for Galway [37]	Quality of life	City and neighborhood	Galway, Ireland			4	9	0	7
Quality of Life Indicators for Thessaloniki [46]	Quality of life	City	Thessaloniki, Greece			10	21	6	19
Quality of Life Reporting System [150]	Quality of life	≥ City	Canada			20	24	10	33
Quality of Life Survey in Istanbul [151]	Quality of life	Neighborhood	Istanbul, Turkey			2	9	1	6
Quality of Living Index [152]	Quality of life	City	International			2	13	2	13
Quality of Pedestrian Level of Service [153]	Walkability/PA	City	International		Y	0	4	0	1
Quality of Urban Life Assessment Tool [154]	Quality of life	Neighborhood	Doha, Qatar			0	83	0	28
Quality of Urban Life Index [36]	Quality of life	City	Atlanta, GA, USA		Y	5	7	3	5
Residential Environment Assessment Tool [155]	Multiple	<Neighborhood	Wales			2	9	0	17
Richmond Health and Wellness Element Indicators [156]	H&W	City and neighborhood	Richmond, CA, USA			6	21	26	22
Richmond Health Equity Indicators [157]	H&W	City	Richmond, CA, USA			6	17	23	26
San Francisco Indicator Project [158]	H&W	City and neighborhood	San Francisco, CA, USA	Y	Y	18	46	8	35
Scientific Assessment Standards of Livable Cities [159]	Liveability	City	China			6	13	1	13
Seattle Healthy Living Assessment [160]	H&W	Neighborhood	Seattle, WA, USA			0	15	0	2
South Lanarkshire Index of Multiple Environmental Deprivation (SLIMED) [161]	H&W	Neighborhood	South Lanarkshire, Scotland		Y	0	7	1	1
SPOTLIGHT Virtual Audit Tool [162]	Walkability/PA	Neighborhood	Europe			0	34	0	6
Subjective Community Well-Being Indicator [163]	Wellbeing	City	Emilia-Romagna, Italy		Y	4	4	1	14
Systematic Pedestrian and Cycling Environmental Scan (SPACES) [164]	Walkability/PA	<Neighborhood	Australia			0	33	0	6

Table 5 (continued)

Tool/index	Topic	Spatial Scale (of data aggregation)	Place (of tool availability)	Format		Scope (no. of indicators)			
				Interactive map	Static map	Economic	Environment	Health	Social
Think Health LA Indicators [165]	H&W	Multiple	Los Angeles, CA, USA	Y	Y	14	30	150	40
Truckee Meadows Tomorrow [166]	Quality of life	City	Truckee Meadows, NV, USA			15	27	19	60
Urban Health Equity Assessment and Response Tool (Urban HEART) [167]	H&W	City and neighborhood	International			4	8	23	7
Urban Health Equity Indicators for Mathare Informal Settlement [16]	H&W	Neighborhood	Nairobi, Kenya			3	9	2	3
Urban Health Indicators for London [168]	H&W	<Neighborhood	London, UK		Y	1	2	0	1
Urban Quality of Life in Switzerland [169]	Quality of life	City and neighborhood	Switzerland	Y		0	7	0	8
Vulnerability Indices [170]	H&W	Neighborhood	Worcester, MA, USA		Y	1	12	1	3
Walk Score [171]	H&W	Multiple	International	Y	Y	0	3	0	0
Walkability Index [172]	Walkability/PA	City and neighborhood	USA		Y	0	3	0	1
Walkability Index (Bradshaw) [41]	Walkability/PA	Neighborhood	USA			0	6	0	4
Wellbeing Index [173]	Wellbeing	City	Santa Monica, CA, USA			11	10	13	44
West County Indicators Project [174]	H&W	Neighborhood	Richmond, CA, USA		Y	2	7	0	2
WHO Environmental Health Indicators [175]	H&W	≥ City	Europe			2	34	7	1
WHO Healthy City Indicators [176]	H&W	City	International			3	14	11	4
Wholeness Index [177]	Quality of life	City and neighborhood	Dallas, TX, USA		Y	4	3	1	4
Wisconsin Assessment of the Built Environment (WASABE) [178]	Multiple	Neighborhood	USA			2	17	0	10
World Health Organization Quality of Life (WHOQOL-100) [179]	Quality of life	<Neighborhood	International			8	12	16	65
World Health Organization Quality of Life (WHOQOL-BREF) [180]	Quality of life	<Neighborhood	International			1	3	4	18

Table 5 (continued)

Tool/index	Purpose							
	International benchmarking	City (or in country) benchmarking	National with local benchmarking	Local benchmarking	Inform policy and decision-making	Communicate with Non-specialists	Monitoring /evaluation	Research
2011 Livable City Index [55]		Y			Y			
Abbreviated Neighborhood Environment Walkability Scale (ANEWS) [56]								Y
Active Neighborhood Checklist [57]					Y	Y		Y
Active Transportation and Health Indicators [58]				Y	Y	Y	Y	
Activity-Friendly Index [59]				Y	Y			
American Fitness Index [60]		Y	Y		Y	Y	Y	
ANQoLHP Neighborhood Health Index [61]				Y	Y	Y	Y	
ANQoLHP Neighborhood Quality of Life Index [36]				Y	Y	Y	Y	
Baltimore Neighborhood Indicators Alliance, Vital Signs [62]				Y	Y	Y	Y	Y
Border Observatory Project [63]	Y	Y			Y		Y	
Bristol Quality of Life Indicators [64]				Y	Y		Y	
British Colombia Atlas of Wellness [65]		Y		Y	Y	Y		
Buffalo City QOL Survey [66]				Y	Y		Y	
Built Environment Assessment Tool [67]					Y	Y	Y	
Built Environment Site Survey Checklist, BESSC [68]								Y
CANVAS (Computer-Assisted Neighborhood Visual Assessment System) [69]								Y
Caya Hueso Urban Ecosystem Health Indicators [70]					Y	Y	Y	
Child Opportunity Index [71]		Y	Y	Y	Y	Y	Y	Y
Childhood wellbeing indicators [72]				Y				
Children's Environmental Health Indicators [73]					Y	Y	Y	Y
Christchurch City Health and Wellbeing Profile [74]					Y	Y		
City Ecosystem Health Index [75]					Y			
City Livability Index [76]		Y			Y			

Table 5 (continued)

Tool/index	Purpose							
	International benchmarking	City (or in country) benchmarking	National with local benchmarking	Local benchmarking	Inform policy and decision-making	Communicate with Non-specialists	Monitoring /evaluation	Research
City of Melbourne Urban Health Profile metrics [77]				Y	Y		Y	
City of Winnipeg Quality-of-Life Indicators [11]					Y		Y	
Coalitions Linking Action and Science for Prevention (CLASP) Tool [78]				Y	Y			
Colorado Health Indicators [79]			Y	Y	Y	Y		Y
Combined Environmental Stressor's Exposure (CENSE) Tool [80]					Y			
Communities Count [81]			Y	Y	Y	Y	Y	
Community Health and Equity Index [82]				Y	Y		Y	
Community Health Environment Scan Survey (CHESS) [83]					Y			Y
Community Health Status Indicators [84]		Y	Y	Y	Y	Y		
Community Healthy Living Index [85]					Y	Y		
Community Indicators Victoria [86]				Y	Y	Y	Y	Y
Community Well-Being Index (A) [87]		Y			Y			
Community Well-Being Index (B) [88]					Y		Y	
Community Wellbeing Questionnaire [13]					Y		Y	Y
Core Environmental Health Indicators in Lucknow and Calcutta [45]					Y	Y		
County Health Rankings [89]				Y	Y	Y	Y	
DECAMB Programme Indicators for the Urban Environment [90]					Y			Y
Edmonton LIFE: Local Indicators For Excellence [91]		Y			Y	Y	Y	
Environmental Index [92]					Y			
Environment Health Sustainability (EHS) Index [93]					Y	Y	Y	
Environmental Health Basic Exposure Survey [94]					Y			Y

Table 5 (continued)

Tool/index	Purpose							
	International benchmarking	City (or in country) benchmarking	National with local benchmarking	Local benchmarking	Inform policy and decision-making	Communicate with Non-specialists	Monitoring /evaluation	Research
Environmental Health Indicators New Zealand (EHINZ) [95]		Y	Y		Y		Y	
Environmental Profile of a Community's Health (EPOCH 1) [96]								Y
Environmental Public Health Tracking Network Indicators [34]		Y	Y	Y	Y		Y	Y
Environmental Quality Index [97]		Y		Y	Y			Y
Environmental Quality Index, EPA [98]		Y			Y			Y
Environmental Supports for Physical Activity Questionnaire [99]								Y
EPOCH Photo Neighborhood Evaluation Tool (EP-NET) [100]								Y
European Livable Cities Index [39]	Y	Y			Y			
EURO-PREVOB Community Questionnaire [101]				Y	Y			Y
EURO-URHIS Urban Health Indicators [102]	Y	Y			Y		Y	Y
FireStar Neighborhood Stability Framework [103]					Y			
Flemish City Monitor [104]		Y			Y		Y	
Glasgow Indicators Project [105]				Y	Y	Y	Y	
Global City Indicators Facility - Your Health in the City Indicators [106]	Y	Y			Y		Y	
Global Liveable Cities Index [107]	Y				Y			
Global Liveability Ranking [108]	Y				Y			
Happy City Index [109]		Y			Y		Y	
Health and Environmental Sustainability Indicators [110]				Y	Y	Y	Y	
Health Determinants Indicators [111]								Y
Health Indicators Dashboard [112]				Y				
Healthy Chicago 2.0 [113]				Y			Y	
Healthy City Noise-Air Index [114]					Y			Y

Table 5 (continued)

Tool/index	Purpose							
	International benchmarking	City (or in country) benchmarking	National with local benchmarking	Local benchmarking	Inform policy and decision-making	Communicate with Non-specialists	Monitoring /evaluation	Research
Healthy Communities Index [115]					Y			Y
Healthy Community Council Assessment [116]					Y		Y	
Healthy Resources Index [59]				Y	Y			
Housing and Environmental Quality Indicators [117]				Y	Y			Y
Indicators of Urban Ecosystem Health [118]								
Intra-city Social Well-Being Indicators [119]				Y	Y			
Irvine-Minnesota Inventory [120]								Y
ISO 37120 [121]					Y		Y	
Kansas Health Matters [122]			Y	Y	Y	Y	Y	Y
Livability Index [47]		Y	Y	Y	Y	Y		
Livable Index System [123]					Y		Y	
Liveability Assessment Tool [124]				Y	Y		Y	Y
Local Climate Change Environmental Public Health Indicators (EPHI) [125]				Y	Y		Y	
Local Health [126]			Y	Y	Y	Y		
London Quality of Life Indicators [44]					Y		Y	
London Ward Well-Being Scores [127]			Y	Y	Y			
London's Health Strategy High Level Indicators [128]						Y	Y	
Maryland Inventory of Urban Design Quality (MIUDQ) [129]								Y
Multiple Environmental Deprivation Index (MEDIx) [130]		Y		Y	Y			Y
Neighborhood Environment Walkability Scale (NEWS) [131]								Y
Neighborhood Health Profile Reports [132]				Y	Y	Y		
Neighborhood Design Characteristics Checklist (NeDeCC) [133]								Y

Table 5 (continued)

Tool/index	Purpose							
	International benchmarking	City (or in country) benchmarking	National with local benchmarking	Local benchmarking	Inform policy and decision-making	Communicate with Non-specialists	Monitoring /evaluation	Research
Neighborhood Environment Indices [134]				Y				Y
Neighborhood Quality Index [135]				Y	Y			Y
New Zealand Quality of Life Project [136]		Y			Y		Y	
New Zealand Systematic Pedestrian and Cycling Environmental Scan (NZ SPACES) [137]								Y
Objective and Subjective Quality of Life Indicators for Taiwan [138]		Y						
Ottawa Neighborhood Study Indicators [139]				Y	Y	Y		Y
Pasadena Quality of Life Index [140]		Y	Y		Y	Y	Y	Y
Pedestrian Environment Data Scan (PEDS) [141]					Y			Y
Peg Well-being Indicators [42]				Y	Y	Y	Y	
Physical Activity Neighborhood Environment Scale (PANES) [142]					Y			Y
Pilot Environmental Public Health Indicators [143]							Y	Y
Places Rated Almanac [144]		Y				Y		
Plan for a Healthy LA Health Atlas/Health Profiles [43]				Y	Y	Y	Y	
Proposed indicators linking health and sustainability [26]					Y	Y	Y	
Proxy Environmental Health Indicators for Accra [14]				Y	Y	Y		
Quality of Life Counts (Local) [10]		Y	Y		Y	Y	Y	Y
Quality of Life in South East Queensland [145]								Y
Quality of Life in the City of Florence [146]				Y	Y		Y	
Quality of Life Index for Urban Transitional Neighborhood [147]					Y			Y
Quality of Life Index in Delhi [148]				Y	Y			

Table 5 (continued)

Tool/index	Purpose							
	International benchmarking	City (or in country) benchmarking	National with local benchmarking	Local benchmarking	Inform policy and decision-making	Communicate with Non-specialists	Monitoring /evaluation	Research
Quality of Life Indicator Program for San Diego-Tijuana Metropolitan Region [149]	Y			Y	Y	Y	Y	Y
Quality of Life Indicators for Galway [37]					Y	Y	Y	
Quality of Life Indicators for Thessaloniki [46]				Y	Y	Y	Y	
Quality of Life Reporting System [150]		Y	Y		Y		Y	
Quality of Life Survey in Istanbul [151]								Y
Quality of Living Index [152]	Y	Y			Y			
Quality of Pedestrian Level of Service [153]					Y			
Quality of Urban Life Assessment Tool [154]					Y			Y
Quality of Urban Life Index [36]		Y			Y			
Residential Environment Assessment Tool [155]					Y			Y
Richmond Health and Wellness Element Indicators [156]				Y	Y	Y	Y	
Richmond Health Equity Indicators [157]		Y			Y	Y	Y	
San Francisco Indicator Project [158]				Y	Y	Y	Y	Y
Scientific Assessment Standards of Livable Cities [159]		Y			Y			
Seattle Healthy Living Assessment [160]					Y	Y	Y	
South Lanarkshire Index of Multiple Environmental Deprivation (SLIMED) [161]				Y	Y			Y
SPOTLIGHT Virtual Audit Tool [162]								Y
Subjective Community Well-Being Indicator [163]		Y			Y			Y
Systematic Pedestrian and Cycling Environmental Scan (SPACES) [164]								Y
Think Health LA Indicators [165]			Y	Y	Y	Y		

Table 5 (continued)

Tool/index	Purpose							
	International benchmarking	City (or in country) benchmarking	National with local benchmarking	Local benchmarking	Inform policy and decision-making	Communicate with Non-specialists	Monitoring /evaluation	Research
Truckee Meadows Tomorrow [166]					Y	Y	Y	
Urban Health Equity Assessment and Response Tool (Urban HEART) [167]			Y	Y	Y		Y	
Urban Health Equity Indicators for Mathare Informal Settlement [16]					Y	Y		
Urban Health Indicators for London [168]				Y	Y			Y
Urban Quality of Life in Switzerland [169]					Y	Y	Y	
Vulnerability Indices [170]				Y	Y	Y		Y
Walk Score [171]		Y		Y	Y	Y		Y
Walkability Index [172]				Y	Y		Y	Y
Walkability Index (Bradshaw) [41]					Y			
Wellbeing Index [173]					Y	Y	Y	
West County Indicators Project [174]					Y	Y		Y
WHO Environmental Health Indicators [175]	Y				Y		Y	
WHO Healthy City Indicators [176]	Y	Y		Y	Y		Y	
Wholeness Index [177]				Y	Y	Y	Y	
Wisconsin Assessment of the Built Environment (WASABE) [178]				Y	Y		Y	Y
World Health Organization Quality of Life (WHOQOL-100) [179]					Y		Y	Y
World Health Organization Quality of Life (WHOQOL-BREF) [180]					Y		Y	Y

Y yes, *U* unknown, *H&W* health and wellbeing, *PA* physical activity

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A1.4 Published supplementary material for Part A results

This supplementary material was published in Pineo et al. (2018a) and reports additional data and graphs about urban health indicator (UHI) tool characteristics. Headings relate to UHI tool characteristics listed in the review protocol.

Producer

Figure 1 reports the types of organisations which produced UHI tools, ranging from international research collaborations to individual community groups. Research institutions were the largest producer of UHI tools (54.5%, 79/145), although their role as producers is reduced in those tools used beyond research purposes (29.1%, 23/79). City government(s) and non-profit partnerships/organisations developed a larger portion of these tools (19.0%, 15/79; 13.9% 11/79; and 12.7%, 10/79 respectively).

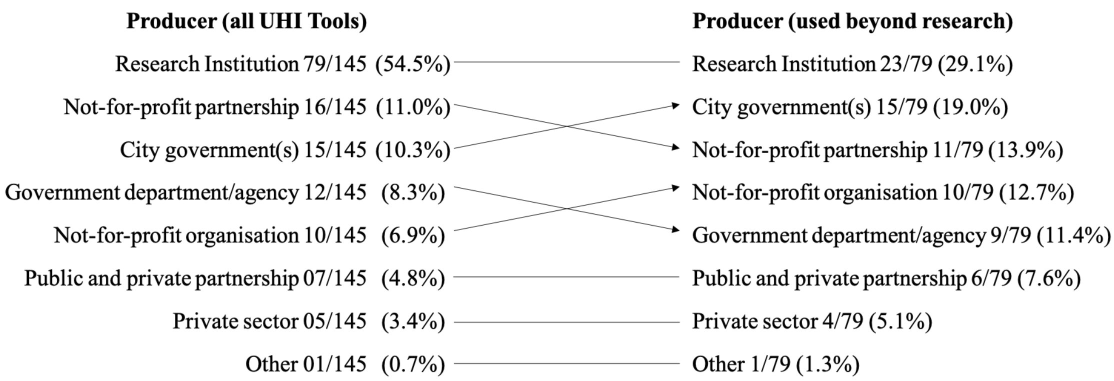


Figure 1 Producers of UHI tools by organisation type, comparing all UHI tools with those used beyond research.

Funder

Figure 2 shows the number of UHI tools funded by different organisation types. The private sector is rarely stated as a funder. Government agencies/bodies were involved in funding 26.2% of all UHI tools (38/145) and 35.4% of those used beyond research (28/79). The amount of funding was not usually stated.

Although research grants were often listed in academic papers, it was not always possible to find the associated funding amount. Three projects reported costs. The EURO-URHIS Urban Health Indicators project, part 2, had a total cost of EUR 3.6 million (The Euro-URHIS Project, 2008). The annual cost of administering one resident Bristol's Quality of Life survey was $20,000 (Shepherd and McMahon, 2009). Developing the Multiple Environmental Deprivation Index (MEDIx) indicators was GBP 74,366 (Richardson et al., 2010). On the basis of this limited data it is not possible to estimate an average cost for the development of new indicator tools.

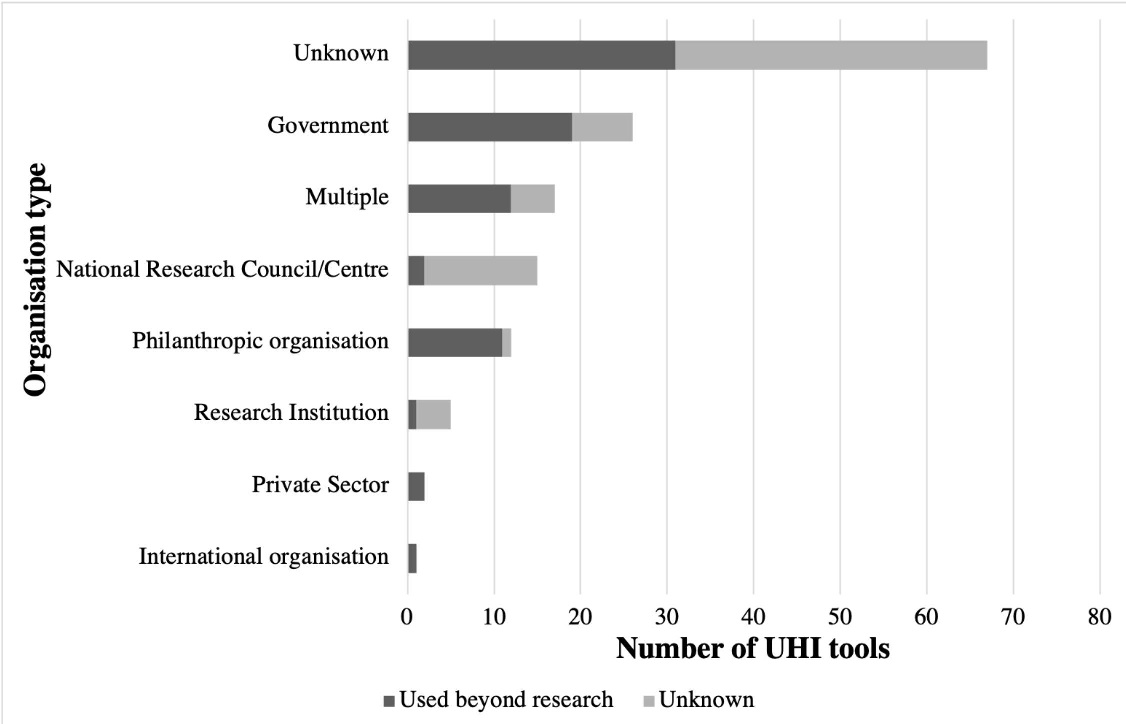


Figure 2 - Number of UHI tools funded by types of organisation, comparing UHI tools used beyond research and those for which their use beyond research is unknown.

Geography

Geography refers to the scale at which particular UHI tools can be accessed. Figure 3 shows the number of tools which are available in various general geographic scales. A large number of tools (41%, 59/145) are available in individual cities, with national systems following closely behind.

