Supplementary material for: Integrating health into the complex urban planning policy and decision-making context: a systems thinking analysis

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Contents

1.1 Interview guide

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? If **no**, how could this be achieved?	Complexity, use of indicators, IF, TD
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? If **no**, why not?	Use of indicators, IF, TD, Policy process
9. Is there anything else that you'd like to add?	Closing
10. Do you have any final questions about how the interview?	Closing

1.2 Thematic analysis process

We followed the six phases to thematic analysis developed by Braun and Clarke's (2006) and further developed by Nowell et al. (2017). Our approach in each of these six phases is outlined below.

1.2.1 Data familiarisation

Audio recordings were professionally transcribed. HP listened to the audio recordings and read the transcriptions to check for accuracy. Then HP read through the transcriptions a second time, whilst making notes in the margins. HP sketched influence diagrams in the margins when interview participants spoke about cause and effect relations or described key processes about the use of indicators.

1.2.2 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, the codebook is described in the manuscript and shown in Table 3.

Table 3 Initial codebook for thematic analysis informed by the systematic review (Pineo et al. 2019), wider literature and theory

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.

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.

1.2.3 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. The process began with identification of an interesting code, 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.

A spreadsheet of the codes was created to track relationships across potential themes and to ensure all of the codes were addressed systematically. 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.

At the end of the theme identification stage there were nine candidate themes (Table 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.

Table 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

1.2.4 Reviewing themes

The candidate themes outlined in Table 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, involving combining and renaming themes. This stage of analysis also involved changes to codes. Some codes were deleted and some data extracts were additionally coded to existing codes. 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. The potential themes were arranged into an initial thematic map which visually displayed and prompted further consideration about the relations between themes.

1.2.5 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 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. Figure 1 shows how the initial set of nine themes (Table 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. Complexity of the policy process was part of all themes. 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 by design'.

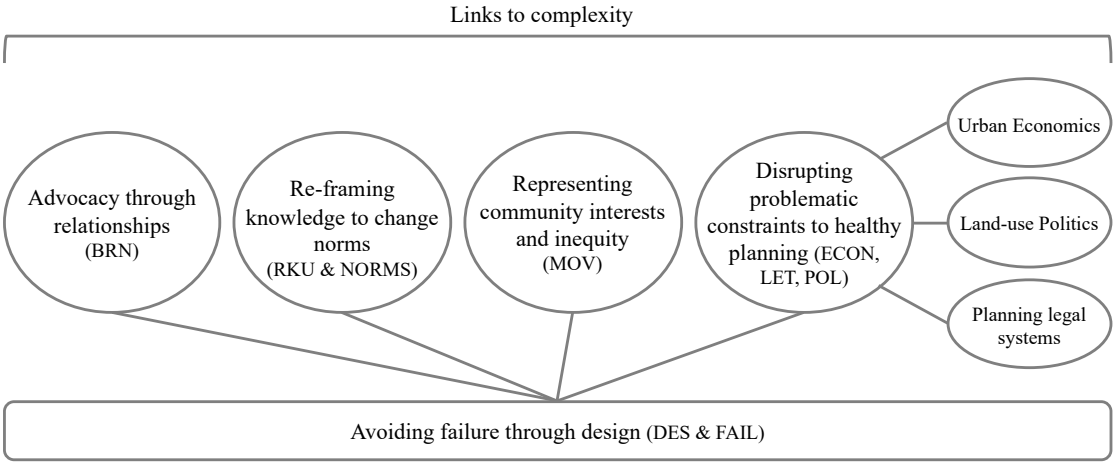

Figure 1 Final thematic map portraying five themes and three sub-themes with reference to the nine themes identified in the previous stage (abbreviations in brackets)

1.3 Development of causal loop diagram

1.3.1 Model conceptualisation

This section which outlines a problem statement, describes the emergence of the problem, sets boundaries for the modelling process and introduces dynamic hypotheses.