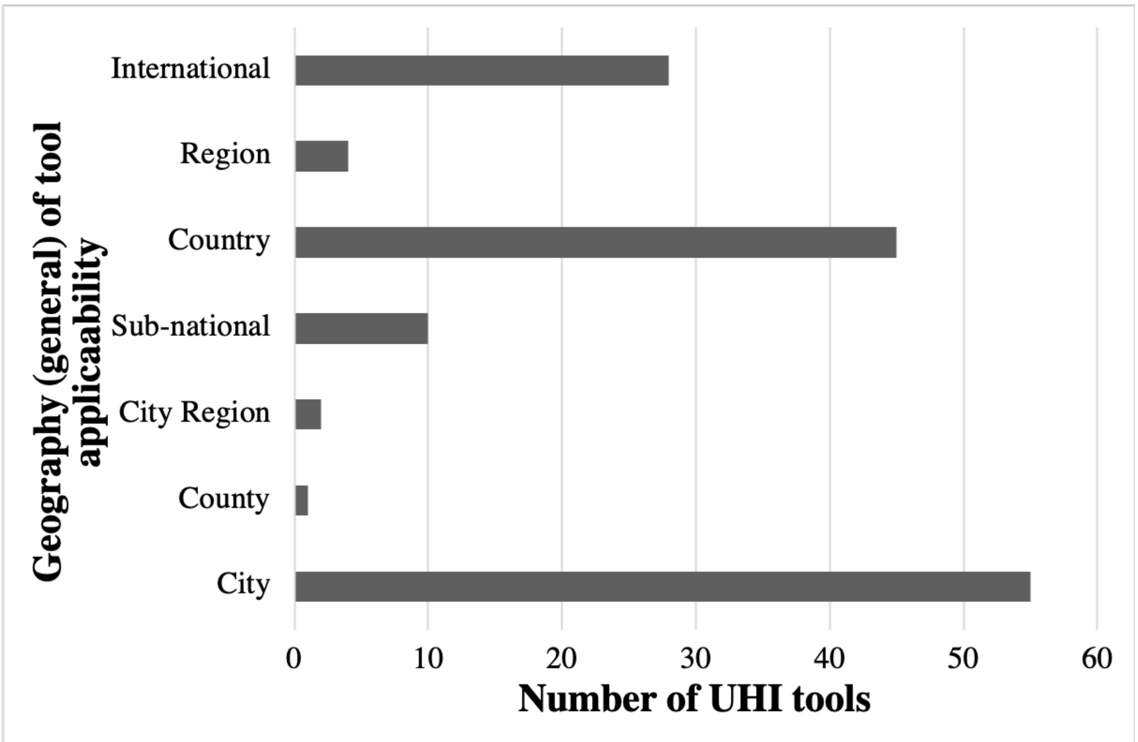


Figure 3 - Number of UHI tools at general geographic scales.

UHI tool methodology

Some information about the methodology used to create the UHI tool was reported in 126/145 (86.9%) of tools. This included a range of potential points including: conceptual considerations, development process, community involvement, indicator selection, evidence-base, data sources, and weighting.

Weighting

The majority of tools (63.4%, 92/145) did not produce an index (or composite indicator). 30.3% (44/145) of UHI tools reported using a weighting system. Of these, 27.3% (12/44) were equally weighted. A number of approaches were taken to derive weighting systems, including statistical methods (such as Z-scores or Principal Component Analysis), expert input (such as Delphi Method or Analytical Hierarchy Process), community input, or user-determined weightings.

Uncertainty

The issue of uncertainty was rarely discussed in the UHI tool methodologies, with only 16 tools mentioning the term. The context of uncertainty can be summarised as the uncertainty related to: the concept of community wellbeing (1 instance), measuring exposure (3 instances), methods of indicator selection (3 instances), risk assessment of exposure (1 instance), small population sizes (3 instances), and not relevant (4 instances).

Main source of data

The majority of tools (57.9%, 84/145) used existing datasets from multiple organisations. Figure 4 shows that resident surveys (questionnaires or door-to-door) were much more likely to be used to gather data for subjective indicators (or tools which contained both subjective and objective indicators). Field audits (measurement of the urban environment by trained auditors) were more than twice as likely to be used for walkability/physical activity UHI tools than health and wellbeing tools or tools which measured multiple topics. Remote sensing, sensors and GIS or other maps were used by very few tools (3, 1 and 2 respectively).

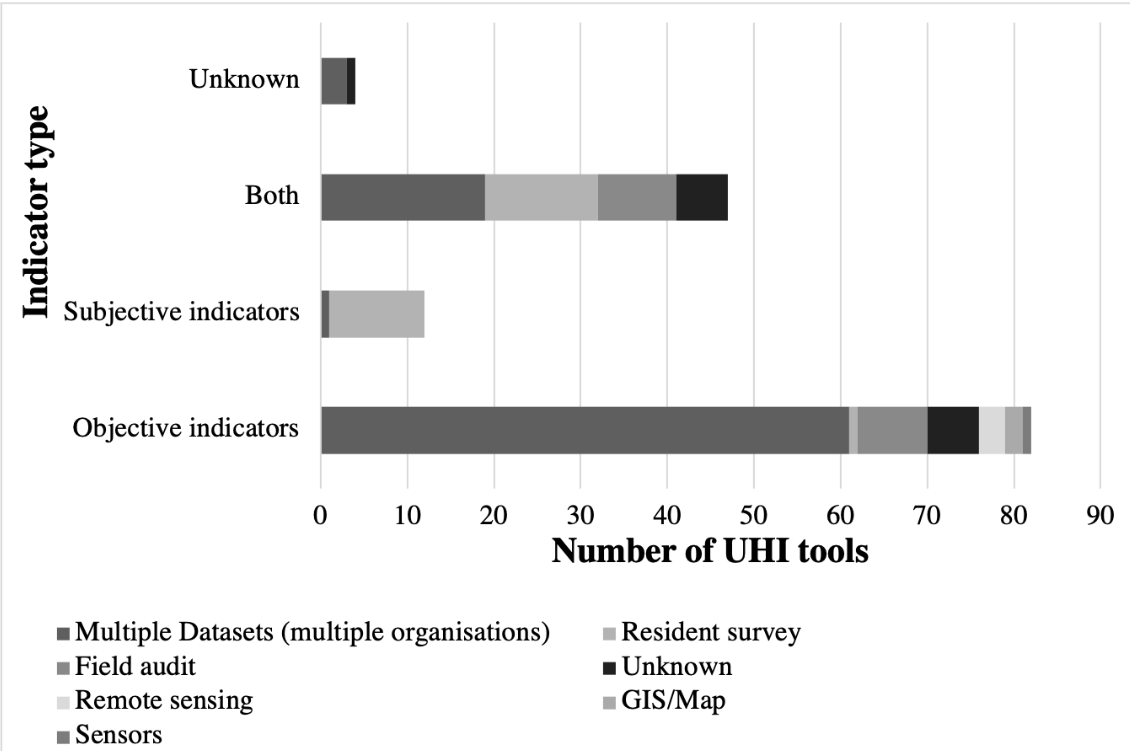


Figure 4 - Primary source of data by indicator type.

A1.5 Completed quality appraisals

The Quality Appraisal Checklist (NICE, 2012) was completed for each study included in the systematic review narrative synthesis. Table 1 shows the full checklist and the subsequent tables are an abridged version that contains the appraisal comments but reduces the example text for each question.

Table 1 Completed quality appraisal checklist for Bhatia (2014)

Study identification: Include author, title, reference, year of publication	Bhatia, R. (2014) Case Study: San Francisco's Use Of Neighborhood Indicators To Encourage Healthy Urban Development. *Health Affairs*. 33(11), 1914–22.	
Guidance [STUDY] topic: Use of San Francisco Indicators Project	**Key research question/aim:** 'This article provides a case study of San Francisco's experience with neighborhood indicators, describing applications of the indicators to community design and development. The account is based on my experience and observations as the director of the design, development and application of the indicators in San Francisco between 2007 and 2013' (Bhatia, 2014, p.2).	
Checklist completed by:	Helen Pineo	
Theoretical approach		
1. Is a qualitative approach appropriate? For example: • **Does the research question seek to understand processes or structures, or illuminate subjective experiences or meanings?** • **Could a quantitative approach better have addressed the research question?**	Appropriate	Comments: The case study explains processes and could not have been conducted with a quantitative approach.
2. Is the study clear in what it seeks to do? For example: • Is the purpose of the study discussed – aims/objectives/ research question/s? • Is there adequate/appropriate reference to the literature?	Clear	Comments: This is a case study without a research question stated. Literature is referenced. Underpinning values, etc. not discussed.

• Are underpinning values/assumptions/theory discussed?		
Study design		
3. How defensible/rigorous is the research design/methodology? For example: • Is the design appropriate to the research question? • Is a rationale given for using a qualitative approach? • Are there clear accounts of the rationale/justification for the sampling, data collection and data analysis techniques used? • Is the selection of cases/sampling strategy theoretically justified?	Appropriate	Comments: This is a case study and is therefore subjective in nature. It states one person's perceptions of the example. However, it provides a detailed account of a process occurring over several years and is therefore amenable to a case study design.
Data collection		
4. How well was the data collection carried out? For example: • Are the data collection methods clearly described? • Were the appropriate data collected to address the research question? • Was the data collection and record keeping systematic?	Not described	Comments: Although data collection is not described, this is a first-hand account of a process led by the author.
Trustworthiness		
5. Is the role of the researcher clearly described? For example: • Has the relationship between the researcher and the participants been adequately considered? • Does the paper describe how the research was explained and presented to the participants?	Clearly described	Comments: The author is potentially biased based on his role leading the development/application of the indicators being described.
6. Is the context clearly described? For example: • Are the characteristics of the participants and settings clearly defined?	Minimally described	Comments: The author reports the circumstances of the use of the indicators on the Eastern Neighborhoods planning process and

• Were observations made in a sufficient variety of circumstances • Was context bias considered		several other examples. Bias not discussed.
7. Were the methods reliable? For example: • Was data collected by more than 1 method? • Is there justification for triangulation, or for not triangulating? • Do the methods investigate what they claim to?	Not described	Comments:
Analysis		
8. Is the data analysis sufficiently rigorous? For example: • Is the procedure explicit – i.e. is it clear how the data was analysed to arrive at the results? • How systematic is the analysis, is the procedure reliable/dependable? • Is it clear how the themes and concepts were derived from the data?	Not described	Comments:
9. Is the data 'rich'? For example: • How well are the contexts of the data described? • Has the diversity of perspective and content been explored? • How well has the detail and depth been demonstrated? • Are responses compared and contrasted across groups/ sites?	Appropriate	Comments: The case study itself provides a rich account of the circumstances surrounding the UHI tool. Diverse perspectives are considered.
10. Is the analysis reliable? For example: • Did more than 1 researcher theme and code transcripts/data? • If so, how were differences resolved? • Did participants feedback on the transcripts/data if possible and relevant? • Were negative/discrepant results addressed or ignored?	Not reported	Comments: The case study was written by one person with no explicit discussion of data collection and analysis.

11. Are the findings convincing? For example: • Are the findings clearly presented? • Are the findings internally coherent? • Are extracts from the original data included? • Are the data appropriately referenced? • Is the reporting clear and coherent?	Appropriate	Comments: The case study description is clear and coherent.
12. Are the findings relevant to the aims of the study?	Yes	Comments:
13. Conclusions For example: • How clear are the links between data, interpretation and conclusions? • Are the conclusions plausible and coherent? • Have alternative explanations been explored and discounted? • Does this enhance understanding of the research topic? • Are the implications of the research clearly defined? **Is there adequate discussion of any limitations encountered?**		Comments: This case study provides one person's perspective, without discussion of methods (data collection, analysis, etc.). The conclusions are plausible in relation to other similar literature. The case study enhances understanding of the research topic. There is no discussion of limitations.
Ethics		
14. How clear and coherent is the reporting of ethics? For example: • Have ethical issues been taken into consideration? • Are they adequately discussed e.g. do they address consent and anonymity? • Have the consequences of the research been considered i.e. raising expectations, changing behaviour? • Was the study approved by an ethics committee?	Not reported	Comments:
Overall assessment As far as can be ascertained from the paper, how well was the study conducted? (see guidance notes)	+/-	Comments: Although methods were not reported, this case study provides a rich account of the San

++ + –		Francisco Indicator Project development by the person who led the work.

Table 2 Completed quality appraisal checklist for Corburn et al. (2014)

Study identification:	Corburn, J., Curl, S., Arredondo, G., Malagon, J. (2014) Health in All Urban Policy: City Services through the Prism of Health. *Journal of Urban Health*. 91(4), 623–636.	
Guidance [STUDY] topic: Case study of HiAP approach in Richmond, CA and the use of health equity indicators within this process	**Key research question/aim:** 'In this paper, we describe and analyze the emergence and development of HiAP in Richmond, California, over the past 4 years. …Using these data, we reveal the conceptual frames, practical strategies, and evaluation evidence that contributed to an urban Health in All Policies practice explicitly focused on addressing health equity' (Corburn et al., 2014, p.624).	
Checklist completed by:	Helen Pineo	
Theoretical approach		
1. Is a qualitative approach appropriate?	Appropriate	Comments: Explains processes, subjective experiences or meanings.
2. Is the study clear in what it seeks to do?	Clear	Comments: The aim of the research is briefly described (no research question clearly stated). Literature is referenced. Underpinning values, etc. of the research method are not discussed.
Study design		
3. How defensible/rigorous is the research design/methodology?	Difficult to judge due to lack of details	Comments: The case study is appropriate to provide a rich account of the HiAP process in Richmond. Authors describe data collected using participant observation, interviews, and document review. Sampling, detailed data collection methods and data analysis are not reported.
Data collection		

4. How well was the data collection carried out?	Appropriate	Comments: Authors describe data collected using participant observation, interviews, and document review. Data were collected over a 4-year period.
Trustworthiness		
5. Is the role of the researcher clearly described?	Not described	Comments: The role of the researchers in the HiAP project is not clearly described.
6. Is the context clearly described?	Minimally described	Comments: The authors report the context. Observation details and context bias were not discussed.
7. Were the methods reliable?	Appropriate data collection methods were applied, although analysis was not discussed.	Comments: Data were collected using multiple methods. Analysis was not described.
Analysis		
8. Is the data analysis sufficiently rigorous?	Not described	Comments:
9. Is the data 'rich'?	Yes	Comments: The case study describes a rich analysis of HiAP process in Richmond. There are no quotes from interview data.
10. Is the analysis reliable?	Not reported	Comments:
11. Are the findings convincing?	Findings are clearly described.	Comments: The findings are plausible in relation to the wider literature. No extracts or references to data.
12. Are the findings relevant to the aims of the study?	Yes	Comments:
13. Conclusions **Is there adequate discussion of any limitations encountered?**		Comments: This case study approach is well-suited to describe the process of HiAP in Richmond and does enhance understanding of the research topic. Regarding limitations, these are not reported.

Ethics		
14. How clear and coherent is the reporting of ethics?	Not reported	Comments:
Overall assessment **As far as can be ascertained from the paper, how well was the study conducted? (see guidance notes)** ++ + –	+/-	Comments: The case study provides some detail on methods but does not describe analysis or limitations. Overall, it provides useful research findings on a topic that is not widely researched.

Table 3 Completed quality appraisal checklist for Corburn and Cohen (2012)

Study identification:	Corburn, J., Cohen, A.K. (2012) Why We Need Urban Health Equity Indicators: Integrating Science, Policy, and Community. *PLOS Medicine*. 9, e1001285.	
Guidance [STUDY] topic: Use of indicators in Richmond, California and Nairobi, Kenya	**Key research question/aim:** 'In this paper, we briefly outline an approach for promoting greater urban health equity through the drafting and monitoring of indicators. We draw examples from the cities of Richmond, California, and Nairobi, Kenya.' (Corburn and Cohen, 2012, p.1)	
Checklist completed by:	Helen Pineo	
Theoretical approach		
1. Is a qualitative approach appropriate?	Appropriate	Comments: The research explains processes and a qualitative approach is most appropriate.
2. Is the study clear in what it seeks to do?	Clear	Comments: This is a short case study example used to illustrate points in a larger paper without a research question stated. Literature is referenced. Underpinning values, etc. not discussed.
Study design		

3. How defensible/rigorous is the research design/methodology?	Not a study	Comments: Describes the experience of the authors: 'Drawing from our collaborative work on healthy urban governance and the drafting of health equity indicators in Richmond, California, and the Mathare Valley…' (p.2)
Data collection		
4. How well was the data collection carried out?	Not described	Comments:
Trustworthiness		
5. Is the role of the researcher clearly described?	Not described	Comments: The researchers were involved in developing the indicators but it is not clearly described.
6. Is the context clearly described?	Minimally described	Comments: The authors briefly report the circumstances of the use of the indicators. Context bias not discussed.
7. Were the methods reliable?	Not described	Comments:
Analysis		
8. Is the data analysis sufficiently rigorous?	Not described	Comments:
9. Is the data 'rich'?	No data is explicitly described	Comments: The account of these examples is brief and would probably not be described as 'rich'.
10. Is the analysis reliable?	Not reported	Comments:
11. Are the findings convincing?	Minimally	Comments: The descriptions of the use of indicators are very brief.
12. Are the findings relevant to the aims of the study?	Not described	Comments:
13. Conclusions		Comments:

Is there adequate discussion of any limitations encountered?		These short case study examples provide the authors' perspectives, without discussion of methods (data collection, analysis, etc.) and therefore there are several limitations. However the findings do enhance understanding of the research topic. There are no discussions of limitations.
Ethics		
14. How clear and coherent is the reporting of ethics?	Not reported	Comments:
Overall assessment **As far as can be ascertained from the paper, how well was the study conducted? (see guidance notes)** ++ + −		Comments: These short case study descriptions are not presented as a study and therefore no score is given.

Table 4 Completed quality appraisal checklist for Farhang et al. (2008)

Study identification:	Farhang, L., Bhatia, R., Scully, C.C., Corburn, J., Gaydos, M., Malekafzali, S. (2008) Creating Tools for Healthy Development: Case Study of San Francisco's Eastern Neighborhoods Community Health Impact Assessment. *Journal of Public Health Management and Practice*. 14(3), 255–265.	
Guidance [STUDY] topic: Case study of Eastern Neighborhoods Community Health Impact Assessment and use of indicators 'Healthy Development Measurement Tool'	**Key research question/aim:** 'This case study describes the 18-month ENCHIA process, key outcomes, and lessons learned. The case study also provides an overview of the Healthy Development Measurement Tool and examples of its first applications to urban planning' (Farhang, et al., p.255)	
Checklist completed by:	Helen Pineo	
Theoretical approach		
1. Is a qualitative approach appropriate?	Appropriate	Comments: Explains processes, subjective experiences or meanings and therefore qualitative approach is appropriate.

2. Is the study clear in what it seeks to do?	Clear	Comments: The aim of the case study is described (no objectives/ research question stated). Literature is referenced. Underpinning values, etc. of the research method are not discussed.
Study design		
3. How defensible/rigorous is the research design/methodology?	Difficult to judge due to lack of details	Comments: No methods are described however the case study approach is appropriate to provide a detailed account of the development of the San Francisco Indicators Project (SFIP).
Data collection		
4. How well was the data collection carried out?	Not described	Comments:
Trustworthiness		
5. Is the role of the researcher clearly described? •	Not described	Comments: The authors include individuals who were creating the indicators and health impact assessment (HIA) being discussed as well as external authors who may also have been involved (not stated).
6. Is the context clearly described?	Minimally	Comments: The stakeholders involved (not described as participants) were clearly described. Observations were clearly made in a wide variety of circumstances. Context bias was not discussed.
7. Were the methods reliable?	Unknown	Comments: The case study does not describe methods.
Analysis		
8. Is the data analysis sufficiently rigorous?	Not described	Comments:
9. Is the data 'rich'?	Yes	Comments:

		The case study does provide rich data about the development of SFIP.
10. Is the analysis reliable?	Not reported	Comments:
11. Are the findings convincing?	Minimally	Comments: Findings are clearly described however lack of data collection and analysis methods descriptions means that judging whether findings are convincing is problematic.
12. Are the findings relevant to the aims of the study?	Yes	Comments:
13. Conclusions **Is there adequate discussion of any limitations encountered?**		Comments: This is a case study approach with unclear methods. The findings are plausible in relation to the wider literature. The findings enhance the understanding of the topic. There is no discussion of limitations.
Ethics		
14. How clear and coherent is the reporting of ethics?	Not reported	Comments:
Overall assessment **As far as can be ascertained from the paper, how well was the study conducted? (see guidance notes)** ++ + –	+/-	Comments: This is a detailed case study but methods are missing.

Table 5 Completed quality appraisal checklist for Hunt and Lewin (2000)

Study identification:	Hunt, C., Lewin, S. (2000) Exploring Decision-Making for Environmental Health Services: Perspectives from Four Cities. *Reviews of Environmental Health*. 15(1-2), 187–206.
Guidance [STUDY] topic: Use of environmental health indicators in 4 cities	**Key research question/aim:** 'The goal of the study was to explore environmental health service decision-making at the local level. Specifically, the study aimed to compare local authority perceptions of environmental health needs and service status with those of local residents and to explore the space for EHIs [environmental health

	indicators] in environmental health decision-making' (Hunt and Lewin, 2000, p.189)	
Checklist completed by:	Helen Pineo	
Theoretical approach		
1. Is a qualitative approach appropriate?	Appropriate	Comments: The research seeks to understand process and actors and therefore qualitative research is appropriate.
2. Is the study clear in what it seeks to do?	Clear	Comments: States specific aim, reviews literature, refers to other papers which describe the methods in more detail.
Study design		
3. How defensible/rigorous is the research design/methodology?	Rigorous	Comments: There is a clear explanation of methods and rationale for case study selection (4 cities).
Data collection		
4. How well was the data collection carried out?	Clear and appropriate	Comments: Data collection is described for different parts of the study and reference is made to other papers by the authors for detailed methods.
Trustworthiness		
5. Is the role of the researcher clearly described?	Partially	Comments: Paper describes how the research was explained (regarding language issues). The researchers were involved in developing indicators with the case study cities.
6. Is the context clearly described?	Clear	Comments: The context of each case is described. Observations were made using different events (attending meetings, running workshops, etc.).
7. Were the methods reliable?	Yes	Comments: Data were collected using several methods. Triangulation was used. Methods investigated the relevant aim.
Analysis		

8. Is the data analysis sufficiently rigorous?	Yes	Comments: Data analysis is clearly described and systematic. Coding was descripted (open coding was used). Themes are explained through interview quote examples.
9. Is the data 'rich'?	Yes	Comments: There are descriptions from different perspectives with detail and comparison across cities. The data is rich.
10. Is the analysis reliable?	Yes	Comments: It is not clear if multiple researchers coded the data. Triangulation was used with the involvement of researchers from different backgrounds. 'Negative' results were discussed.
11. Are the findings convincing?	Yes	Comments: Findings are clear, coherent and backed up with extract quotes. Data are referenced and reporting is clear.
12. Are the findings relevant to the aims of the study?	Relevant	Comments:
13. Conclusions **Is there adequate discussion of any limitations encountered?**		Comments: There are clear links between data examples and interpretations. Conclusions are plausible and coherent. The research does increase understanding of this research topic through detailed examples. Implications are discussed. Limitations are not discussed.
Ethics		
14. How clear and coherent is the reporting of ethics?	Not reported	Comments: No discussion of ethics. Possibly reported in the other referenced studies regarding methods.
Overall assessment **As far as can be ascertained from the paper, how well was the study conducted? (see guidance notes)** ++	++	Comments: Clear methods and rich data and interpretation.

+ –		

Table 6 Completed quality appraisal checklist for Landis and Sawicki (1988)

Study identification:	Landis, J.D., Sawicki, D.S. (1988) A Planner's Guide to the Places Rated Almanac. *Journal of the American Planning Association*. 54(3), 336–346.	
Guidance [STUDY] topic: Review of Places Rated Almanac and its value to planners	**Key research question/aim:** 'We are concerned first with the appropriateness and reliability of the concepts and measures the Places Rated Almanac uses: how well the place ratings meet the needs and demands of migrating households and individuals who, after all, comprise the primary intended audience for such systems. Second, we are concerned with the extent to which place rating systems evaluate quality of place versus quality of life. Third, we are concerned with how the almanac measures and compares quality of place issues; to address that topic, we examine the types of categories and components the publication includes. Fourth, we are concerned with how the results of such schemes do or do not affect the conduct of local planning and policy making' (Landis and Sawicki, 1988, p.336	
Checklist completed by:	Helen Pineo	
Theoretical approach		
1. Is a qualitative approach appropriate?	Appropriate	Comments: The study used a quantitative survey of actors views (conducted via interviews) on the Places Rated Almanac, therefore this is quantitative social research.
2. Is the study clear in what it seeks to do?	Clear	Comments: States specific aim, reviews literature. Underpinning values, assumptions, theory are not discussed.
Study design		
3. How defensible/rigorous is the research design/methodology?	Appropriate	Comments: Specifically regarding the use of Places Rated Almanac, the authors surveyed planners in 32 cities (with justification about which planners and which cities).

Data collection		
4. How well was the data collection carried out?	Appropriate	Comments: Survey methods described in terms of sampling rationale and the method was via interview.
Trustworthiness		
5. Is the role of the researcher clearly described?	Not described	Comments:
6. Is the context clearly described?	Clear	Comments: Surveys were in 32 cities.
7. Were the methods reliable?	Yes	Comments: Survey was the only method and it did investigate the stated aims.
Analysis		
8. Is the data analysis sufficiently rigorous?	Not described	Comments: Although the analysis methods are not fully described, the results provide some indication of the analysis which appears to be appropriate.
9. Is the data 'rich'?	Partially	Comments: Survey may not have provided depth but gives a good overview of perspectives.
10. Is the analysis reliable?	Not described	Comments:
11. Are the findings convincing?	Partially	Comments: Findings are clear and coherent. Data is not described in detail.
12. Are the findings relevant to the aims of the study?	Relevant	Comments:
13. Conclusions **Is there adequate discussion of any limitations encountered?**	Clear and coherent	Comments: Useful overview of perceptions of Places Rated Almanac by planning directors in 32 cities. No discussion of limitations.
Ethics		

14. How clear and coherent is the reporting of ethics?	Not reported	Comments: No discussion of ethics.
Overall assessment **As far as can be ascertained from the paper, how well was the study conducted? (see guidance notes)** ++ + –	+	Comments: Clear methods regarding sampling and survey questions. Clear description of findings. Lack of information on analysis and limitations.

Table 7 Completed quality appraisal checklist for Lerman (2011)

Study identification	Lerman, S. (2011) *Seattle Healthy Living Assessment: Pilot Implementation Report*. Seattle, Healthy Communities Consulting.	
Guidance [STUDY] topic: Report of development and piloting of Seattle Healthy Living Assessment	**Key research question/aim:** The report describes the data collection and results of the HLA. It also describes the benefits of using the HLA.	
Checklist completed by:	Helen Pineo	
Theoretical approach		
1. Is a qualitative approach appropriate?	Appropriate	Comments: The report explains processes and subjective experiences, although this is not a qualitative study.
2. Is the study clear in what it seeks to do?	Partially	Comments: The aim of the report is described (no objectives/ research question stated). Literature and underpinning values are not referenced/discussed.
Study design		
3. How defensible/rigorous is the research design/methodology?	Not relevant.	Comments: No methods are described – it is a project report not research.
Data collection		
4. How well was the data collection carried out?	Not described	Comments: The methods for gathering data about the project benefits are not

		reported. Data collection for the Healthy Living Assessment is reported.
Trustworthiness		
5. Is the role of the researcher clearly described?	Not described	Comments: The authors include individuals who were creating the indicators and Healthy Living Assessment.
6. Is the context clearly described?	Context of the project is described	Comments: No clear participants or observations. Bias was not discussed.
7. Were the methods reliable?	Unknown	Comments: The report does not describe methods related to identifying the benefits of the Healthy Living Assessment.
Analysis		
8. Is the data analysis sufficiently rigorous?	Not described	Comments: The benefits are reported but there is no discussion of how they were collated and reported.
9. Is the data 'rich'?	No	Comments: The benefits are described without discussion of different perspectives. There are no quotes from participants or stakeholders.
10. Is the analysis reliable?	Unknown	Comments: Analysis was not reported.
11. Are the findings convincing?	Yes, within limits.	Comments: Findings are clearly described but methods are unknown.
12. Are the findings relevant to the aims of the study?	Yes	Comments:
13. Conclusions **Is there adequate discussion of any limitations encountered?**		Comments: This is a project report with unclear methods. However it provides valuable information considering the lack of research on the use of UHI tools.

		Inadequate discussion of limitations
Ethics		
14. How clear and coherent is the reporting of ethics?	Not reported	Comments:
Overall assessment **As far as can be ascertained from the paper, how well was the study conducted? (see guidance notes)** ++ + −		Comments: - This is not reported as a study and therefore the lack of methods and details explaining how findings on the use of the UHI tool were achieved is difficult to assess.

Table 8 Completed quality appraisal checklist for Lowe et al. (2015)

Study identification:	Lowe, M., Whitzman, C., Badland, H., Davern, M., Aye, L., Hes, D., Butterworth, I., Giles-Corti, B. (2015) Planning Healthy, Liveable and Sustainable Cities: How Can Indicators Inform Policy? *Urban Policy and Research*. 33(2), 131–144.	
Guidance [STUDY] topic: Review of liveability indicators and consultation with Melbourne policy-makers on their potential use	**Key research question/aim:** ‘Our research responds to this challenge of creating liveability indicators that are able to influence policy and practice. Conceptualising liveability through a social determinants of health lens, this article reviews existing liveability indicators and considers how they are utilised. Based on the results of consultations with academics, policymakers from all levels of government, and community and private sector decision-makers in Melbourne, it then considers how indicators could be developed, reported and used to more strongly influence policy and support integrated planning for health, liveability and sustainability’ (Lowe et al., 2015, p.134).	
Checklist completed by:	Helen Pineo	
Theoretical approach		
1. Is a qualitative approach appropriate?	Appropriate	Comments: Describes process and actors thus a qualitative approach was appropriate.
2. Is the study clear in what it seeks to do?	Clear	Comments:

		States specific aim, reviews literature. Underpinning values, etc. not discussed.
Study design		
3. How defensible/rigorous is the research design/methodology?	Appropriate	Comments: Authors used workshops to gather views from policy-makers. Sampling, data collection and analysis is discussed.
Data collection		
4. How well was the data collection carried out?	Appropriately	Comments: Researchers took notes during workshops and collated these.
Trustworthiness		
5. Is the role of the researcher clearly described?	Not described	Comments: Unclear if/how this has been described.
6. Is the context clearly described?	Clear	Comments: Multiple workshops were used. Bias not discussed.
7. Were the methods reliable?	Partially	Comments: Workshop discussions were the only method but it did investigate the stated aim. Triangulation not discussed.
Analysis		
8. Is the data analysis sufficiently rigorous?	Not described	Comments: Analysis not described.
9. Is the data 'rich'?	Not sure	Comments: Results are brief. Perspectives of different people are not reported.
10. Is the analysis reliable?	Not described	Comments: Analysis not described.
11. Are the findings convincing?	Partially	Comments: Findings are clear and coherent. Data is not described in detail.
12. Are the findings relevant to the aims of the study?	Relevant	Comments:

13. Conclusions **Is there adequate discussion of any limitations encountered?**		Comments: Findings are useful in understanding the research topic. Data is not discussed in detail. Limitations not discussed.
Ethics		
14. How clear and coherent is the reporting of ethics?	Not reported	Comments: No discussion of ethics.
Overall assessment **As far as can be ascertained from the paper, how well was the study conducted? (see guidance notes)** ++ + –		Comments: + Useful study to understand the research topics with some details lacking on analysis.

Table 9 Completed quality appraisal checklist for Shepherd and McMahon (2009)

Study identification:	Shepherd, S., McMahon, S. (2009) The Importance of Local Information: Quality of Life Indicators in Bristol, in: Sirgy, P.M.J., Phillips, D.R., Rahtz, P.D.R. (Eds.), *Community Quality-of-Life Indicators: Best Cases IV, Community Quality-of Life Indicators.* Dordrecht, Springer Netherlands, pp. 111–120.	
Guidance [STUDY] topic: Use of QOL indicators in Bristol	**Key research question/aim:** To demonstrate 'how important local-level information has been in enabling QoL indicators to become highly effective tools for improving local quality of life' through 'decision making, [and] collaboration' (Shepherd and McMahon, 2009, p. 111).	
Checklist completed by:	Helen Pineo	
Theoretical approach		
1. Is a qualitative approach appropriate?	Appropriate	Comments: Investigates process and actors thus a qualitative approach is appropriate.
2. Is the study clear in what it seeks to do?	Clear	Comments: Minimally discussed as described in key research aims above. No reference to literature. No underpinning theory discussed.
Study design		

3. How defensible/rigorous is the research design/methodology?	Inadequately reported	Comments: No discussion of research design. No rationale. No discussion of participants or sampling.
Data collection		
4. How well was the data collection carried out?	Inadequately reported	Comments: No discussion of data collection.
Trustworthiness		
5. Is the role of the researcher clearly described?	Not described	Comments: No discussion of researcher role.
6. Is the context clearly described?	Unclear	Comments: Multiple council teams/roles are referenced. No discussion of observations or context bias.
7. Were the methods reliable?	Not reported	Comments: No information on methods.
Analysis		
8. Is the data analysis sufficiently rigorous?	Not reported	Comments: No discussion of data analysis.
9. Is the data 'rich'?	Not reported	Comments: There are descriptions of multiple examples across council teams with some quotes. Many perspectives are discussed.
10. Is the analysis reliable?	Not reported	Comments: None of the data analysis methods were reported.
11. Are the findings convincing?	Not reported	Comments: Findings are clearly presented and internally coherent. Extracts are presented.
12. Are the findings relevant to the aims of the study?	Relevant	Comments: Reports multiple built environment policy/decision-making uses of indicators. Reports perceptions of indicators.
13. Conclusions	Adequate	Comments:

Is there adequate discussion of any limitations encountered?		Clear links between data examples and interpretations. Conclusions plausible and coherent. No alternatives discussed. Does increase understanding through detailed examples. Implications mentioned.
Ethics		
14. How clear and coherent is the reporting of ethics?	Not reported	Comments: No discussion of ethics.
Overall assessment **As far as can be ascertained from the paper, how well was the study conducted? (see guidance notes)** ++ + –		Comments: + Useful case study with detailed findings but lacking some information on methods of data collection and analysis.

Table 10 Completed quality appraisal checklist for Van Assche et al. (2010)

Study identification:	Van Assche, J., Block, T., Reynaert, H. (2010) Can Community Indicators Live Up to Their Expectations? The Case of the Flemish City Monitor for Livable and Sustainable Urban Development. *Applied Research in Quality of Life*. 5(4), 341–352.	
Guidance [STUDY] topic: Case study of Flemish City Monitor	**Key research question/aim:** Stated as questions in the abstract: 'Does it [Flemish City Monitor] live up to its expectations? And will the vision and indicators on urban sustainability stir up the debate about urban sustainable development?' (Van Assche et al., 2010, p.341)	
Checklist completed by:	Helen Pineo	
Theoretical approach		
1. Is a qualitative approach appropriate?	Appropriate	Comments: Explains processes, subjective experiences or meanings.
2. Is the study clear in what it seeks to do?	Clear	Comments: The aim of the case study is primarily to discuss the development of the Flemish City Monitor. However there is substantive data on the use in local government (with reference to another paper not

		available in English). Literature referenced. Some discussion of theoretical building blocks of indicators.
Study design		
3. How defensible/rigorous is the research design/methodology?	Unclear.	Comments: No methods are described – there is reference to another paper (not in English). It is essentially a case study of the authors' experience developing and using the Flemish City Monitor.
Data collection		
4. How well was the data collection carried out?	Not described	Comments: No discussion of data collection.
Trustworthiness		
5. Is the role of the researcher clearly described?	Yes	Comments: The authors were involved in developing the indicators and then handed over the ongoing work to local government. Not clear how the research was described to participants although there is discussion of how they were perceived: 'after all kinds of suspicions (of policy makers versus academics…' p.350.
6. Is the context clearly described?	Minimally	Comments: Detail of observations is not discussed. The timescales of observation appear to be extensive (at least between 2004 to 2008). Bias was not discussed.
7. Were the methods reliable?	Not reported	Comments: The case study does not describe methods (however, there is another paper which is not available in English)
Analysis		
8. Is the data analysis sufficiently rigorous?	Not reported	Comments: No discussion of data analysis.
9. Is the data 'rich'?	Yes	Comments:

		There are example quotes and a range of perspectives from different people (policy makers and politicians)
10. Is the analysis reliable?	Not reported	Comments: None of the data analysis methods were reported.
11. Are the findings convincing?	Yes	Comments: Findings are clearly described and convincing. Findings are clearly presented and internally coherent. Extracts are presented.
12. Are the findings relevant to the aims of the study?	Relevant	Comments: Reports multiple built environment policy/decision-making uses of indicators. Reports perceptions of indicators.
13. Conclusions **Is there adequate discussion of any limitations encountered?**		Comments: This is a case study approach with unspecified methods. Data are rich and conclusions are plausible. Limitations are not discussed.
Ethics		
14. How clear and coherent is the reporting of ethics?	Not reported	Comments: No discussion of ethics.
Overall assessment **As far as can be ascertained from the paper, how well was the study conducted? (see guidance notes)** ++ + –		Comments: + Useful case study with detailed findings but lacking methods of data collection and analysis.

A1.6 Theory of Change methods

The theory of change (ToC) was developed iteratively using guidance from Popay et al. (2006), Morra Imas and Rist (2009), Weiss (1998) and Breuer et al. (2016) following the process in Table 1.

Table 1 Process for developing a theory of change based on descriptions in the literature (Morra Imas and Rist, 2009; Weiss, 1998)

Stage	Summary
1	Identify the problem using existing literature (research, organisation documents, etc.), quantitative data, and expert knowledge from the client.
2	Identify the near and medium-term desired results (outputs and outcomes) and long-term goal of the intervention (impact).
3	Identify potential barriers and facilitators that might affect the results (inputs, context), including unintended consequences. Potentially distinguish between subgroups.
4	Create hypothesis pathways of how programme activities result in change. Make underlying assumptions explicit.
5	Draw a ToC with arrows connecting change pathways (input, output, outcome, impact) allowing arrows to connect backward and forward to demonstrate non-linearity.
6	Test pathways within the ToC using data (quantitative and/or qualitative).
7	Refine the ToC based on evaluation results and discussion with the client.

Early versions informed the process of conducting the narrative synthesis. Figure 1 shows an early version of the ToC, documenting how the researcher interpreted and made sense of two stages of UHI tools (development and application) which can be either expert-led or participatory (on a spectrum). Figure 1 also shows how some processes were understood as iterative or cyclical.

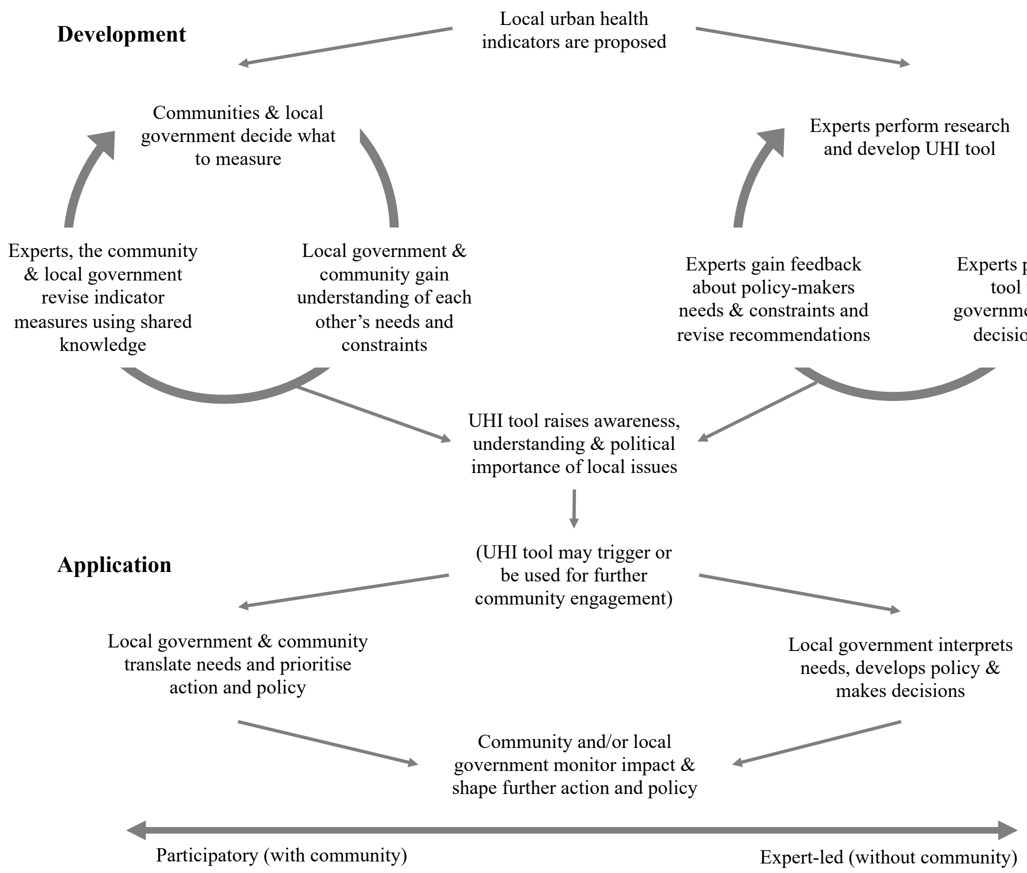


Figure 1 Early version of theory of change used to guide the narrative synthesis analysis

This study used data coded during the narrative synthesis of systematic review studies to develop the ToC. The process was iterative and used conceptual mapping alongside the processes of coding qualitative data (in Nvivo) for the thematic analysis. The analysis identified varied uses and benefits (outcomes) of UHI tools based on how they were developed, either through a participatory or an expert-led process. These were identified as two key 'approaches' for the ToC. The elements in the ToC were identified through data coded in Nvivo from the thematic analysis, shown in Table 2. The facilitators and barriers to UHI tool development and application were translated into inputs. The descriptions of how UHI tools were developed were translated to activities. The uses and benefits of using UHI tools identified in the review naturally aligned with the theory of change components (outputs and outcomes respectively). Differentiation between outputs and outcomes was based on whether they were achieved in the short to mid-term (outputs) and long-term (outcomes).

Table 2 Nvivo codes and sub-codes from which theory of change elements were derived

ToC element	Nvivo codes	Nvivo sub-codes
Inputs	Facilitators	Data quality Linked to other monitoring requirements Partnership working Presentation of information Scale of data is local Tied to policy
	Barriers	N/A
Activities	Indicator development process	Evidence-based Experts Multi-stakeholder co-production Public health leading community group
	Community participation	Capacity building Community actions to avoid harms (sub-code: Power(less)) Community used indicators Stakeholder relations
Outputs and outcomes	Uses or benefits of UHI tool	Benchmarking Capacity building in local government Collaboration Communication Create awareness of urban health issues Definition of urban health concept Engage politicians Engage public or change behaviour Funding allocation Highlight community needs Identification of local issues Improve or protect environment Informed decisions (sub code: evaluate development proposals) Informed policy development Justification of policy or decision Monitoring Ownership Performance management Prioritisation of policy areas Reduce inequalities Target resources or policies Transparency (sub-code: gaining trust)
	Community participation	See above

Breuer et al. (2016) created a checklist to increase transparency when reporting a ToC, which is completed and presented in Table 3.