1.3.1.1 *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:

> *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).

1.3.1.2 *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 2) (Pineo *et al.*, 2018). 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).

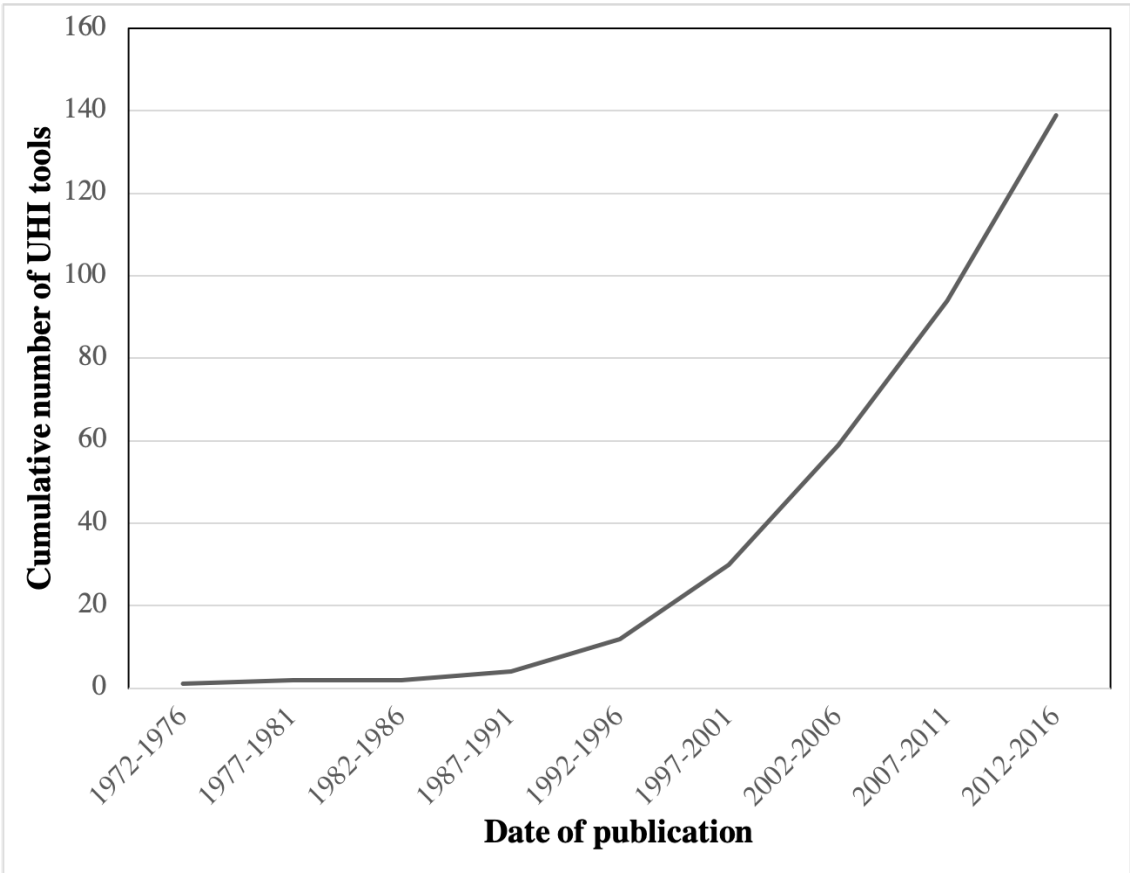

Figure 2 Cumulative growth of UHI tools over time

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 (Pineo *et al.*, 2019) 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 the census of UHI tools 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.

The growth of UHI tools over time is shown in Figure 2, however 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, Bauler and Lehtonen, 2014). The narrative synthesis of studies on the use of UHI tools (Pineo *et al.*, 2019) 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, Bauler and Lehtonen, 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.