Table 3 Completed Theory of Change checklist from Breuer et al. (2016)

ToC Checklist by Breuer et al. (2016)	Responses for this study
1. Is the ToC approach defined? a. Is a definition of ToC given by the authors? b. Do the authors explain their reasons for using a ToC approach?	a. Provided definitions from Weiss (1998) and Morra Imas and Rist (2009) in section 3.5.2. b. Justified producing a ToC due to recommendation by Popay et al. (2006), a related example from the literature (Allen et al.), and findings from Breuer et al. (2016) systematic review of ToC in public health intervention evaluation (in section 3.5.2).
2. Is the ToC development process described? a. Are the methods used to develop the ToC, such as stakeholder meetings and interviews, document reviews, programme observation, existing conceptual frameworks or published research, described? b. Where stakeholders are involved, is it clear how many stakeholders participated, what their role is in relation to the intervention, how they were consulted (e.g. number of interviews, focus groups, ToC workshops) and the extent to which the consultations were participatory? c. Is the method used to compile the data into a ToC described? (including how disagreements between stakeholders were resolved) d. Is the extent to which stakeholders were able to validate the resultant ToC and were owners of the final product described?	a. The ToC was developed using the process of narrative synthesis (of systematic review studies) and supported by findings from the wider literature, as described in section 4.4.7 and appendix A1.6. b. Stakeholder were not involved. c. The methods section (section 4.4.7 and appendix A1.6) describes how data from the systematic review informed the ToC development. The limitations section (4.10.1) notes heterogeneity in study designs and findings. d. The desirability of future stakeholder validation is covered in the Discussion section (4.10.1).

ToC Checklist by Breuer et al. (2016)	**Responses for this study**
3. Is the resultant ToC (or a summary thereof) depicted in a diagrammatic form and does it include? a. The long-term outcome or impact of the intervention b. The anticipated short and medium term outcomes and the process of change c. The intervention components which happen at different stages of the pathway d. The context of the intervention e. Assumptions about how change would occur f. Additional ToC elements such as indicators, supporting research evidence, beneficiaries, actors in the context, sphere of influence and timelines where relevant.	The ToC is described through a diagram and a table. a. Yes, both include reference and/or detail of the long-term outcome and desired impact. b. Yes, both include reference and/or detail of the short and medium-term outcome and the process of change. c. The intervention components are described in relation to the indicator development and application process. d. The context is described in both diagram and table. e. Assumptions are described regarding how change would occur in terms of the generation of new knowledge, collaborations and actions. f. Additional elements include the relevant actors in the UHI tool and policy-making context and supporting research evidence (from the systematic review) which is not explicitly described in the summary diagram/table, but is discussed in the chapter.
4. Is the process of intervention development from the ToC described? a. Are the methods of how interventions were refined from the ToC to something which can be implemented described? (For example, further stakeholder workshops, interviews, systematic literature reviews)	Yes, further testing of the ToC is described in section 4.10.1, including remarks on the value of developing a ToC to inform future UHI tool projects.

ToC Checklist by Breuer et al. (2016)	Responses for this study
5. Is the way in which the ToC was used to develop and implement the evaluation described? a. Are evaluation research questions generated from the ToC? b. Is the role of ToC in the design, plan or conduct of the evaluation clear? c. Does the paper describe the extent to which the key elements described in the ToC were measured in the evaluation (i.e. impact, short and medium term outcomes and the process of change, context, assumptions and the intervention)? d. Does the paper describe whether and how process indicators were used to improve the quality of the intervention? e. Is the role of the ToC in the analysis of the results of the evaluation clear? f. Is the role of ToC in the interpretation of the results of the evaluation described? (including the breakdown of programme theory, unanticipated outcomes and causation including the strength and direction of causal relationships)	a. The ToC was developed iteratively during the narrative synthesis and early examples informed the systematic review. The review findings and ToC were developed together. b. Yes, the role of the ToC in the overall study is described in chapters 1, 3 and 4. c. Yes, there is a description of the ToC elements being derived from the narrative synthesis. d. Process indicators would not have been appropriate in this context. e. Yes, the role of the ToC is clearly explained as both informing the narrative synthesis and being a result of the narrative synthesis. f. The ToC is described in the Discussion section (4.10) alongside other results and the Methods section (4.4.7) notes that the narrative synthesis and ToC were developed together.

APPENDIX 2 SUPPLEMENTARY MATERIAL FOR CHAPTER 6

A2.1 Interview questions

Tables 1 and 2 outline the interview questions for indicator producers and users respectively, with the associated themes which informed the development of each question.

Table 1 Interview questions for indicator producers and associated themes which informed the development of each question

Question	Theme(s)
1. Can you start by telling me about your role in this organisation?	Background
2. When did you start working on urban health/liveability indicators and what was/is your role in the project?	Background
3. Can you tell me about the process of developing/updating the indicators (e.g. who, when, why, how)?	Process, Information Flows (IF), Time Delays (TD)
4. Have you been involved in any projects to apply the indicators with policy or decision-makers? If **yes**, thinking of a recent project, can you explain how the project was initiated and who was involved? If **no**, who gets involved in applying the indicators from inside and outside your organisation?	Use of indicators, IF
5. Building on the last question, from your perspective, what did the indicators provide for the policy/decision-makers? How were they used? **Prompt:** list of indicator benefits from systematic review	Use of indicators, IF, TD
6. What difference do you think the indicators made? For example, did they help people learn something, look at things differently or understand new relationships?	Use of indicators, IF, TD
7. The urban environment's impact on health and wellbeing is characterised as a complex system. Can you tell me how you think indicators address or do not address this complexity? **Prompt:** Complexity of health in urban contexts diagram from Rydin et al (2012, p. 2086)	Complexity
8. Do you think that the process of using the indicators, or selecting particular indicators, helps users deal with the complexity of urban health systems and… If **yes**, how is this achieved?	Complexity, use of indicators, IF, TD

If **no**, how could this be achieved?	
9. In my research to date, I have perceived that there is less take-up of indicators on the part of policy and decision-makers than might be expected given the academic literature and the number of indicator tools available. Are indicators a helpful tool to improve the built environment for health and wellbeing and… If **yes**, what is required to increase the use of indicators? If **no**, why not?	Use of indicators, IF, TD, Policy process
10. Is there anything else that you'd like to add?	Closing
11. Do you have any final questions about how the interview?	Closing

Table 2 - Interview questions for indicator users and associated themes which informed the development of each question

Question	**Theme(s)**
1. Can you start by telling me about your role in this organisation?	Background
2. Have you come across urban health/liveability indicators in your work? When was this and how did you become aware of them? **Prompt:** list of example urban health indicators from systematic review	Background
3. Were you involved/consulted in the process of developing/updating the indicators (e.g. who, when, why, how)?	Process, Information Flows (IF), Time Delays (TD)
4. Can you tell me about a piece of your work where you made use of these indicators? Who was involved? What value did the indicators provide?	Use of indicators, IF
5. What difference did the indicators make? For example, did you (or others) learn something, look at things differently or understand new relationships?	Use of indicators, IF, TD
6. The urban environment's impact on health and wellbeing is characterised as a complex system. (Show prompt) Can you tell me how you think indicators address or do not address this complexity? (Complexity: dynamic, counterintuitive, interconnected, non-linear, etc.)	Complexity
7. Do you think that the process of using the indicators, or selecting particular indicators, helps you deal with the complexity of urban health systems and… If **yes**, how is this achieved? If **no**, how could this be achieved?	Complexity, use of indicators, IF, TD
8. In my research to date, I have perceived that there is less take-up of indicators on the part of policy and decision-makers than might be expected given the academic literature and the number of indicator tools available. Are indicators a helpful tool to improve the built environment for health and wellbeing and… If **yes**, what is required to increase the use of indicators?	Use of indicators, IF, TD, Policy process

If **no**, why not?	
9. Is there anything else that you'd like to add?	Closing
10. Do you have any final questions about how the interview?	Closing

A2.2 First round of thematic analysis codes

Table 1 shows the first round of codes with the number of sources (interview participants) and references (sections of interview text). There were three codes to keep track of indicator timelines and interesting vignettes about the use of UHI tools that were not part of the thematic analysis (marked with an asterisk).

Table 1 Thematic analysis codes with number of sources and references after first round of coding. Asterisk denotes code that was solely used to keep track of information for reporting (timelines and useful vignettes)

Codes	Sources	References
1 Complexity	11	25
Counterintuitive	2	2
Dynamic	3	3
Feedback	3	4
Full picture	7	12
High number of variables	1	1
Interconnected	8	18
Linearity	1	1
Policy resistance	1	1
Unintended consequences	3	8
2 Governance	1	1
Collaborative governance	10	28
Cross-departmental working	14	33
Evidence-based decision_policy-making	12	31
Legitimizing community priorities	1	5
Policy implementation	12	22
Policy levers	6	9
Policy timescale opportunity	5	5
Politics	16	46
Reluctance to engage with health, fear blockage	2	3
Stakeholder strategies	4	11
Advocacy	13	35
Building relationships_networks	16	54
Time and effort of advocacy	2	8
Training as advocacy	2	2
State to local gov	7	33

Codes	Sources	References
3 Knowledge	3	3
Communication	7	27
Telling difficult truths	1	1
Understanding others' constraints and opportunities	1	1
Knowledge basis	16	49
Knowledge claims	13	24
Knowledge fades over time	2	4
Knowledge gap about urban economics	1	1
Learning from others	6	10
Re-framing knowledge	10	28
Technical skills_knowledge to use UHIs	5	9
Uncertainty	1	3
Urban health relations	6	10
4 Professional	6	8
Integrated planning	2	7
Legal and technical	9	30
Negotiating with developers	6	10
Planning constraints	9	26
Planning opportunities	5	8
Professional norms	15	44
Professional values	10	17
Proud of professional achievements	5	5
Training and education	10	19
5 Social Context	1	1
Controversy	10	19
Disadvantaged communities	11	17
Ownership	4	10
Power	7	13
Urban context	11	23
Urban economics	14	45
6 Perceptions of indicators	5	9
Data presentation	7	9
Data quality and availability	10	20
Indicator metaphors	3	5
Motivation or value	16	44
Building a business case	7	10
Challenging 'business as usual'	4	5
Number of indicators	6	16
Performance affects how data is used	2	3

Codes	Sources	References
Persistence	2	2
Scale of interest	6	14
7 UHI tools projects	9	21
Building on other UHI tools	12	31
CIV timeline*	2	6
Community involvement	13	27
Duplication	2	3
Focus on problems not data	2	6
Fragility of UHI tools	9	17
Funding	9	24
Gap between aspiration and reality	4	4
Limitations	5	10
SFIP timeline*	3	9
Stakeholders	11	23
Vignette*	9	15

A2.3 Thematic analysis mind maps

Figures 1 to 9 show nine mind maps that were developed during the thematic analysis. Red boxes related to specific codes in Nvivo. Grey boxes did not relate to codes but emerged from data extracts. Blue boxes were connectors within the mind map to help the researcher organise related concepts.

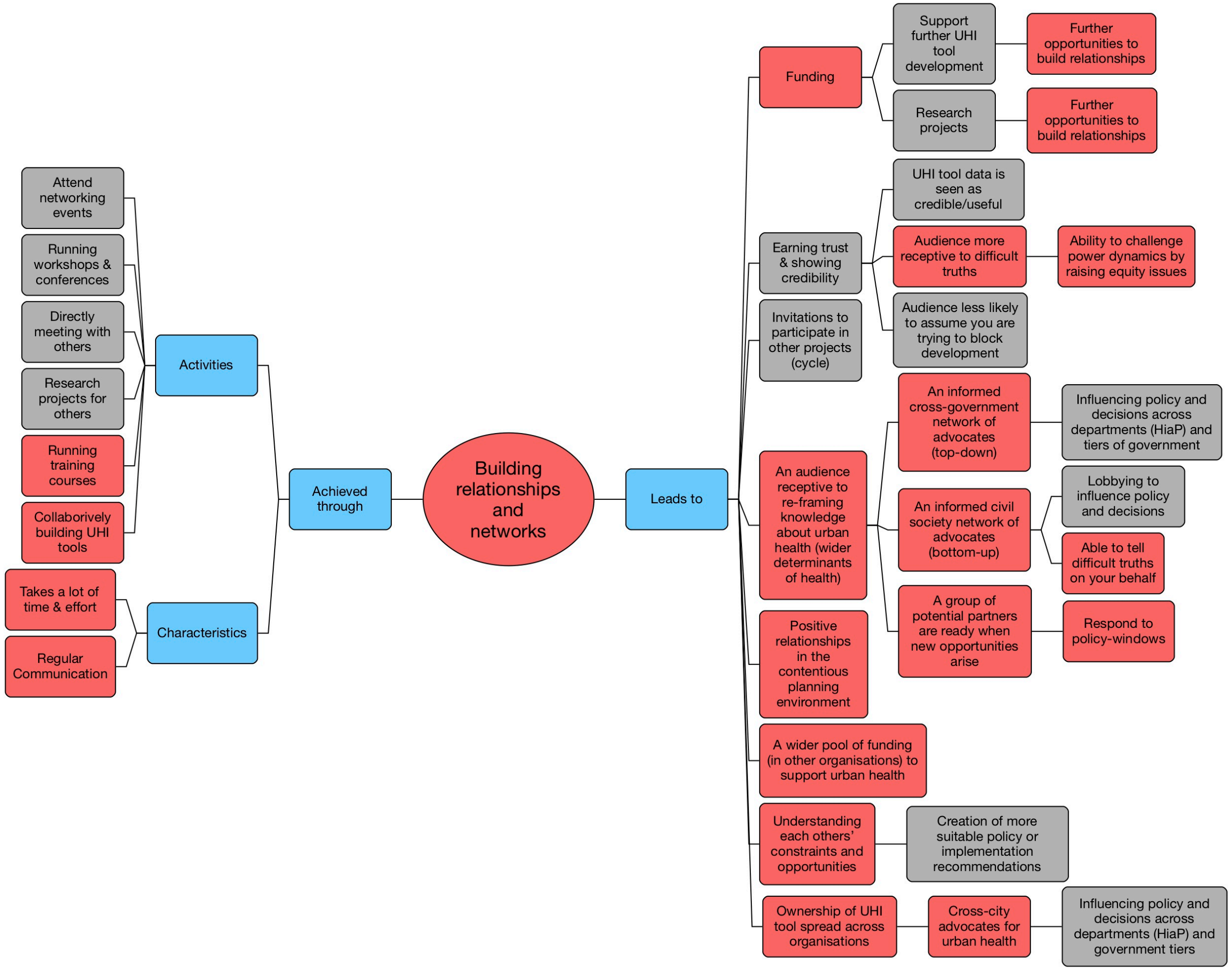


Figure 1 Mind map 'Building relationships and networks'

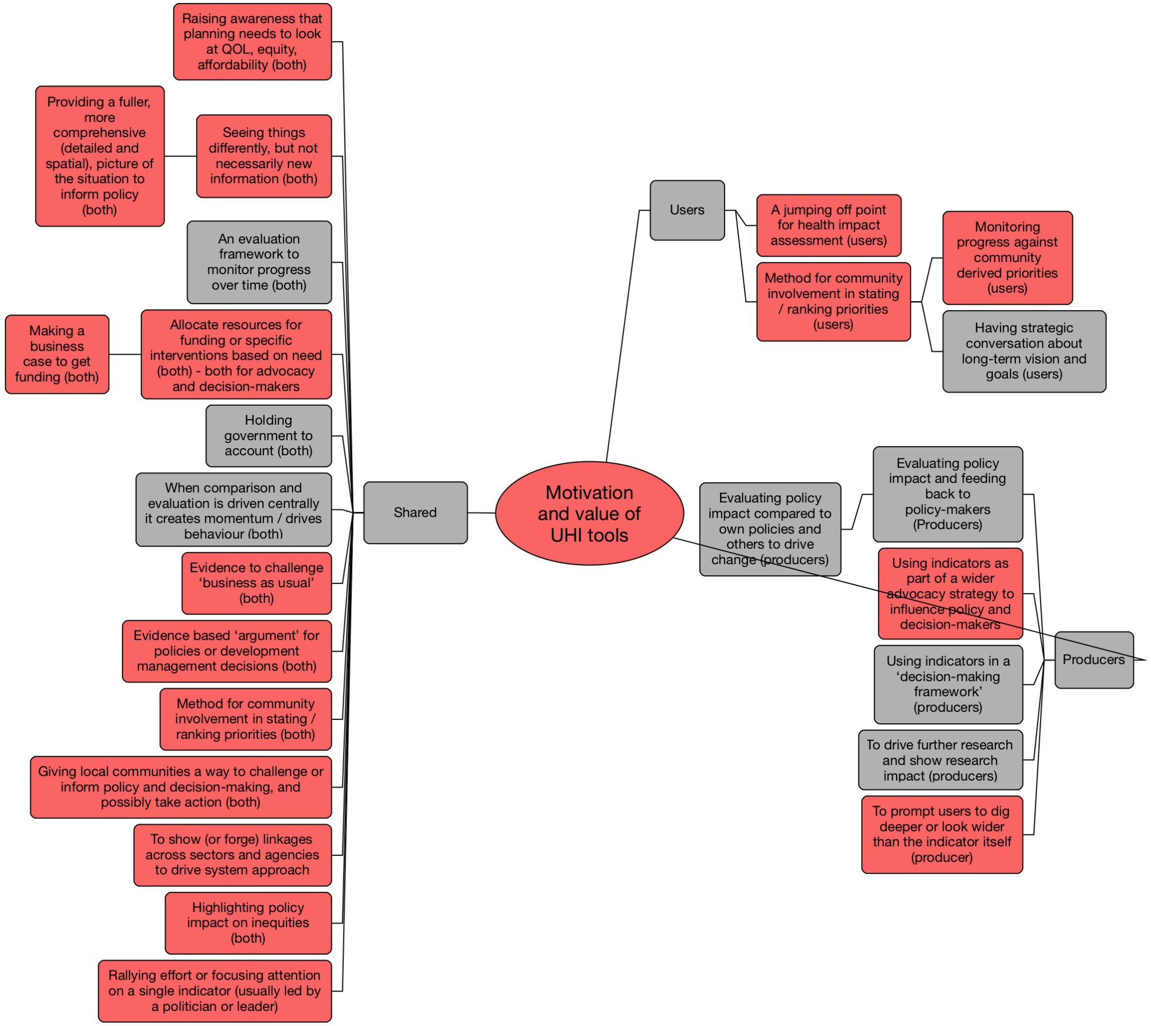


Figure 2 Mind map 'Motivation and value of UHI tools

Figure 3 Mind map 'Professional norms of knowledge, values, remit and ways of working'

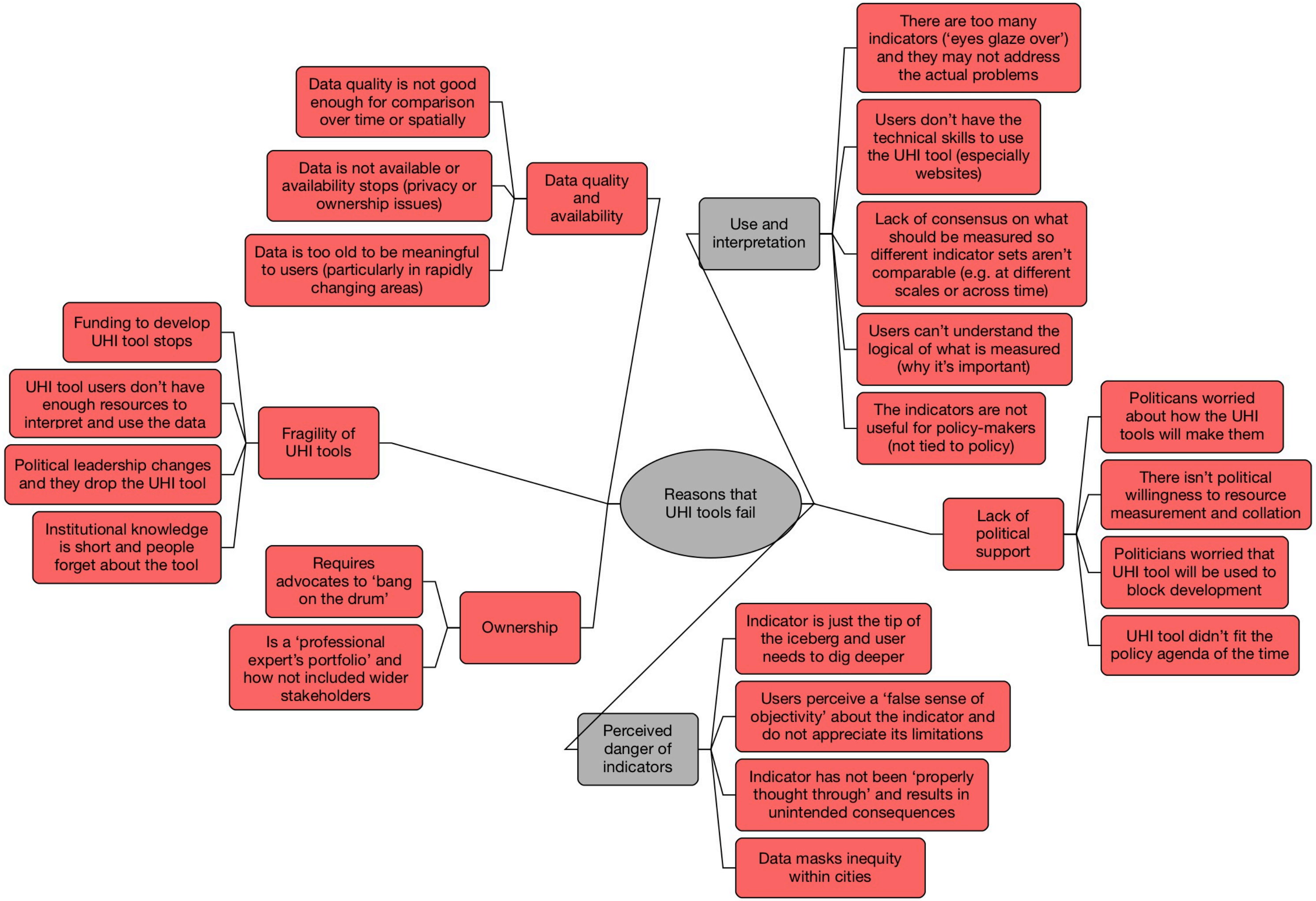


Figure 4 Mind map 'Reasons that UHI tools fail'