1.3.1.3 *Boundaries for the modelling process*

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), however these were iteratively reviewed throughout the study. 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 were identified in the systematic review as important facilitators/barriers and uses/benefits of UHI tools.

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

Endogenous	Exogenous	Excluded
Appropriate data scale	Resources for UHI tool development	Specific urban planning policies and regulations
Stakeholder knowledge	Resources for stakeholder involvement	Urban health issues measured by UHI tools
Diversity of knowledge types in UHI tool	Stakeholder ability to participate	
Pre-existing conflict amongst stakeholders	Identified indicator user	
Involvement of community representatives	Indicators tied to policy areas	
Involvement of diverse stakeholders	Accountability of local government	
New knowledge of UH		
New knowledge of urban planning processes & constraints		
Collaboration across stakeholders		
New relationships		
Community capacity		

Endogenous	Exogenous	Excluded
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		

1.3.1.4 *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. Therefore, the modelling process begins with a range of potential dynamic hypotheses which were later explored through semi-structured interviews. The dynamic hypotheses were drawn into causal loop diagrams and can be described narratively as:

1. **Community engagement in UHI tools leads to municipal action**: 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.
2. **UHI tool engagement leads to dispersed knowledge:** This 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).
3. **Poor performance leads to political action**: This hypothesis also represents a 'balancing process with a delay' systems archetype. 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'. 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.

1.3.2 Six research design dimensions

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 6 and elaborated in turn below.

Table 6 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

The characteristics in Table 6 are described in more details as follows.

- **Group characteristics**: Asynchronous data collection in individual interviews (or sometimes pairs) allowed participants to speak freely about their perceptions of indicators without risk of offending other research participants.
- **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.
- **Coder characteristics:** The first author (HP) 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 HP was involved in coding data. This increased her ability to draw on the context and meaning of the interviews to develop generic variable names (Turner et al., 2013). Her interpretation of qualitative data was documented throughout the

thematic analysis and causal mapping process to "maintain objectivity" as much as possible (ibid, p.258). As a team, we discussed and agreed the coding and modelling process.

1.3.3 Coding approach

We adapted Eker and Zimmermann (2016) and Kim and Anderson's (2012) description of the relation between coding stages and causal mapping inputs and outputs, the primary difference being that their studies used grounded theory for interview data analysis. Table 7 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 section 1.2. 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 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 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 8). 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 8 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

1.4 Participatory modelling workshop agenda

Table 9 shows the facilitator's copy of the participatory modelling workshop. The overall workshop ran for 2.5 hours with two small group discussions (3 participants each) and a final plenary group discussion. HP facilitated plenary and small group discussions to enable each participant to express views in different formats and audio-recorded the latter. Specifically, we used two system dynamics group model building 'scripts' (Andersen and Richardson, 1997): 1) 'eliciting mental model-based policy stories' (p.124) and 2) 'direct feedback loop elicitation' (p.120).

Analysis and interpretation of the workshop findings first involved HP listening to audio-recordings and creating discussion summaries. Then HP combined discussion summaries with the participants' hand-drawn changes to models and the facilitator's notes. In reviewing this data, we looked for participants' views on the workshop aims (described above). We reviewed the suggested changes to the model (from both drawings and discussions) in relation to the interview data. If interview data supported changes, we adapted the model. We took this approach to ensure the final model was consistent with interview participants' mental modes.

Table 9 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

1.5 UHI tools described by participants

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 10 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 10.

Table 10 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

Indicator tools	Location	Described as linked* to SFIP or CIV
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	-

1.6 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.

1.6.1 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 3 shows the detailed view beneath loops B3 and R8, which also affect B2 and R7. Two additional feedback loops are evident, Rf and Ba.

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.