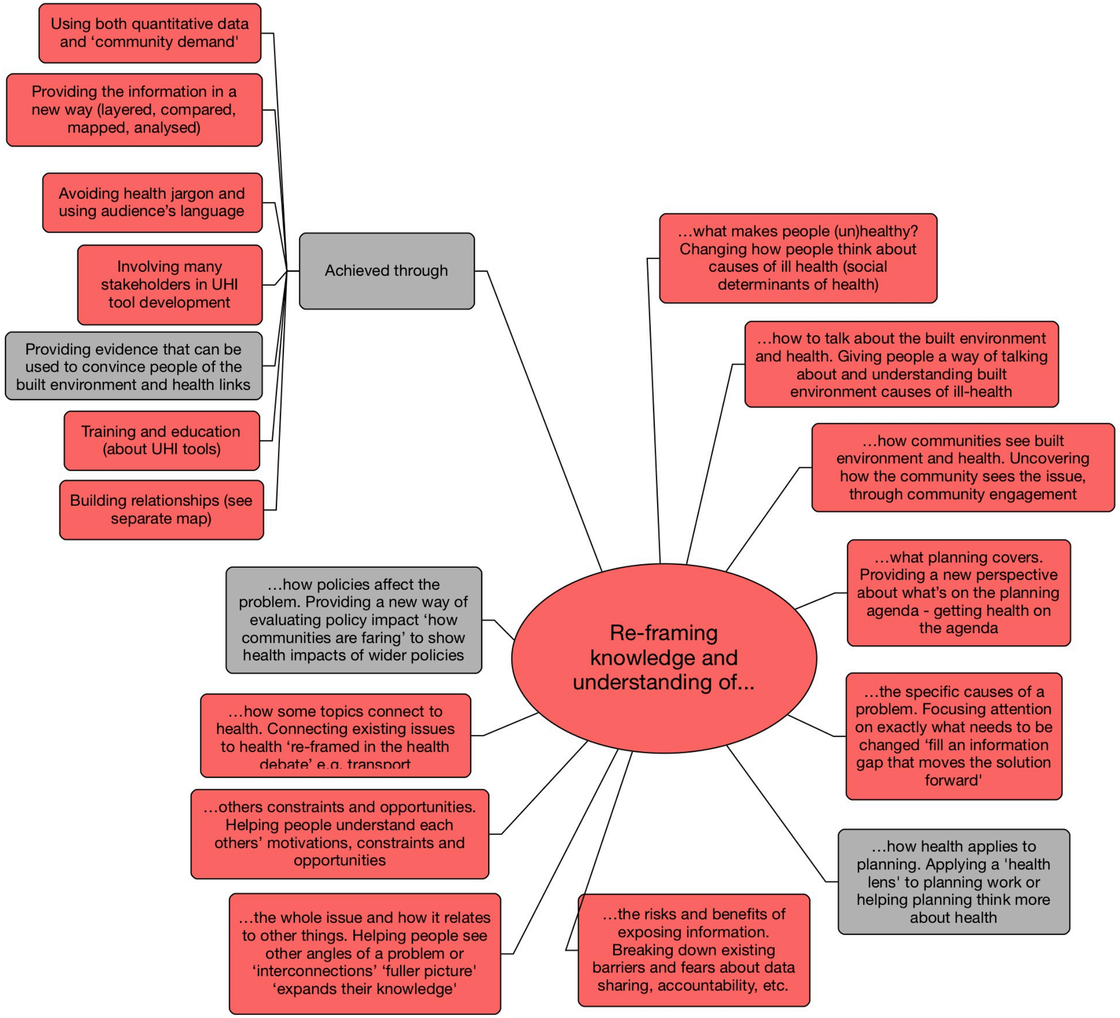


Figure 5 Mind map 'Re-framing knowledge and understanding of…'

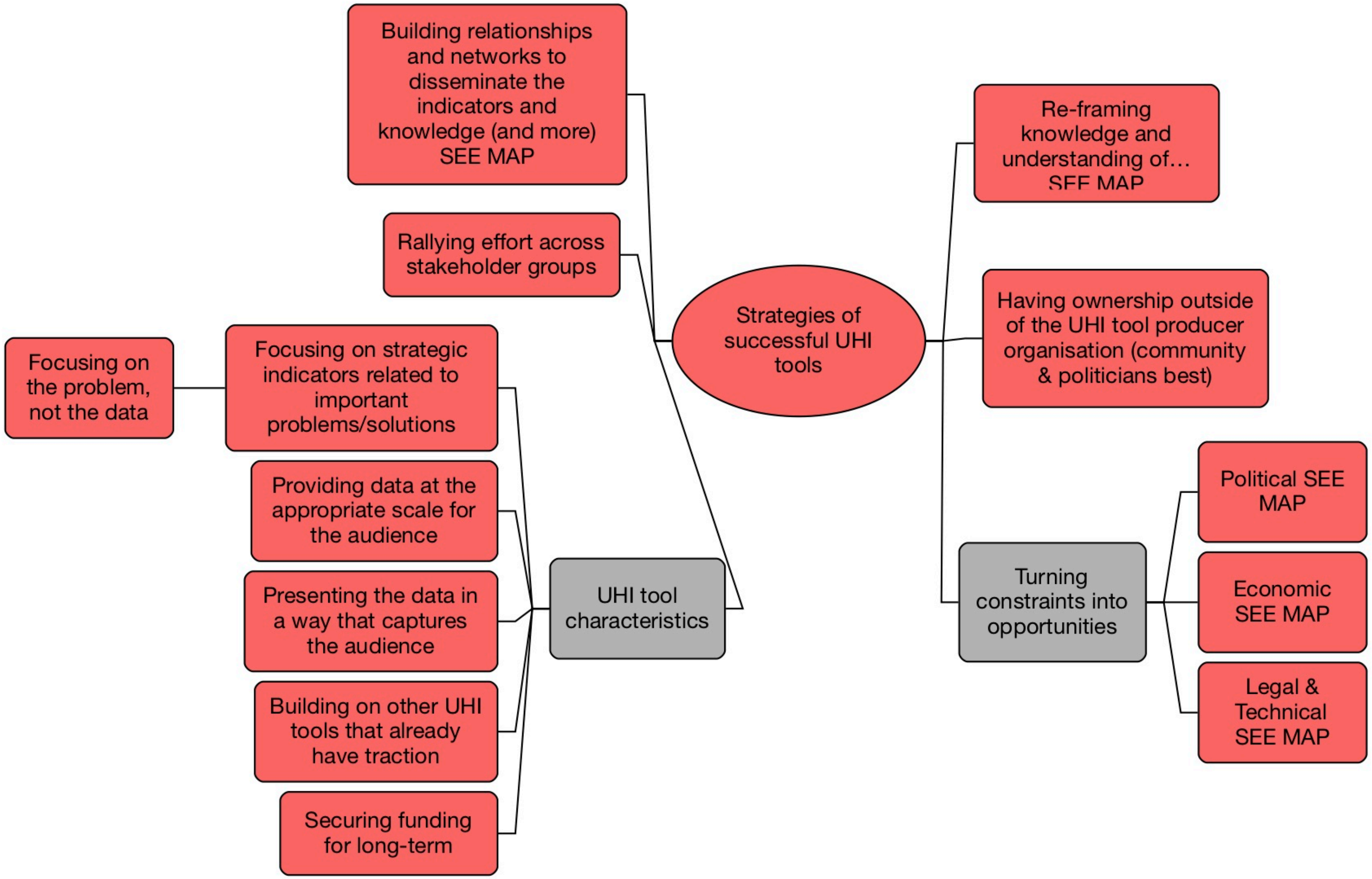


Figure 6 Mind Map 'Strategies of successful UHI tools'

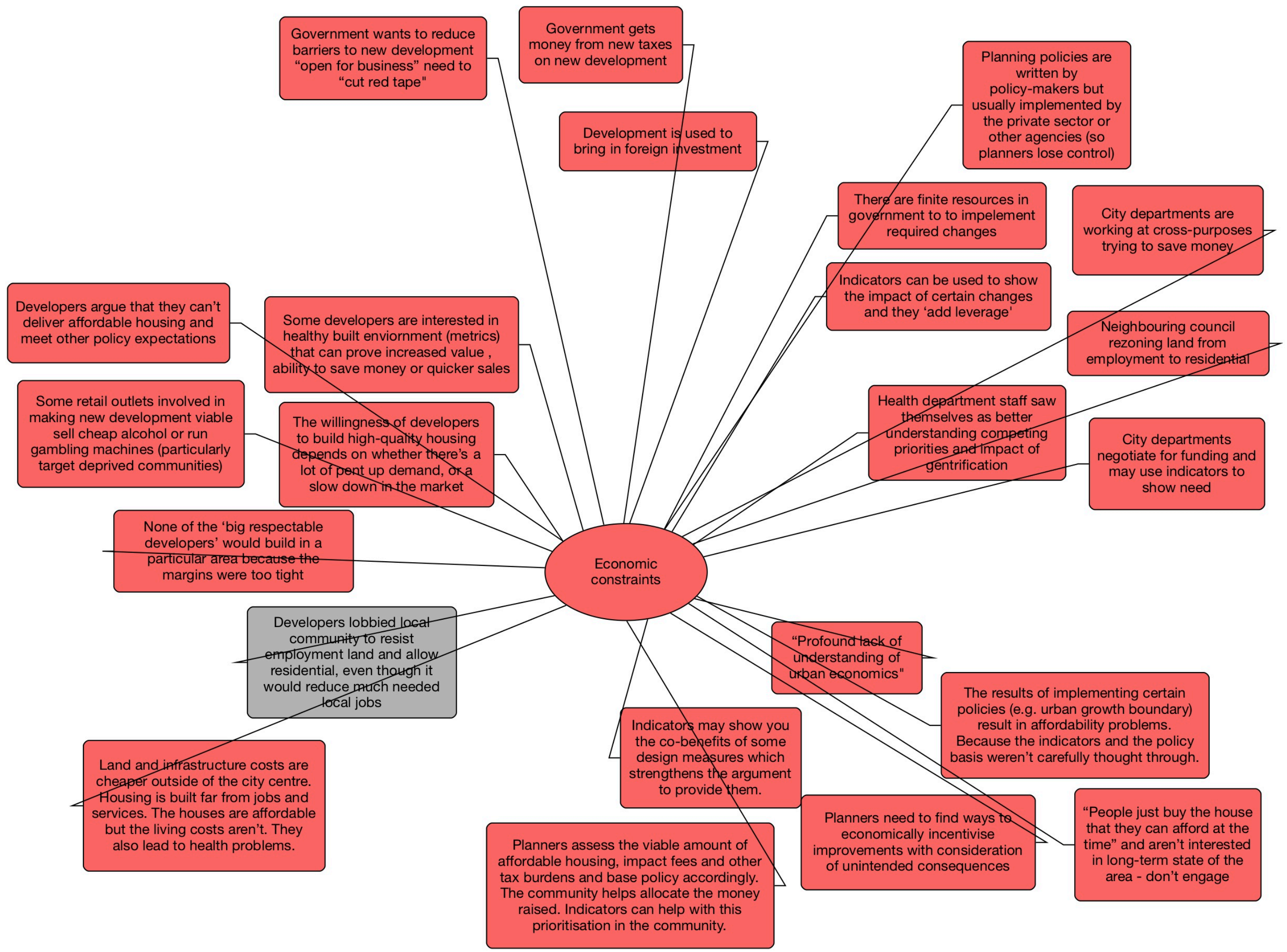


Figure 7 Mind map 'Turning constraints into opportunities: Economic'

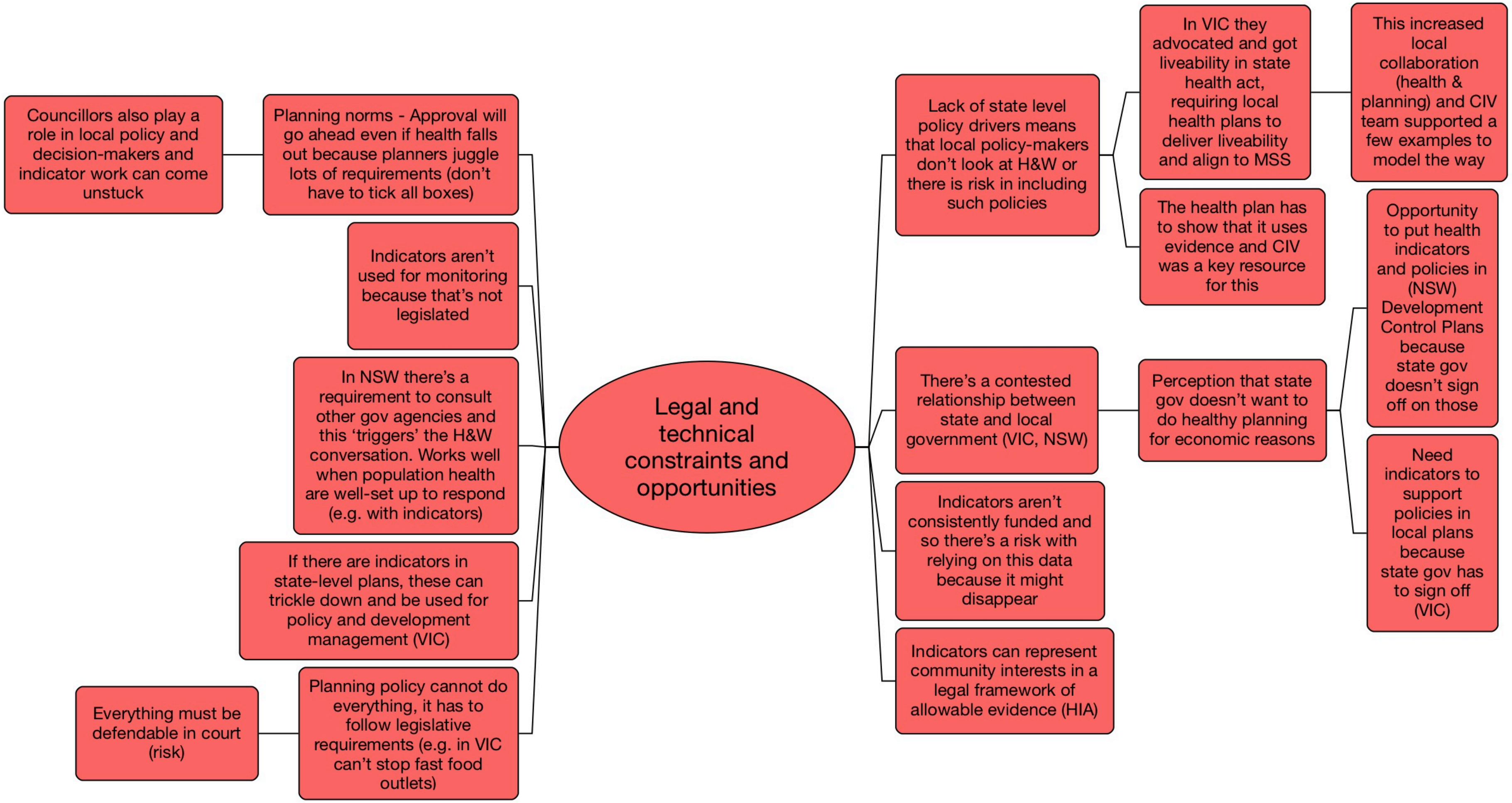


Figure 8 Mind map 'Turning constraints into opportunities: Legal and technical'

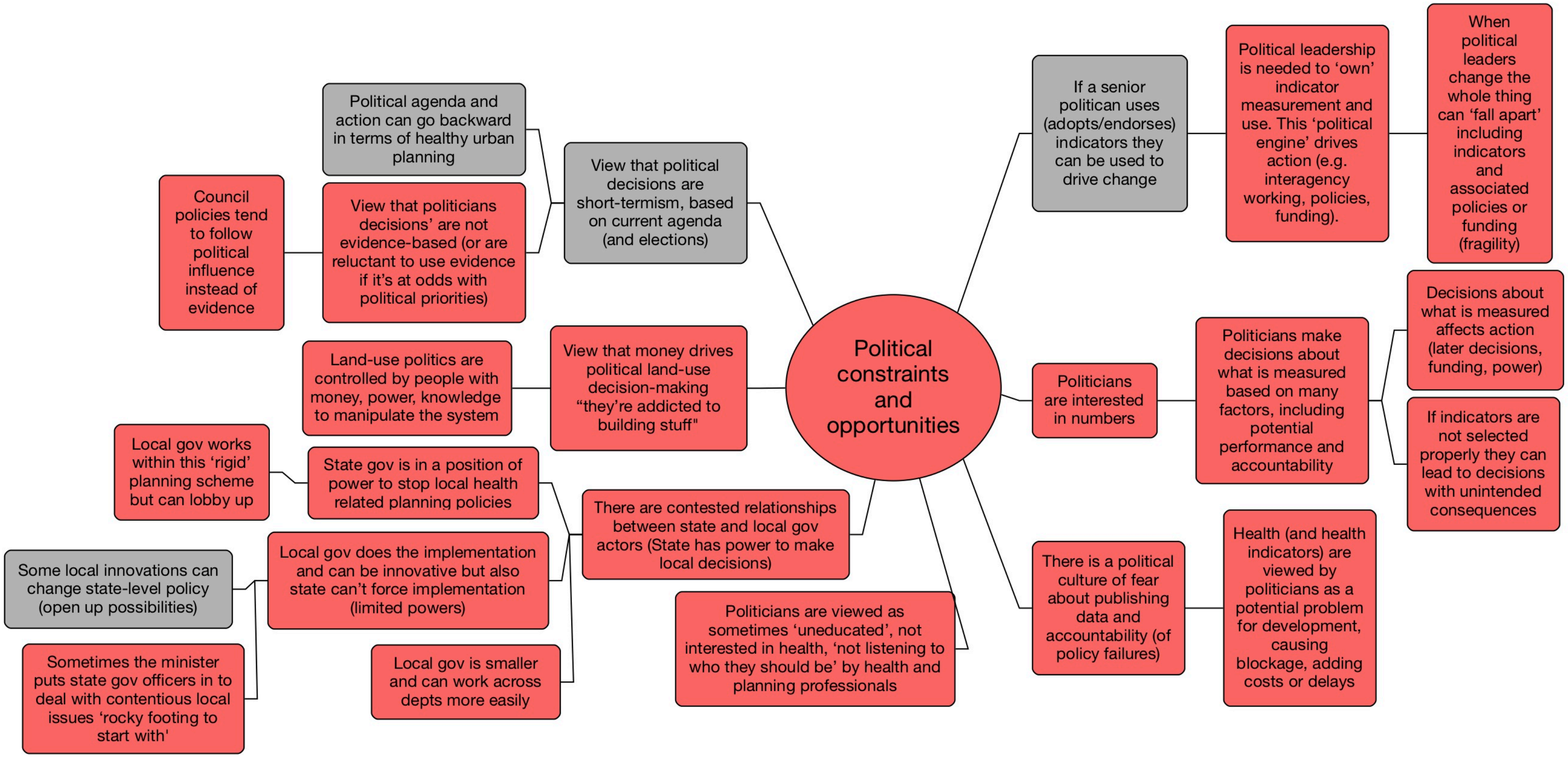
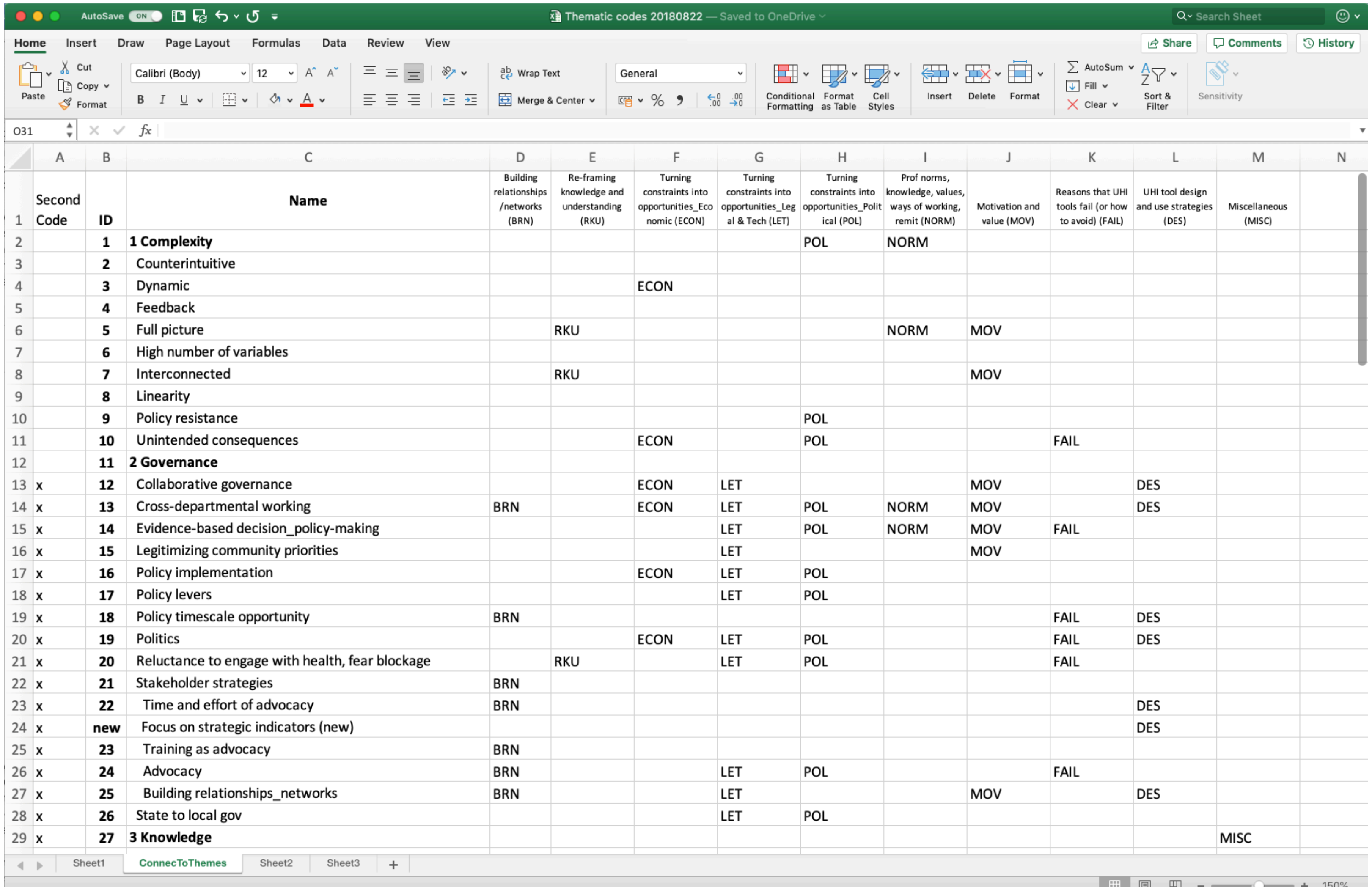


Figure 9 Mind map 'Turning constraints into opportunities: Political'

A2.4 Thematic coding spreadsheet

Figure 1 shows a screenshot of the Excel spreadsheet that was used to map codes from Nvivo across emerging themes during the thematic analysis process.