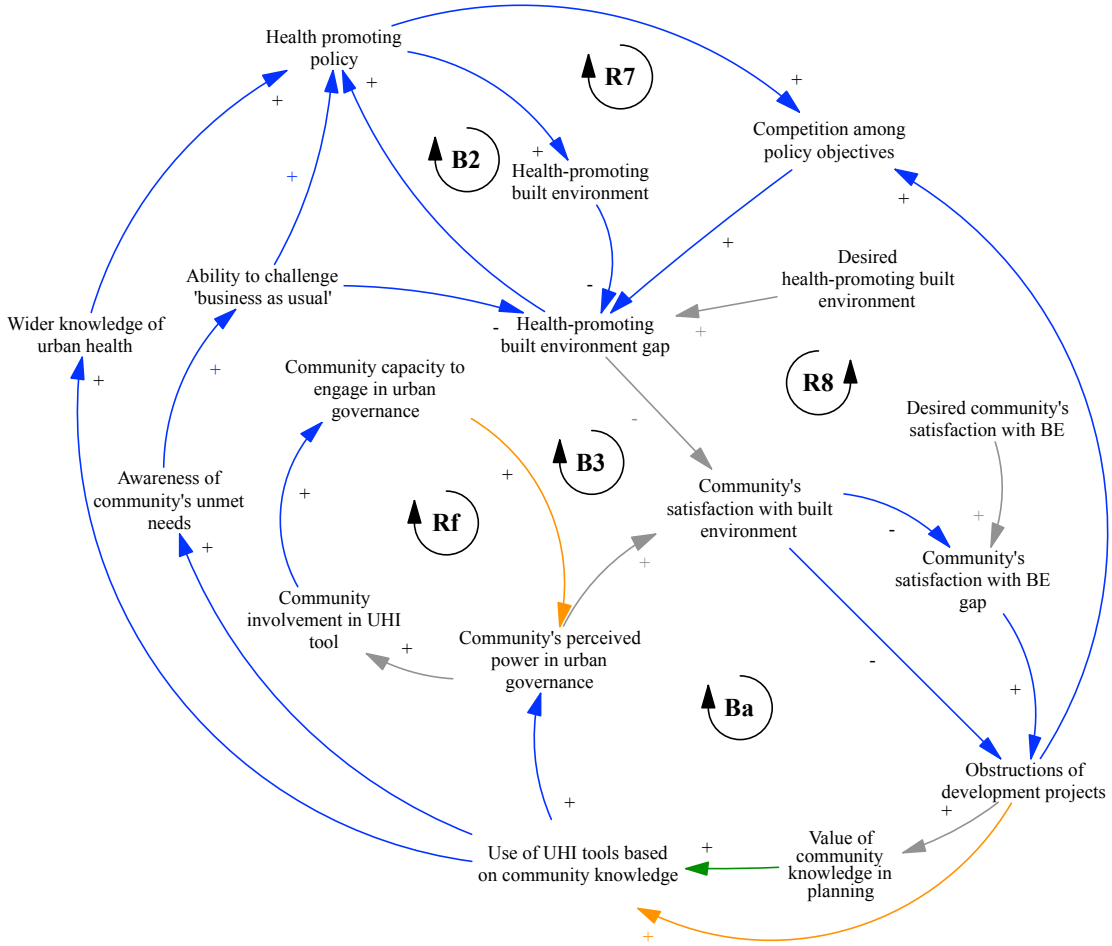

Figure 3 Detailed view of the causes and effects of the community's role in governance (Arrow colour: blue for both, orange for producers, green for users, grey for the researcher. BE: Built environment)

1.6.2 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 4). 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.

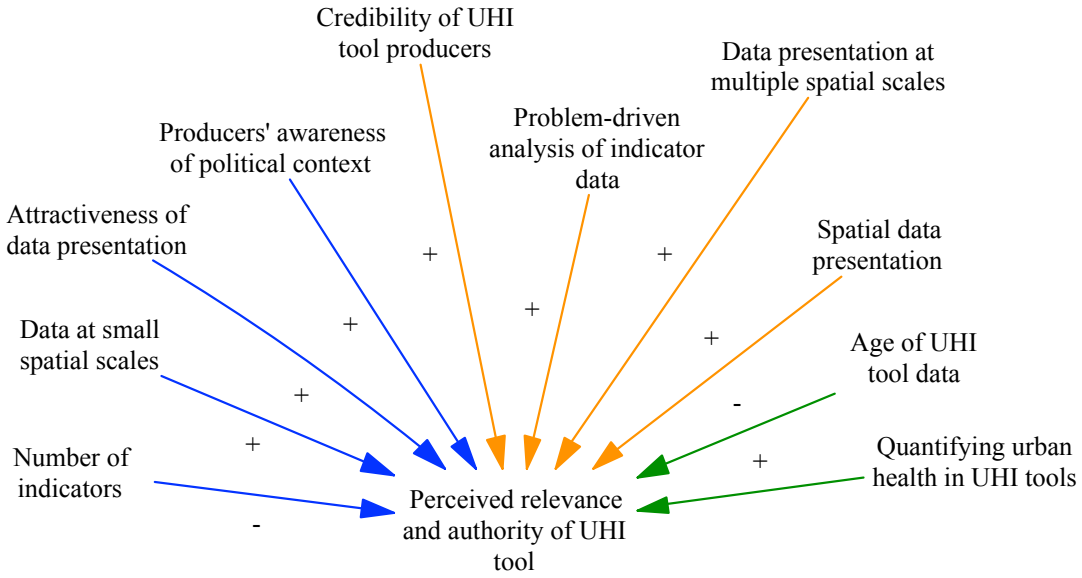

Figure 4 Detailed view of the causes of perceived relevance and authority of UHI tools. Arrow colour: blue for both, orange for producers, and green for users.

1.7 Glossary of CLD variables

Table 11 describes each variable name as interpreted from the interview text and states the first CLD in which the variable was used.

Table 11 Descriptions of the causal loop diagram variable names and the CLD in which they first appear

Variable name	Description	CLD (first use)
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.	High-level
Advocacy effectiveness	The level of effectiveness of urban health advocates, e.g. policy and decision-makers listen to their needs and arguments.	High-level
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.	Policy implementation
Age of UHI tool data	The age of data sources (high indicates more years passed since data collection) used in the UHI tool.	Design of 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.	Design of UHI tool
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 involvement
Collaborative projects	Research or policy projects involving health and built environment sector partners.	Inter-sectoral relationships

Variable name	Description	CLD (first use)
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
Community involvement in UHI tool	The extent to which the community engages in the development and/or application of a UHI tool.	Community involvement
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.	High-level
Community's satisfaction with built environment	The extent to which the community is satisfied with the state of the built environment.	High-level
Community's satisfaction with BE gap	The gap between the desired and current extent to which the community is satisfied with the state of the built environment.	Community involvement
Competition among policy objectives	The extent to which built environment policies compete for resources to be applied in new development.	High-level
Credibility of UHI tool producers	The level of credibility, judged by indicator users and other actors, of UHI tool producers.	Design of UHI tool
Culture of health-promotion	The level of culture within an organisation geared toward promoting health through policies, programmes and activities.	Stability of UHI tools
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.	Design of UHI tool
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.	Design of UHI tool
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.	Community involvement
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.	High-level
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.	High-level
Developer appeals	The number of appeals against planning policy requirements or decisions filed by developers.	Policy implementation
Developer's perceived cost of policy compliance	The amount of money which developers perceive is required to build development in compliance with planning policies.	Policy implementation
Effort in building relationships	The level of effort indicator producers exert to build relationships with non-health sector partners.	Inter-sectoral relationships
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-sectoral relationships
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.	Policy implementation