	Second Code	ID	Name	Building relationships /networks (BRN)	Re-framing knowledge and understanding (RKU)	Turning constraints into opportunities_Economic (ECON)	Turning constraints into opportunities_Legal & Tech (LET)	Turning constraints into opportunities_Political (POL)	Prof norms, knowledge, values, ways of working, remit (NORM)	Motivation and value (MOV)	Reasons that UHI tools fail (or how to avoid) (FAIL)	UHI tool design and use strategies (DES)	Miscellaneous (MISC)
2		1	**1 Complexity**					POL	NORM				
3		2	Counterintuitive										
4		3	Dynamic			ECON							
5		4	Feedback										
6		5	Full picture		RKU				NORM	MOV			
7		6	High number of variables										
8		7	Interconnected		RKU					MOV			
9		8	Linearity										
10		9	Policy resistance					POL					
11		10	Unintended consequences			ECON		POL			FAIL		
12		11	**2 Governance**										
13	x	12	Collaborative governance			ECON	LET			MOV		DES	
14	x	13	Cross-departmental working	BRN		ECON	LET	POL	NORM	MOV		DES	
15	x	14	Evidence-based decision_policy-making				LET	POL	NORM	MOV	FAIL		
16	x	15	Legitimizing community priorities				LET			MOV			
17	x	16	Policy implementation			ECON	LET	POL					
18	x	17	Policy levers				LET	POL					
19	x	18	Policy timescale opportunity	BRN							FAIL	DES	
20	x	19	Politics			ECON	LET	POL			FAIL	DES	
21	x	20	Reluctance to engage with health, fear blockage		RKU		LET	POL			FAIL		
22	x	21	Stakeholder strategies	BRN									
23	x	22	Time and effort of advocacy	BRN								DES	
24	x	new	Focus on strategic indicators (new)									DES	
25	x	23	Training as advocacy	BRN									
26	x	24	Advocacy	BRN			LET	POL			FAIL		
27	x	25	Building relationships_networks	BRN			LET			MOV		DES	
28	x	26	State to local gov				LET	POL					
29	x	27	**3 Knowledge**										MISC

Figure 1 Screenshot of Thematic Codes mapping spreadsheet

A2.5 Complexity category analysis

Table 1 was used to analyse interview data related to complexity. Interview quotations were grouped under the complexity characteristic codes used in Nvivo, including: interconnected, feedback, unintended consequences, counterintuitive, number of variables, policy resistance, linearity and dynamic.

Table 1 Complexity characteristics described by interview participants with regard to their understanding and strategy for addressing.

Complexity characteristic	Understanding	Strategy for addressing
Interconnected	"As a topic of interest to me, I'd really like to understand… I don't know what the correlations are between the various different indicators that we have possession of. A typical example of house price, environmental value, but also looking at those health indices, so not everywhere has pavements, for example. So there's plenty of residential areas without a pavement. And then, again, looking at obesity rates, et cetera, and trying to have that understanding of how all the different data sets fit together, and just seeing if there are correlations. Doesn't mean there's a cause… but at least make a start in that space." (user) "Drawing relationships between them is typically challenging, because often they're coming from different sources. So yes you can infer to a degree, but it is a little tricky from time to time to bring evidence from multiple sources and try and draw a conclusion." (user) "If you were to say, to try to optimise, and again this is an extreme, and highly unlikely scenario, but let's say the transport plans across [the state] were going to really focus now on optimising the public transportation network to boost their score on the indicator that we've created. That would be done potentially at the expense of the performance on other indicators. Because at the end of the day, there's a finite amount of resources available to implement these sorts of	"…there are lots of levers that you can pull, and obviously sometimes, some levers they're going to have stronger or weaker effects than others. And sometime pulling one lever will actually move some of the other levers as well, because they're interconnected. And I think that... what the indicators give is a way of measuring something that has been validated to have a real-world association." (producer) "But maybe the interrelation part is the difficult piece, and that's no fault of [the UHI tool producer], it's actually a citywide issue, and so that's why we're thinking what sort of indicators can create more of those interrelations. So things that are not necessarily just an indicator of one thing, but of many different systems." (user) "I think we tend to, when it's a big issue, we take that indicator and we really massage it, and we work with it from lots of different angles. We don't just use an indicator and say, "Oh, look at that." I think we've done the same thing with traffic safety. We look at it from many different angles. Look at things that are related to it…" (producer) "Well, the framework was there that influenced the way people thought, but I think it's actually making that real for them, taking it, and giving them an example… that gets them to see how they're all interrelated. It also expands their

	changes. And possibly even just by virtue of trying to improve one indicator because the interconnectedness performance on other indicators may actually suffer. As a hypothetical scenario, that's unlikely to occur and it's probably a good thing that it's unlikely to occur because it wouldn't necessarily be the way that we're advocating an indicator should be used." (producer) "I think because it serves more as a data warehouse right now, people will seek out the issues that really matter to them most. So it might not, like I said, describe the complexity." (user) "I think when you don't have geographic granularity, that's where you can lose a lot of complexity, because when you have both aggregations and disaggregations, it allows you to see the forest and the trees. It's not just one or the other. I think that's the nice thing about indicators, because usually when it comes to ... Like if you look at the city performance score card or whatever, a lot of times when they're only focused on a citywide measurement, then you're only seeing the forest. When you're just looking at individual eviction data or something, you're only seeing the trees. When you have the opportunity to zoom in and out, and have that dynamic nature, then that allows you to look at trends, and then think about what's the intervention point." (producer) "…one of the pitfalls of indicators that I don't think has happened [here], is that if you use them without this holistic complex vision, you can see trends without understanding why. You'll see a lot of correlation, but not causation." (producer)	knowledge beyond what they might have already thought. I think in practise is where the real benefit comes. I used to say, "Look at the framework," and the framework page was the most well-used page because it had all five of the domains and it talked about each of the indicators. Not the specific measures, but then you could get that overall sense of how does this all connect up." (producer) "Within this plan, there's no clear line from one liveability factor to one health and social outcome. It's very much a messy web. We know that, for example, in terms of reducing obesity, that's going to involve a whole heap of work around active travel, in terms of education, employment around ensuring people have jobs close to home so they have time to exercise, food, obviously. So we know that there's different elements within all these liveability factors that affect those outcomes. So we haven't gotten to the stage where we have mapped out all of that because it's just too huge, to be honest, and we just don't have capacity to do that. …the objectives and the strategies that we've chosen under each of these policy areas to address the long-term outcomes, are really based on our understanding of what we know we can influence at a local level. (…) Those indicators, I guess, we do use them... to show impact in multiple areas." (user) "…the value of indicators, especially linked to a very deep conceptual framework… (…) …our work really did spearhead the use of a socio-ecological model to actually show the linkages across other sectors." (producer)

	"…any use of indicators you've got to be careful with, because they'll only give you… a snapshot, and it only gives you one bit of insight into what's happening. The world is a far more complex place, and I think the challenge that we haven't yet met is understanding 'what is the matrix of indicators we actually require?'" (user)	
Feedback	"…we're working on a project at the moment around our local food system. (…) We look at those interactions between different parts of the system and how they interact and where the feedback loops are. I think it's really challenging to get to that next stage where you're using set indicators to show the degree of impact from one element to another." (user)	"… [the UHI tool] shows the consequences over time about what can happen… sort of plays it out in terms of 'if, then'. If we do this, then this could happen, and then this could happen. So [a colleague] produced a slide deck that sort of showed it progressing over time, and that's very useful because I'm able to say to policy-makers, "What your policies include influence what's built or what's not built. That then influences how people interact with that space and what their experiences are, and sort of behaviours that have built up over time, which influences people's ... " (producer) "It's a feedback. It's a complete loop, right? That is a characteristic of a good indicator. It fits into a responsive system loop. There's an action, the action happens, the indicator is changed. (…) …but let's say the indicator doesn't exist yet. You have to first think about what feedback loop you want, and then what levers and actions need to happen, and then, what is the information system that drives those levers and actions? You first understand the problem, then you understand, you propose a solution or imagine a solution that either doesn't exist or isn't being implemented. Then, you select the indicator to drive the whole, the action, but to drive and motivate the action, but the indicator has to

		be responsive to the action, and show the problem improves if you implement the action." (producer)
Unintended consequences	"I'm not sure how deeply anyone thinks, once they've got an indicator on the page, how deeply they think about what it's doing. And maybe they never will. (…) the best example I can think of… We tend to have plans about population growth and how population growth is going to be managed. (…) And what tends to happen is when a government is elected, they review the plan or they look at the plan and they do a new one... And often the plan will have a target for densification or an urban growth boundary that's never going to move... And the politicians think, well, that's terrific, yeah, great, that's all the advice we've got, and all the academics tell us that's the right thing to do, and that's what we'll do... And so they endorse it, and then in the implementation, it becomes clear that it has a significant impact on affordability... And so the politicians pull back, and they expand the urban growth boundary, or they change, or they rezone, or they reduce the requirements for whatever, or they build in green wedges, or all of that stuff. (…) And it happens all over the world. Because why? Because the indicators haven't been carefully thought through, and the policy basis hasn't been carefully enough thought through." (user)	"if you're tracking [liveability] across multiple domains, even where improvement in one area may come at the expense of something else... Like for example, a push to increase density, to increase walkability, could be at odds with a push to increase access to public open space. Maybe, but maybe not. I think those inherent tensions are not addressed directly by the indicators that we're looking at, but by the fact that we're providing a suite of indicators across multiple domains at least means that if you're pushing to heighten a particular area and it's driving something else down, at least you're starting to see that emerge in a way that you can act on it." (producer)
Counterintuitive		"The narrative for sea level rise and extreme storm is that although we weighted sea level and precipitation, like internal flooding higher, that a lot of the impacts based on socioeconomics and on health indicators aren't in the areas that have the highest sea level rise… One of the impacts that we're hoping is that people see that just because an extreme

		storm will hit the [coastal neighbourhood] the most, you'll still see areas that maybe are a little bit more inland, like [xx], be impacted because they have all these other inequalities that they're dealing with." (producer)
Number of variables	"I think what I'd say from a municipal perspective is that we've got so many different areas of the community that we touch on, and our role in the social, economic, natural environment, cultural, government spaces, means you can't really use one of those frameworks in isolation. You kind of need to use multiple to tell a story and provide a full picture." (user) "There is a sort of reductionist sense that you're trying to reduce complexity down to something measurable. (…) You can't measure everything and you can't measure the relationship between everything in this system. It gives some points of reference. It helps with prioritising and decision making in certain areas." (producer)	"The idea of networks and network science is now part of the zeitgeist as well. Now, those sorts of things were in the back of my mind when I was developing …the domains [then] each of these measures. I saw ... I didn't want to go overboard, and having lots and lots, tried to distil them down to as few as logical, but still give a robust picture of the area that you're studying. Saw that for each of these questions, you could have a number of measures, so that you made each of those measures whole in themselves, but they interacted together to give a richer picture in relation to each of the questions." (producer)
Policy resistance	"Because right now the city is really committed to this idea of [transport policy] to reducing street fatalities to zero. So there's been a number of pedestrian injuries. Too many. And so the city has, with public health department's lead, has looked at what are the major causes of injuries. Are they right turns? Are they left turns? Are they pedestrians crossing without a signal? And then they have specific counter measures that are supposed to address those types of collisions. And we've been doing it for about two years and the fatalities aren't going down. And so it's been sort of this larger conversation and just kind of thought process about how you address this. We're doing very detailed analysis over	

	what are the cause and effects and what are the right tools to address these things. We aren't seeing the results that everyone wants us to see. That's somewhere we're really using this data and [these] indicators to really inform traffic engineering." (user)	
Linearity	"User 1: It's really hard to explain to a lot of people and I think it's been a really difficult process embedding liveability into a health and wellbeing plan because traditionally the way that health and wellbeing plans are being developed is very linear, …hasn't considered that complexity traditionally, I would say. So we've kind of tried to, we've gone from- User 2: It's more than just a tick box now, it's- User 1: ... yeah it's actually, we've gone to that next stage with this plan."	
Dynamic	(delays) "But what we've said all along is that these are long-term planning decisions that need to be made now in order to see improvements in the future. They're not improvements that you will see overnight. And that's something probably from a population health point of view that we're sort of used to advocating for, because it's taken us a long time to get people to make changes. People who go out to smoking you know, and other things and...we don't see changes immediately but, if we don't start advocating for them…" (producer)	"I guess the way that it's being presented here is a way that actually shows the consequences over time about what can happen, which I think builds on this systems model…" (producer) "…a lot of the work in climate change is focused on these long range infrastructure projects, and that's primarily what climate adaptation has been. It's looked at like, okay this building will have a lifespan of 75 years, what will happen? We're focused on the human element of that, so what is the impact of new developments in a flood plain? Or if there's more extreme heat, what can health services do. I think that

		going forward there's a way that those two get united, but they've kind of been happening in separate so far." (producer)

A2.6 Emerging themes

Figure 1 shows a thematic map of the nine initial themes. The grey box shows how the 'strategies of successful UHI tools' theme (abbreviated as 'strategies to succeed') related to its sub-themes and inversely to the 'reasons UHI tools fail' theme. These themes were all connected to the emerging 'professional norms, knowledge, values, ways of working, and remit' theme, which moderated how UHI tools were developed and used. Finally, all of those themes relate to the overall 'motivation and value of UHI tools' theme.

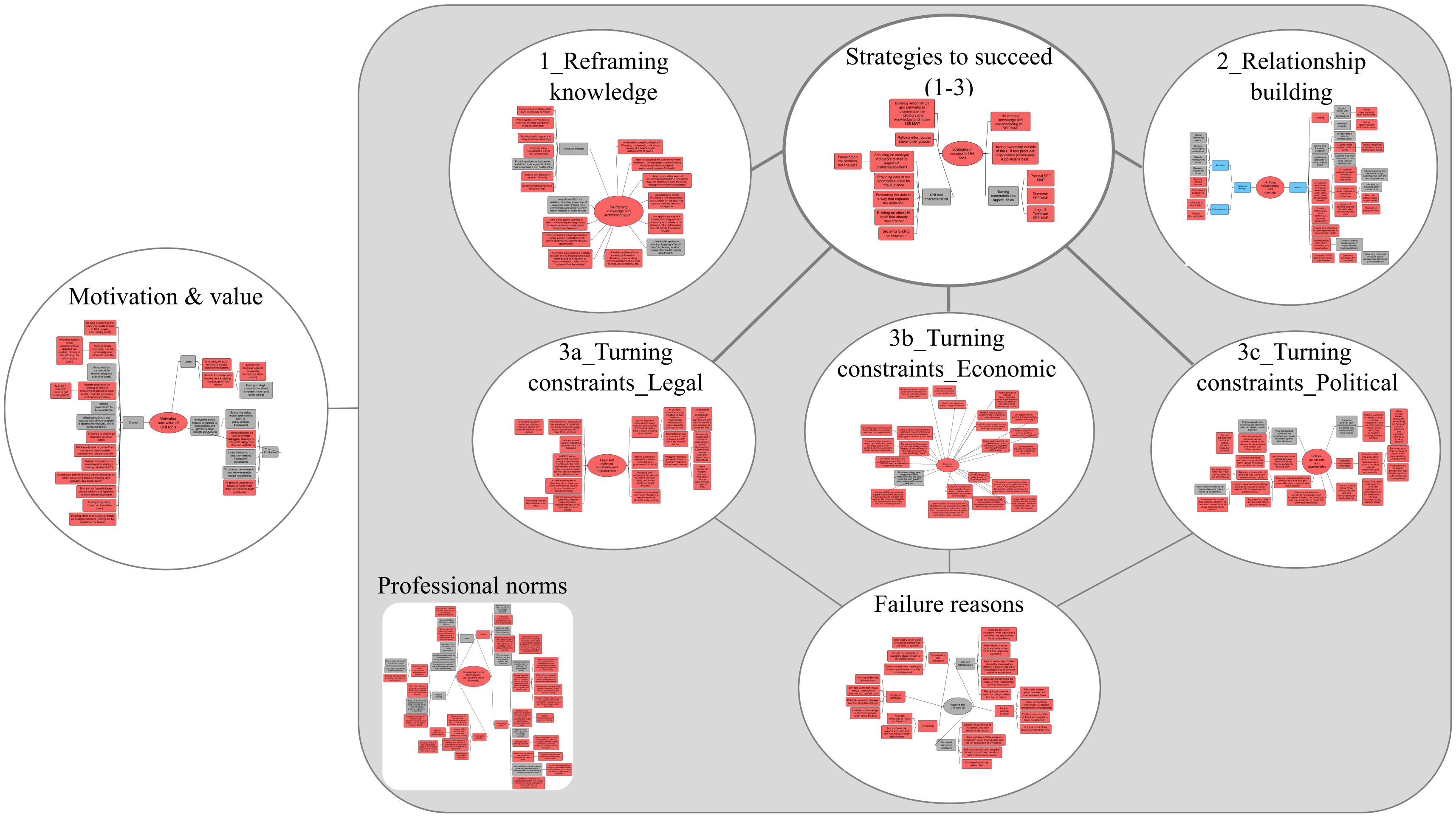


Figure 1 Thematic map of emerging themes

A2.7 Benefits or uses of UHI tools

Table 1 provides quotations from the interview data regarding the benefits and uses of UHI tools. These are accompanied by vignettes from the interviews that describe how a particular benefit or use occurred in practice.

Table 1 Interview participants' descriptions of the benefits or uses of UHI tools and vignettes of UHI tools in action

Description of UHI tool benefit or value	Quotes describing the value or benefit	Vignette of this benefit or value in action
Described by both producers and users		
Raising awareness that planning should address quality of life, health, equity, and liveability issues	"They certainly provide the new perspective on what issues planning should be planning for…" (user) "…we want to move outside of the tradition quote, unquote "sustainability" measures... And we want to really think more holistically about issues of equity, and health and quality of life. And we've heard a lot that people will tune out if we don't include those issues." (user)	"And so as part of this intensive community-led process, [the indicator producers] developed these sets of areas for the indicators, and then over a hundred different indicators within that. And really it was a message that planning needs to be looking at quality of life, and needs to be looking at affordability." (user)
Helping people to see issues differently (bigger picture, detailed, spatial), but not necessarily through new information	"Sometimes you anecdotally or theoretically know a lot about neighbourhood, but when you use indicator data it provides a visual picture of what you already know, or like a distribution…" (producer) "…a lot of times if you're working in certain neighbourhoods you know things, but geographic data provides you with the opportunity to see the distribution and to make more targeted changes." (producer) "Well, the framework was there …gets them to see how [the indicators are] all interrelated. It also expands their knowledge..." (producer)	"And [the UHI tool] adds another dimension. More of a qualitative dimension. Like is there trash on the street? Is it dark? Do you feel ... Are there perceptions around crime and safety? Those more like qualitative things don't show up necessarily in pictures or in GIS. I think it makes it a little bit more comprehensive. We are sort of covering our assessment of existing conditions more thoroughly. (…) I think all the data was helpful. I don't think there were many surprises. I think for the most part, [the city] is very small. So we ... I think most people are kind of familiar with the neighbourhoods on a more macro level. So yeah, I don't think any big surprises." (user)

Description of UHI tool benefit or value	Quotes describing the value or benefit	Vignette of this benefit or value in action
Providing a framework for evaluating change or progress over time	"…we also do want to track things over time." (user) "… [the UHI tool] shows the consequences over time about what can happen… sort of plays it out in terms of 'if, then'. If we do this, then this could happen, and then this could happen." (producer)	"…the city is really committed to this idea of Vision Zero to reducing street fatalities to zero. So there's been a number of pedestrian injuries. And so the city has, with public health department's lead, has looked at what are the major causes of injuries. (…) And then they have specific counter measures that are supposed to address those types of collisions. And we've been doing it for about two years and the fatalities aren't going down. And so it's been sort of this larger conversation and just kind of thought process about how you address this. We're doing very detailed analysis over what are the cause and effects and what are the right tools to address these things. We aren't seeing the results that everyone wants us to see. That's somewhere we're really using this data and [these] indicators to really inform traffic engineering."
Providing evidence (a 'business case') to justify funding or specific interventions based on need (including vulnerable or disadvantaged communities)	"…we expect that it will be used to allocate resources and interventions…" (producer) "I think the way that people will use this the most is as an advocacy tool to advocate for resources that go into these impacted neighbourhoods... Because it's comparative. …so you know that this [is] where resources and time and energy should go." (producer) "…we are really interested in seeing how those or other indicators can look at spatial planning on a sub-municipal level because that really is going to be needed to inform how we approach	"If you were working in an area and someone was only focused on what are the street speeds, what is the width of the curbs and you say, "Oh we've talked to people and they're concerned about safety. We want to add lighting". They'll say, "Oh we don't have money for lighting". Then you could point to another area, where here's an area that has lighting. People have felt really safe so we have an opportunity to do something. Then at least we can compare. It maybe adds leverage. And we know in terms of implementing these things in [this city] in particular, it's very expensive. So having that rich data is also really helpful too, for our politicians. Because it gives them something to help state the case to get funds for things." (user)

Description of UHI tool benefit or value	Quotes describing the value or benefit	Vignette of this benefit or value in action
	things. We can't just get a figure for [the whole city] and then know where to target our responses.” (user) “Huge help in trying to secure the funds. Helps that business case development.” (user)	
Giving people information with which to hold government to account for policy impact	“…you end up with information that is comparable and that allows people to hold governments, organisations, to account. And for people to assess whether government spending is actually making a difference or not.” (user) “Maybe people in government or certain agencies knew this. But, it's different to have it called out by an independent research organisation isn’t it.” (producer)	“I know even thinking back years ago, there was an MP... I had collated a whole heap of transport indicators for her… She was using it to go to say, "Look how bad our access to transport is in the western suburbs. We're not getting the attention and the support, the services that we need." She would then take it into her position and use it for advocacy.” (producer)
Establishing evidence that can challenge ‘business as usual’ approaches (or using the indicators to point out unpopular ideas)	“…it helps challenge the perception in the business as usual models. I think it's fair to say we're quite a conservative area, so if we're looking to have a change in practise, you do need some strong evidence base to challenge that orthodoxy.” (user) “Then it gives you more of an impetus, again, to say we need to do it.” (user) “I want to understand where our interventions are going to be most effective. We tend to	“The [city’s perspective of the] problem frame was that pedestrians, it was behavioural, pedestrian or automobile driver behaviour. We had the highest injury rate in the country, the highest fatality rate in the country, per capita. We [indicator producers] knew that this was environmental. It was based on traffic design and traffic volume and traffic speed. (…) We did epidemiology that demonstrated that, but that wasn’t useful evidence. Then, we created a new measure which instead of doing the intersection density of the injuries, we calculated the linear density of injuries on cumulative road segments. (…) It became a manageable problem, so 5% of the

Description of UHI tool benefit or value	Quotes describing the value or benefit	Vignette of this benefit or value in action
	follow political influences. (…) I'd prefer us to become more place based, more specific in terms of saying, well, that area is already catered for sport. (…) And have that more honest conversation and saying, well, sometimes, because you've always had the funding, you're not going to continue to get the funding." (user)	streets accounted for 55% of the serious and fatal injuries. (…) What that said was, this was a road problem. When we did that, almost immediately city policy shifted from focusing on residential neighbourhood traffic calming, to the realisation they need arterial traffic calming." (producer)
Providing evidence to underpin planning policies or development management decisions	"So they actually analysed the main street segments [using the UHI tool] and we cited that in the plan, too." (user) "I want to understand where our interventions are going to be most effective. We tend to follow political influences. I think it'd be better to have a more evidence-based approach…" (user) "…if I'm going to have a policy change, I need to have some degree of evidence to show to the state government why that change should occur. Now that might be relatively straightforward indicator information." (user)	"Like they were wanting to develop a public site into a park... We were also able to say, "We know that this neighbourhood is lacking a lot of green space, but this is how much this neighbourhood is lacking green space compared to the rest of the city." To quantify the magnitude of the problem, but then to also say ... When taking into account the fact that it's good to build this green space, but based on its location in a very traffic dense environment, it's really important to consider pedestrian crossings and different types of environmental protections in that location. To maybe put up signage to say, "This park is really close to a freeway. If you have asthma or COPD [Chronic Obstructive Pulmonary Disease], maybe you don't exercise really hard here." Or just something to kind of allow it to have benefit, but then to also to protect against possible challenges that may result from that." (producer)
Forming a method for community involvement in stating or	"we took that list of …indicators, and worked with our partners …who are the community representatives, and we ranked all of the indicators, in terms of their priorities and what they thought was really relevant in that specific	"I am interested in who has ownership of those indicators. That's why our 20-minute neighbourhood project… I want the community to have some degree of ownership in choosing the indicators… and helping influence and shape how they get improved. (…) But in striving to get

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ranking local priorities	community, and then we added others that were geared towards objectives of that grant and really neighbourhood priorities." (user)	the community more aware and more engaged in the planning profession, I think we in the profession have to use different indicators which mean something to the community. My local community… couldn't care two hoots if I've got ten years' land supply in my area. What will matter to them is, it's more than a five-minute walk to get to a foot path to walk their dog." (user)
Giving local communities the means to challenge or inform policy and decision-making, and possibly taking their own action	"[the UHI tool is] a really good advocacy tool for constituents. (…) Cause it sort of gives them something a little more tangible to push policy towards. Because it's something also that can be measured. Because you know, a lot of feedback that we get it is, "I don't like this. My view is blocked. I can't park on my street". It's hard for us to do things with that kind of information. But if you can tie it to something that can be measured, I think that really is helpful." (users) "… you'd be asking them to help create the indicators that ultimately the community's going to be measured on in the future. So I think that really can help gain greater ownership, buy-in, and hopefully responsiveness to whatever the indicator is actually measuring. If they're aware of what's being measured, then hopefully they can actually play a more active role in helping it to go in the direction you want it to go." (user)	"…through that [UHI tool] process... the community identified traffic safety or pedestrian safety as a really key issue, and so… (…) that became [the director's] singular focus in many ways. Over many years she worked to build relationships with transportation agencies, planning. They got a pedestrian strategy, and then finally a tipping point came where they were able to come together and get a Vision Zero policy passed. That, I think, came from that process of starting to develop maps showing the distribution of pedestrian injuries throughout [the city]. Then air quality similarly. But, in both instances, they were indicators [that] …were really priorities for the community, and that's why they were in there in the first place." (producer) "it was a participatory democracy. (…) The first thing was getting everybody, getting kind of a Noah's Ark of the stakeholders together and that created some problems… I was just trying to kind of maintain balance. We said, "Okay, here's our goal. We want to look at the city's development process, and we want to analyse it, and we want to make recommendations. That's what we

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	"It's giving people participatory roles in producing health supportive environments." (producer) "…you've got to talk to the people on the ground, and give them power at the same time." (producer)	want to do. How are we going to do that?" People very early said, "You know what? If we're going to do that, we need a yardstick [the UHI tool]. We learned how to do that, and we learned how to do it well, that community groups started demanding that the planning department go through this process, because we had created … This was a tool owned by this constituency. The constituency wanted it used, and so they became … Then, we just became the implementers, and that worked…" (producer)
Showing linkages across sectors, agencies and tiers of government to drive system approaches	"…to actually show the linkages across other sectors. (…) …so different government departments, different sectors, different parts of any one department are looking at different parts of the whole, and the idea of this is to show how it all fits together, but also to show how the evidence can then be used to create a systematic work that actually addresses it all at once." "I've worked in [local and] state government for a long time, and it always struck me that… (…) …the really critical issue was how you break down the silos. How you actually get collective effort to drive outcomes. Which is probably the hardest thing to do in government. And collective effort to engage the private sector and the non-government sector as well is even harder. And that's the huge benefit of indicators, that you potentially actually look at outcomes that you want to achieve over a period of time,	"One example that I feel like shows where a non-health agency really took health into account is, we have this ordinance called… which requires indoor air quality ventilation that removes 80% of outdoor particulate matter. In the recent update that we did in collaboration with planning, we streamlined the process for new permits for buildings that would be built in these areas that are deemed as air quality hazard zones, so that instead of having to do a building by building analysis, we created a map that said your parcel's either in, or it's out. If it's in, you have to install it on every floor, every unit. Whereas before, [developers] used to be able to say, "Well this unit is not going to be exposed, but this unit is." So they wouldn't have to install it throughout the building. What we did was we took the zip codes that were deemed as care zones by the air quality management district because they have higher proportions of air quality sensitive conditions like asthma and heart disease, and we set the cut point lower for those. Instead of it being like a 10 microgram per metre cubed concentration

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	and you can rally effort to drive to that outcome. Across the different silos and levels of government…” (user)	of particulate matter, it was a nine concentration in those areas.”
Rallying effort or focusing attention on a single issue (when adopted by politicians or other leaders)	“You can quote a number. Politicians do it all the time…” (producer) “So I think it helps if you're interested in numbers, and a lot of our politicians are. It helps to kind of quantify something that is more of a qualitative thing.” (user) (see last quote in previous row)	“…we need to simplify things for people, but it's such a complex issue. And the simplification is really helpful for political action, so one very salient example right now is everything is focused on housing, the mayor has this target of 30,000 units, and everyone, when you have those very clear benchmarks, it gives something for everyone to work towards, and that is a very good example because it has inspired a lot of inter-agency work and all of that.” (user)
Described by users		
Forming a ‘jumping off point’ for health impact assessment or other indicator projects	“…we would look at the [UHI tool] and just use that as almost a jumping off point for scoping health impact assessments.” (user) “We took the same domains from the [existing UHI tool] because we viewed our indicators as ... we wanted to build on the work that [they were] doing. We see that they all kind of fit together... Especially because those domains have been internalised and institutionalised, so we wanted to use the same domains.” (producer)	“But essentially one of predecessors in sustainability work… led this two year process with other agencies to come up a [sustainable neighbourhood development] protocol for [the city]. And so what they did was they took a look at the [existing UHI tool], as well as their own agency metrics and strategic plans, and they came up with a set of 63 metrics. (…) But about 75% of those metrics were actually also in the indicator project. And I think that was a very strategic decision on [her] part, in order to piggyback off of what they'd already done, especially because they'd collected all that data. But also to just forge that link and hopefully start integrating more of the quality of life and health indicators.” (user)

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Acting as a way to monitor progress (also against community derived priorities, specifically)	"And the idea's that we're setting a baseline for the neighbourhood that they'll be able to look to to monitor their progress." (user)	"… one of the outcome areas is a safe, healthy, and active community, which are really three outcomes. …each of them [has]… a suite of indicators because there probably isn't one indicator that tells us that full story. (…) Again, the challenge for us is all of the information is only available at a municipal level… In nearly every case, we can get some of this data. (…) We do a review of the data basically every 12 months. (…) And the theory is, a lot of this information informs our strategy and policy development. It doesn't allow us to do low level spatial planning…" (user)
Providing a basis for strategic city-wide conversations to define long-term goals and how these will be measured	"And so the idea is that it wouldn't just be, "How do we monitor this plan?" It's like how do we, as a city, measure our progress at meeting these really long-term goals. So we're in the process of trying to figure out how that conversation happens and who we need to engage…" (user)	"…probably about four years ago now, we adopted a new vision for [the city], which was based on basically 12 months of engagement with our community, looking at where do we want to be over the next 15, 20 years or so? Trying to understand what would be the social outcomes, and perhaps some of the non-social outcomes. (…)And this was intended to sort of drive our policy framework for the organisation. That resulted in essentially a vision document which articulates our policy framework around, we have eight outcome areas, …[and] a suite of indicators under each area." (user)
Described by producers		
Evaluating policy impact and feeding back to policy-makers (compared to	"…feeding back to policy-makers about who are the winners, who are the losers in terms of their policy and their level of policy implementation… (…) So it shows inequities in the city. It's very powerful."	"So we shared with them some of the data from the report, and they've been using that in their discussions with the state government. (…) They use some of the data that we've provided to point out that on the national benchmark for public transport, that two of the five

Description of UHI tool benefit or value	Quotes describing the value or benefit	Vignette of this benefit or value in action
policy-makers own policies and other governments' policies)	"…we actually looked at the policy first and said this is what you aspired to. You said that you wanted 95% of people to have access to your public transport within this distance of people's homes. Then if you can actually see on a map because we've measured it. (...) We can see that we're not even close to achieving the policy aspirations."	poorest-performing local government areas are in [the city's] west. …for example, just under half the population has access in accordance with the state government policy, although the state government's target is 95%. But then if you actually look at who has access to frequent transport, I mean already, they're not doing well. They've got less than 50% when they should have 95%, but then it drops down to 4%. 50% have access to some form of transport, but only 4% have access to frequent transport. And that's basically the case they're looking to make." (producer)
Using indicators as part of an advocacy strategy (on the producer's part) to influence policy and decision-makers	"So for me, indicators, they're useful only in the sense that you engage people in the right way, link it to direct policy questions, which I think is what we did in this work, we linked it directly to an existing governance arrangement, and we've sought to influence [state] health policy as well as [the state's planning policy]." "It needs to be more than just an indicator. You've got to have some advocacy around it. (…) You've got to have the likes the Planning Institute of Australia, the Heart Foundation of Australia, the advocacy groups who will pick up and run with this."	"And this paper includes a definition of liveability that I think ... I mean it's a big mouthful, but we were able to get this included in the [state's health plan]. …which, for us, was a major coup." "By having that measure that can watch both access and frequency, it does create, I guess, the onus to provide public transport that people will use, because we've got a measure that's predictive of people using it. …in terms of how that's being used by planners and so on, after the release of the report, we were contacted by a peak body of six or so local government areas in [the city's] west, who have basically kicked off a campaign looking to improve public transport. So they wanted to use some of our data to support their case, they were in talking to state government, talking to people from the Minister's office, and they're also talking to the media as well."

Description of UHI tool benefit or value	Quotes describing the value or benefit	Vignette of this benefit or value in action
Prompting users to dig deeper into an issue	"The idea is to prompt people to think wider than this. This is not... (…) …be all and end all." (producer) "…it's a conversation starting point, but not necessarily a totally decision-making tool. Because when you need to make a decision, you need to look deeper, usually, than what we have out there." (producer)	
Driving further research and showing research impact (for academics)	"It's actually the complete translation of research knowledge into something that's useful for policy." "…we could also use it for research because all the spatial indicators we've produced, social, economic, environmental, all the built environment factors, we could then link to existing survey sources so that that would also increase research capability." "…as we move towards an impact kind of framework in terms of research, [indicator work is] seen to be more useful for people."	"Anything that got produced within our research team, I would ensure it was turned into an indicator where possible and disseminated back into [the UHI tool]. As an example, say transport. We had questions on transport limitations previously in terms of we asked people about their access to transport availability, but we had less spatial quantitative measures because we were looking at factors in terms of transport access and things like service frequency later on, but previously, just do you live within 400 metres of a bus stop, 800 metres of a tram or train stop. We actually had these measures that we'd produced in a small area that we could aggregate up at LGA [local government authority] or municipal level. We disseminated them out as new indicators within [the UHI tool]. People got access to more and more and more of these as we went along." (producer)

APPENDIX 3 SUPPLEMENTARY MATERIAL FOR CHAPTER 7

A3.1 Iterations of the causal loop diagram model

Figures 1 to 8 show iterations of the causal loop diagrams. Figures 2 to 5 display sub-sectors of the full causal loop diagram that were developed independently. Whereas Figure 1 and Figures 6 to 8 depict versions of the whole causal loop diagram as it reduces in detail through each iteration.

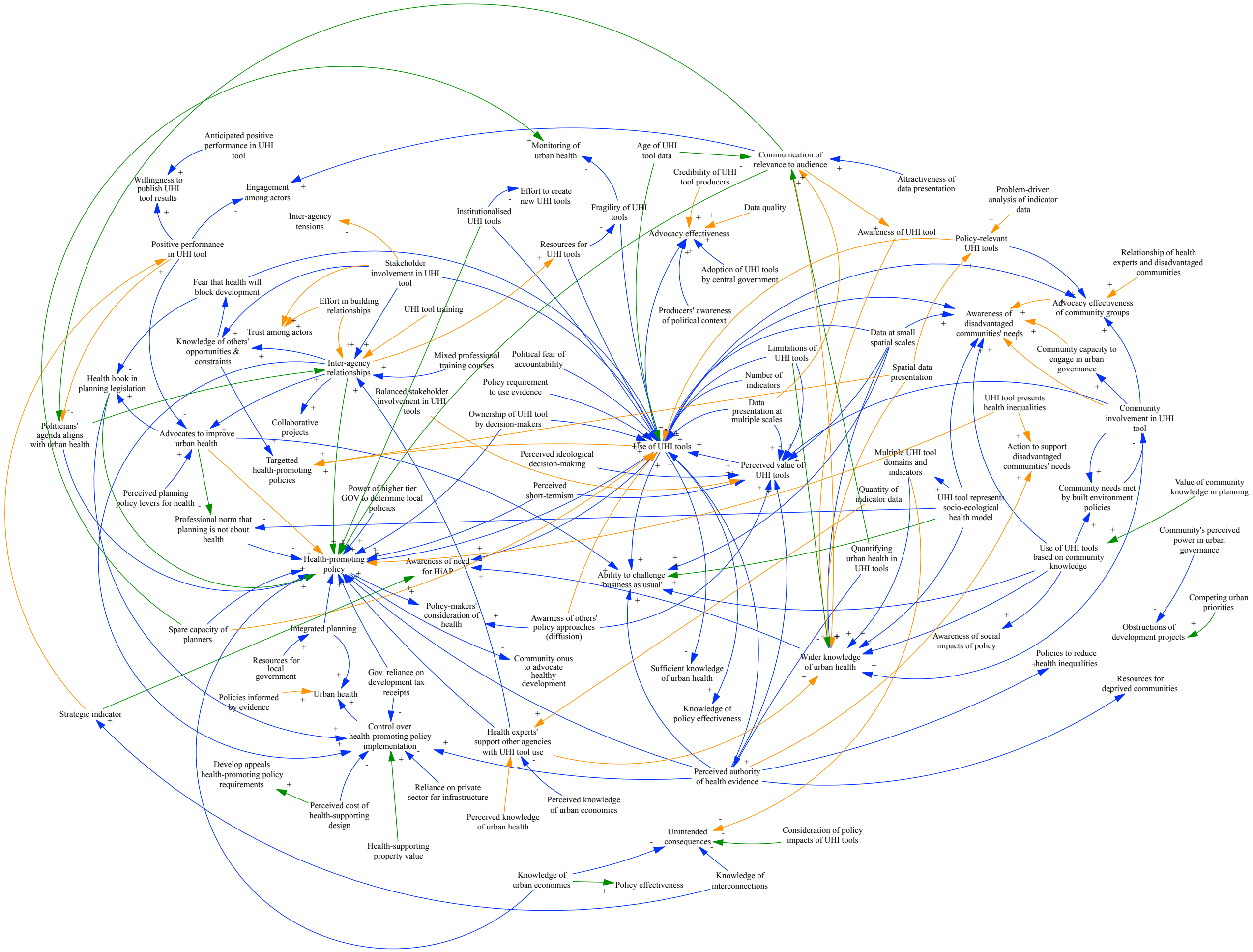

Figure 1 Version 1 of the model involved minimal adjustments to overlapping variables and connections. Arrow colour: blue for both, orange for producers, green for users, grey for arrows introduced by the researcher

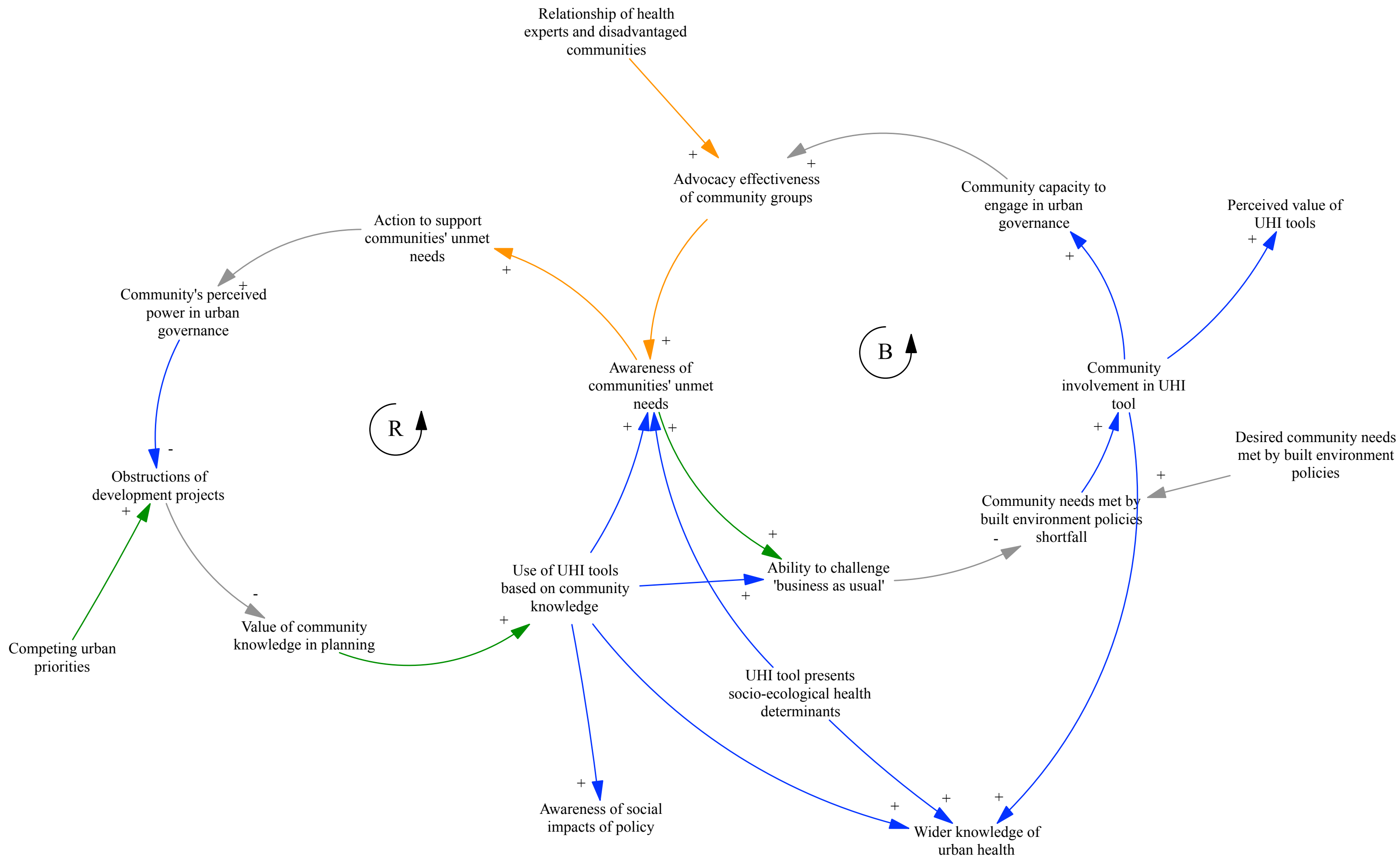

Figure 2 The first 'community sub-sector' of the model sought to further simplify variables and identify additional feedback relations (noted with grey arrows). Arrow colour: blue for both, orange for producers, green for users, grey for arrows introduced by the researcher.