Variable name	Description	CLD (first use)
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.	Policy implementation
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.	High-level
Health-promoting built environment gap	The gap between the desired and actual health-promoting state of the built environment.	High-level
Health-promoting policy	The number of urban planning policies at any scale of government which support population health and wellbeing.	High-level
Institutionalised UHI tools	The extent to which (a) UHI tool(s) is/are regularly used and recognised within a particular institution.	High-level
Inter-agency tensions	The level of tension between actors working across city departments and agencies.	Inter-sectoral relationships
Inter-sectoral relationships	The number and strength of relationships across urban government agencies and departments.	High-level
Knowledge of others' opportunities & constraints	The extent to which actors working in different agencies/departments understand each other's policy-related opportunities and constraints.	Inter-sectoral relationships
Knowledge of policy impacts	The level of knowledge about the various potential impacts of urban planning policies.	Policy implementation
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.	Policy implementation
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.	Policy implementation
Mixed professional training courses	Training courses related to urban health which are taught simultaneously to health and built environment university students or professionals.	Inter-sectoral relationships
Number of advocates	The number of people or organisations which represent urban health interests in public debate and lobbying efforts.	High-level
Number of indicators	The number of single indicators available to urban planning policy and decision-makers.	High-level
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.	High-level
Organisational memory	The level of shared knowledge within an institution of previous programmes and initiatives, alongside their successes and failures.	Stability of UHI tools

Variable name	Description	CLD (first use)
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.	High-level
Perceived urban health knowledge	The extent of knowledge about urban health that indicator producers perceive urban planners to obtain.	High-level
Perceived urban health knowledge gap	The gap between the desired extent of urban health knowledge and the perceived level of urban health knowledge.	High-level
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.	High-level
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).	Stability of UHI tools
Political fear of accountability	The extent to which politicians fear having a public record of the impact of policies and decisions.	Stability of UHI tools
Politicians' agenda aligns with urban health	The extent to which the issues on politicians' agenda would support urban health, e.g. reducing traffic speeds.	Stability of UHI tools
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.	Policy implementation
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).	Design of UHI tool
Producers' awareness of political context	The extent to which indicator producers understand the political context in which UHI tools operate.	Design of UHI tool
Production of new UHI tools	The level of creation of new UHI tools by UHI tool producers.	High-level
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).	Design of UHI tool
Resources for UHI tools	The level of funding to support UHI tool data collection, publication and application.	Stability of UHI tools
Spatial data presentation	The extent to which UHI tool data are presented via maps.	Design of UHI tool
Stability of UHI tools	The extent to which UHI tools have secure funding over time for data collection, publication and application.	Stability of UHI tools
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.	Inter-sectoral relationships
Success rate of developer appeals	The rate at which appeals (against policy requirements or decisions) are decided in favour of the developer.	Policy implementation
Trust among actors	The level of trust between health and non-health actors across city agencies/departments.	Inter-sectoral relationships
UHI tool training	Training courses about how to use UHI tools, typically run by indicator producers.	Inter-sectoral relationships

Variable name	Description	CLD (first use)
Urban population health	The extent to which the urban population is healthy.	Policy implementation
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.	High-level
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.	High-level
Value of community knowledge in planning	The extent to which policy and decision-makers value using the community's knowledge in planning activities.	Community involvement
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.	High-level

1.8 Participatory workshop feedback

As described in the manuscript, participants were supportive of the model and found it useful. This section documents their detailed feedback and our decision-making process when considering making changes to the preliminary model.

1.8.1 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.

1.8.2 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 2 main manuscript) and detailed (Figure 5 main manuscript) 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 2 main manuscript). 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 5 (main manuscript).

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 2, main manuscript). 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.

1.8.3 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 4 (main manuscript):

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 4 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 4) 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'.

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'. 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 5 (main manuscript) contains variables about political agendas including 'Politicians' agenda alignment with urban health' and 'Political fear of accountability', while Figure 4 (main manuscript) 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 (Wikipedia contributors, 2019). These relations could be represented through the 'Advocacy effectiveness' variable (Figure 2 main manuscript, 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.

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