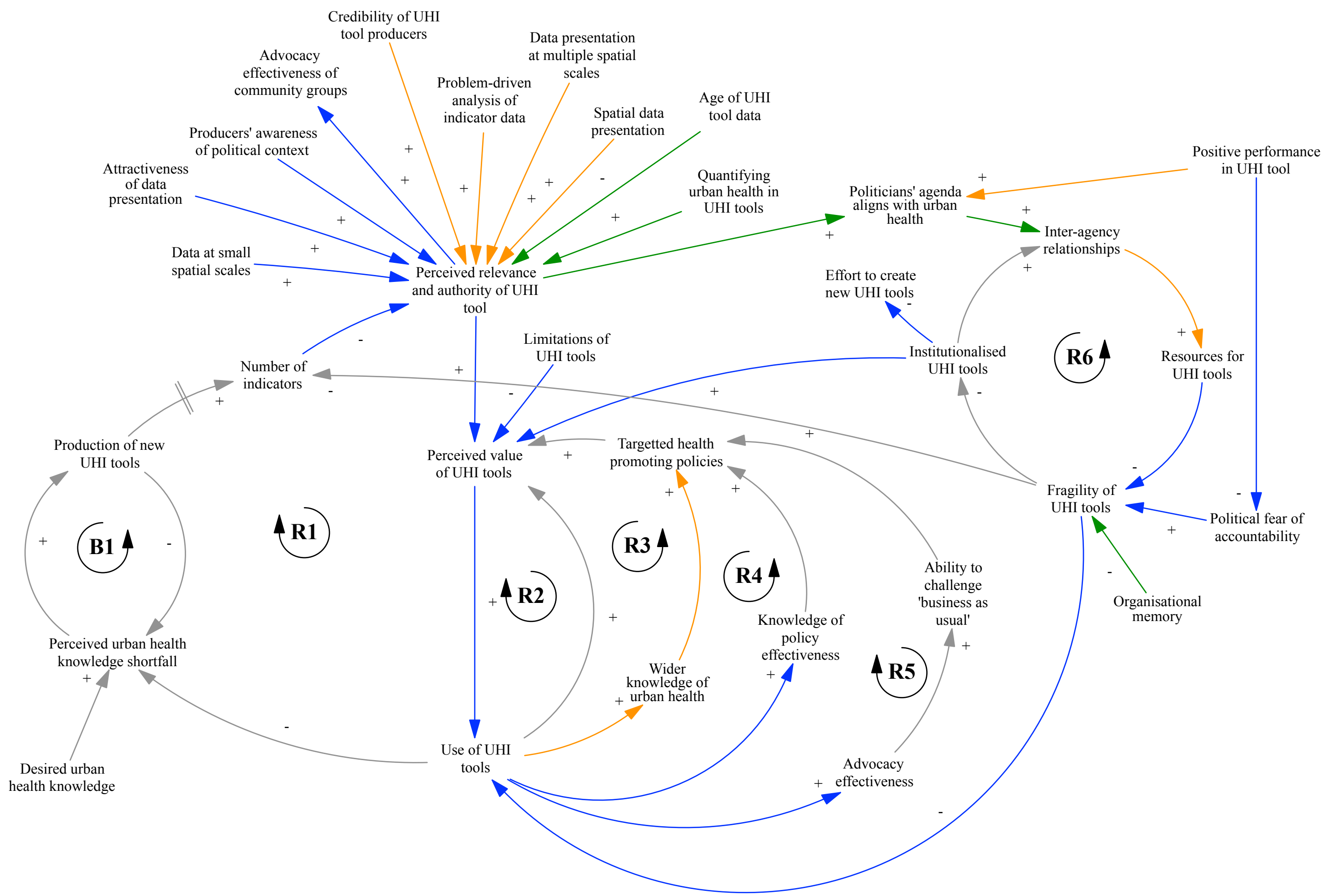

Figure 3 The first 'design sub-sector' model dealt primarily with the characteristics of UHI tools which influenced their value. Arrow colour: blue for both, orange for producers, green for users, grey for arrows introduced by the researcher.

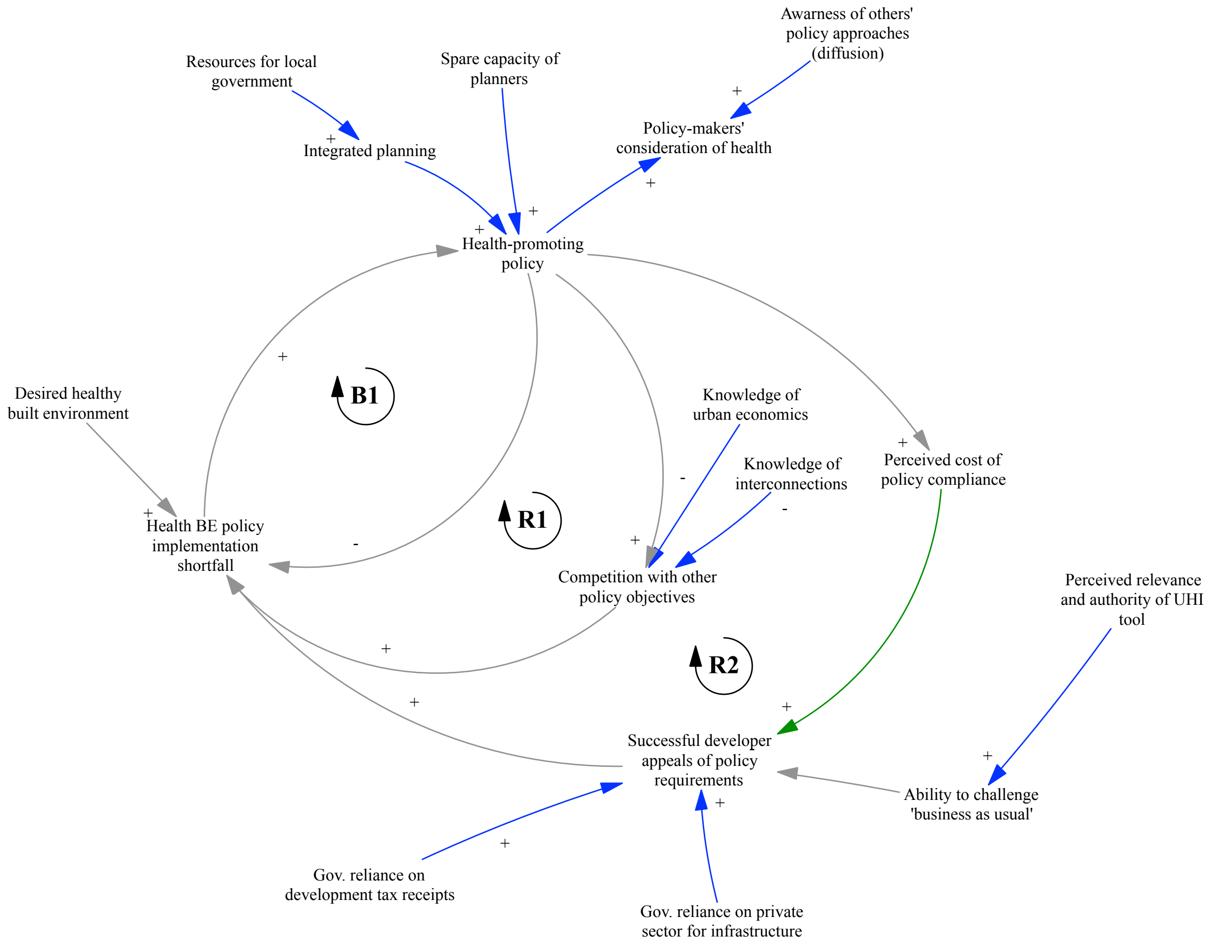

Figure 4 The first 'policy sub-sector' model described the factors which impeded implementation of health-promoting policy. Arrow colour: blue for both, orange for producers, green for users, grey for arrows introduced by the researcher.

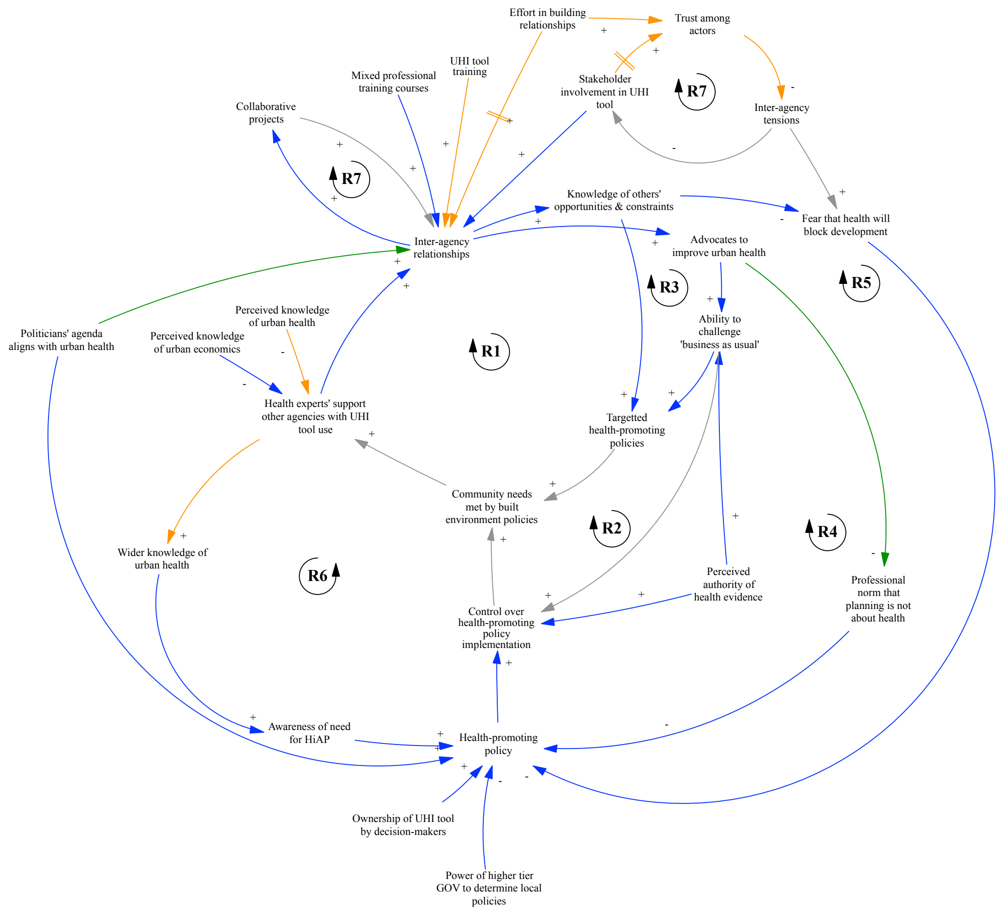

Figure 5 The first 'relationships sub-sector' model showed how inter-sectoral relationships were formed and their value in influencing health-promoting policy and implementation. Arrow colour: blue for both, orange for producers, green for users, grey for arrows introduced by the researcher

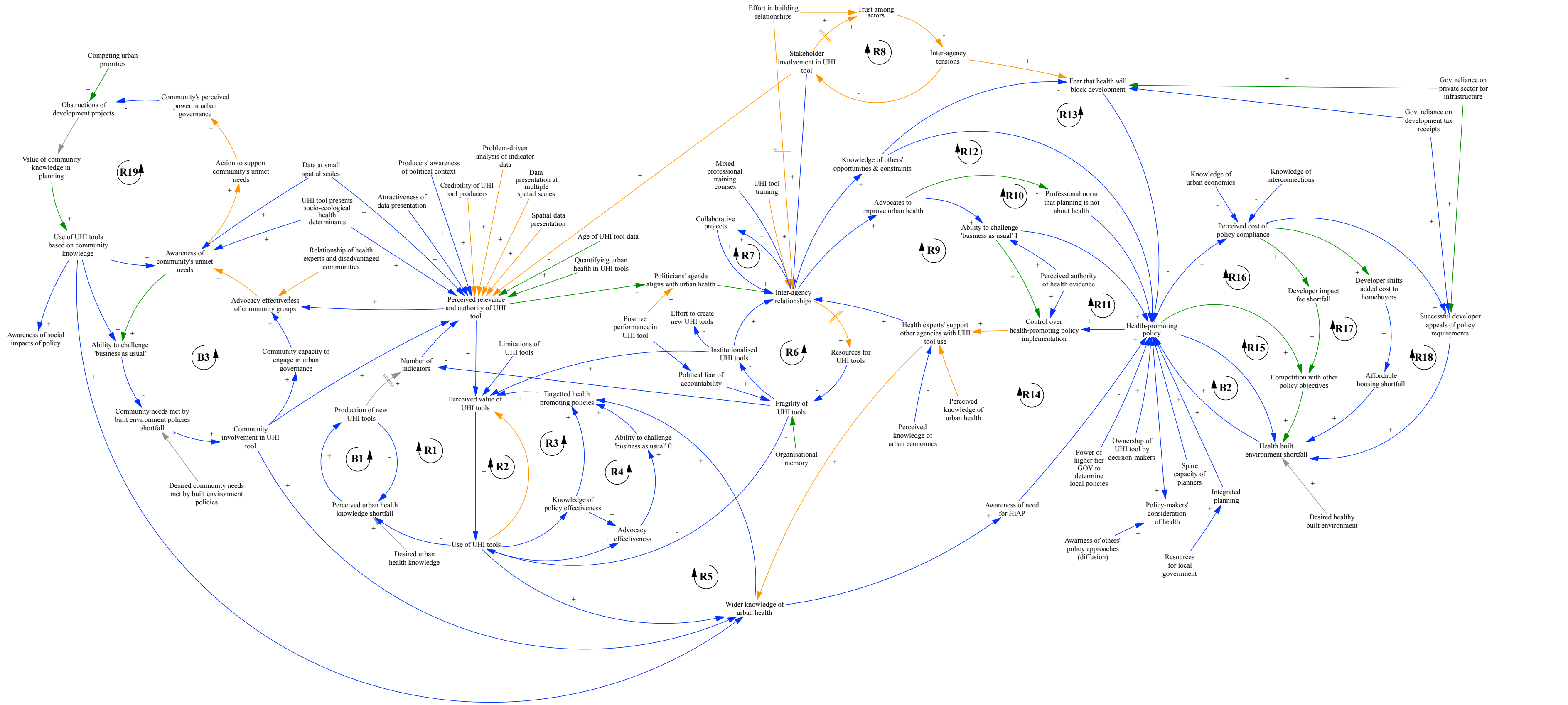

Figure 6 Version 2 of the model combined the four sub-sectors and sought to reduce duplicated variables and feedback relations. Arrow colour: blue for both, orange for producers, green for users, grey for arrows introduced by the researcher

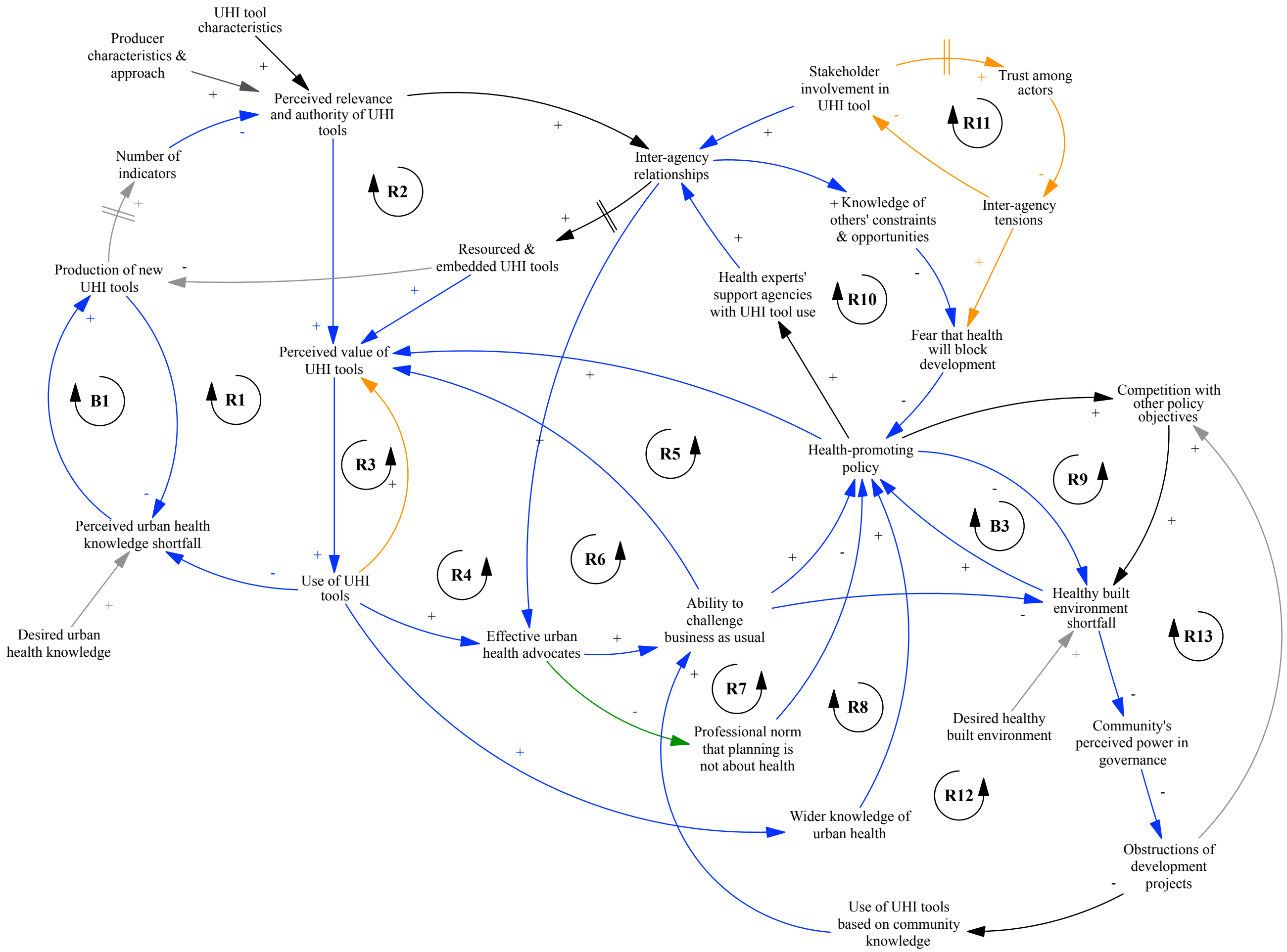

Figure 7 Version 3 of the model was contrasted with version 4 to determine an appropriate level of aggregation for communicating to workshop participants. Arrow colour: blue for both, orange for producers, green for users, grey for arrows introduced by the researcher

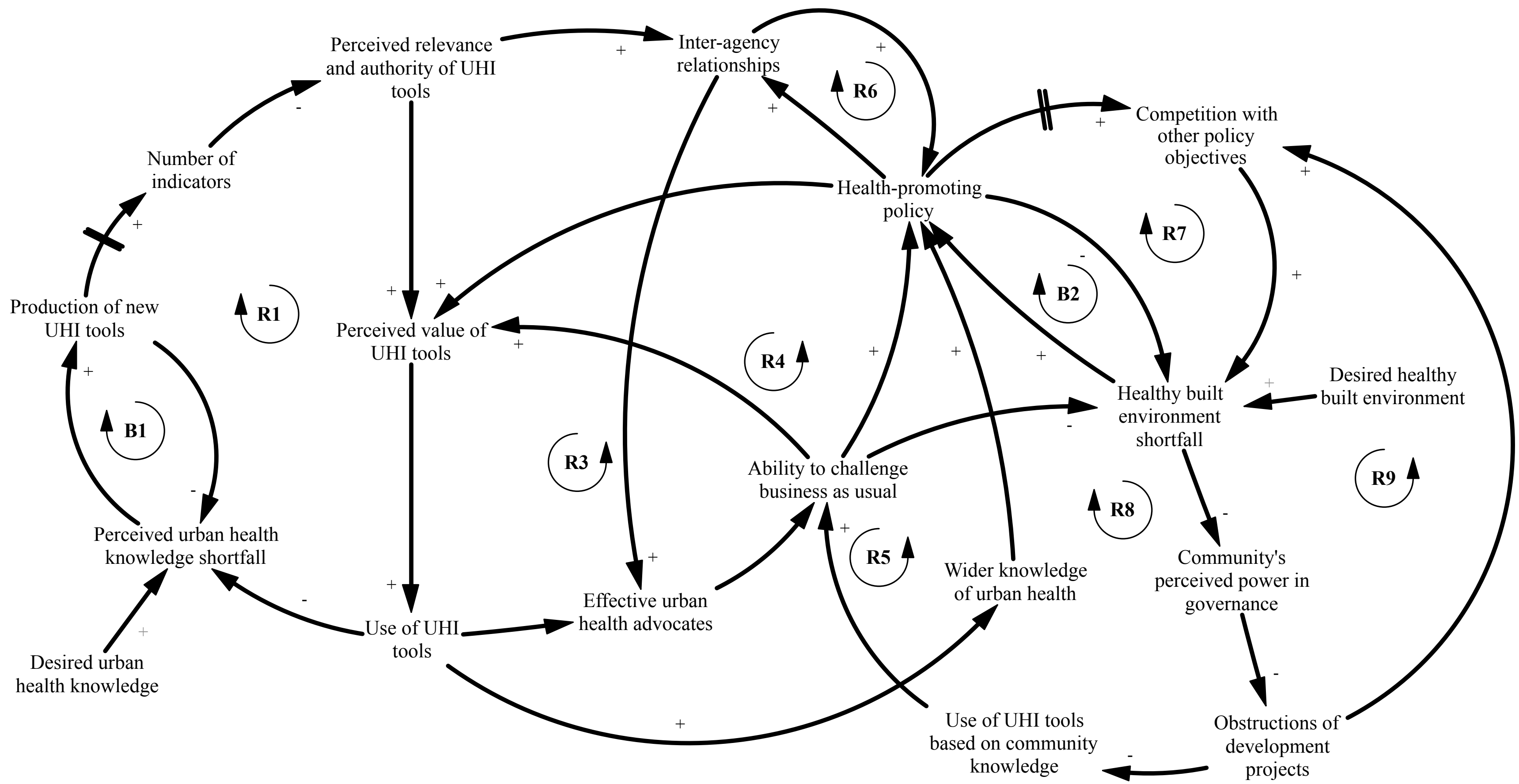

Figure 8 Version 4 (here) was contrasted with version 3 to find an appropriate level of aggregation for presentation to internal workshop participants. Arrow colours were all changed to black due to the combination of variables and arrows from the initial analysis