

Mental models of cities and their relevance to urban resilience

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Abstract

We believe that cities are important for humans as essential forms of social organisation in contemporary human life. Currently, the integrity of cities as enduring systems faces many challenges — ‘exogenous’ factors such as unsustainable consumption of energy and other resources and ‘endogenous’ factors such as ‘liveability’ and the ‘human scale’ of cities. Therefore we must work to ensure their future, hence the emerging importance of the concept of resilience. But how do we ensure the future of cities? Current slow, de-centralised and business-as-usual urban development is problematic. Instead, a planned approach to urban development is necessary, but how do we plan for cities to be resilient? Planning must inevitably rest on an understanding of how a city functions, and this leads us to thinking of developing mental or computational models of cities. In this paper we explore a number of mental models of cities, which could form the basis for directed urban planning. We identify three types of urban models, urban-state models, urban-learning models, and urban-systems models. Furthermore, we argue that all the current urban models are piecemeal and/or impractical and either do not adequately consider the complexity of the city or are not suitable for the interface with governance. We suggest that the best way forward is to embed multiple urban models within an adaptive governance framework, thereby providing a way for urban decision makers and planning organisations to better handle the complexity of their cities. To enable this, further work is required to identify suitable urban systems archetypes.

Introduction

Managing a complex adaptive system is a challenge encountered in many domains. We need to manage firms, factories, infrastructure, natural resources, economies and nations. For some systems, like firms and factories, the purpose of the management may appear well defined (maximising profits or production), although a more careful analysis often reveals that it may also involve proper accounting of many more factors, like balancing short vs long-term profits, power tensions within the organisation, future expectations, etc. For other systems, such trade-offs are more explicit. For example, different people see different purposes for managing a natural resource (profit maximisation, ecosystem service provision, employment, environmental conservation, respect of cultural values, etc.), some of which may be irreconcilable.

The complexity inherent in managing a complex adaptive system comes to full display when we consider how to manage a city. It is so because not only is the purpose of urban governance contested, but also the very essence and functions of a city are understood differently by different parties because the multi-faceted nature of a city imposes inevitably narrow experiences to its inhabitants.

It is therefore unsurprising that the governance of a city needs to be thought of in terms of systems properties, and this is why urban resilience is an increasing popular and desired goal of urban governance. We are particularly interested in the notion of urban resilience and will explore this concept further. In this work we adopt the definition of urban emergence proposed in¹ which we included in Table 1. Meerow and colleagues¹ have also undertaken the most comprehensive review of urban resilience notions so far and has uncovered a set of related conceptual tensions inherent in the literature on urban resilience:

- It is often unclear where the boundaries of 'the urban' start and finish, both in spatial and temporal terms; as well as in terms of social and political terms. Modern cities interact with their region and are closely intertwined with global processes. Furthermore, a city can be thought of as both a socio-ecological and a socio-technical system. We argue that a city system needs to be thought of in the context of multiple scales, and simultaneously socio-ecological and socio-technical.
 - Steady state vs non-equilibrium, i.e. much of the urban literature assumes a steady state, yet cities undergo constant change. In terms of resilience, it would seem that a more useful goal is to try to maintain the desired function, within an ever-changing system.
 - Resilience as a negative, neutral or positive concept. As resilience refers to the capacity to maintain and/or return to a 'normal' state, its value judgment depends on whether that normal state is desirable. It needs to be acknowledged that the desired state is contested, and urban resilience refers to the ability to maintain a 'desired state', even if this state is contested.
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- The range of pathway to change vary in literature, i.e. persistence, transition or transformation, often relating to the varying degree and mechanisms of required change and the speed of change. We argue that due to the pressures of the 21st century, cities need to be completely reimagined and transformed in order to maintain the functions required for the future viability of humanity. Luckily, there is significant potential for technological and social reform progress to allow this to happen.
 - Specific vs general resilience. Should the city be resilient to specific or general threats? The specific threats may relate to natural disasters, drought or resource shortages. The general threats, however, act at a system level, are unpredictable and hard to prepare for and would warrant a general adaptive capacity and flexibility to change. We argue that much of the urban adaptive capacity to both specific and general threats is inherent in the governance systems, and therefore the focus should be on urban governance processes.
 - The timescales that people focus on vary depending on the issue under consideration, i.e. natural disasters play out over short timeframes and climate change plays out over the longer timeframe. Future generations are occasionally considered, but perhaps, more importantly, the question of timeframe neglects the anticipatory capacity of urban governance systems as a critical aspect of urban resilience. We argue that the time frame is both short term and long term and involves future communities.

As mentioned, the notion of urban resilience is inevitably contested. The desired functions of a city change depending on what people understand a city to be (a built environment? a large group of people? a political entity?), how it functions (it evolves as a whole? It has a life in itself? It responds to social development? It responds to politicians and businesses?) What role it plays (it generates economic growth? it produces pollution? it fosters culture and innovation?). A city can be different things to different people in different circumstances. Notwithstanding the contested nature of urban resilience, we believe the definition included in Table 1 provides a good starting point in addressing the conceptual tensions. However, we believe two additional points are needed to place the definition firmly in the context of the 21st century:

- a significant urban transformation is necessary to ensure that the global environmental footprint helps the planet to be within a safe operating space.^{2,3}
- an anticipatory capacity is necessary in order to foresee future challenges, and to identify and devise strategies to avoid significant hardship.⁴

These points also lead us to the belief that for urban transformation to occur at the necessary speed, cities need to be managed

in a deliberate manner.³

While, subjectively, urban resilience is a positive notion only when aligned with desired goals and functions that are embedded within it, let us here assume that a city governance system has defined a goal and function that most of its current, future and past inhabitants could agree with. What then? How does a city ensure this goal and function into the future?

To understand how a city could adapt and change, either in anticipation of hardship, or in response to hardship, or simply to improve the ability of the city to achieve desired functions, urban managers need to choose how to act. In systems terms this requires the identification of the system leverage points⁵ and in turns a representation, be it mental models or computer models, of how cities function.⁶ Definitions of mental and computational models, and how they differ is provided in Table 1.

In this article we report on reflections from our experience in selecting a suitable computer model of urban dynamics for a project aimed at studying the resilience of large Australian cities.⁴ We also report on reviews and surveys of mental and computational models of urban systems, and how they align with the need of governance systems to support urban resilience.

Table 1

Glossary of terms used in this work
Metaphor: a figure of speech that describes an object or action in a way that isn't literally true, but helps explain an idea by making a comparison with an unrelated object or action.
Mental model: a personal, internal representation of a system and how it functions that people use to interact with it.
Computational model: a formalisation of a mental model, in the form of an algorithm coded in a formal language on a computer.
Worldview: a description of our understanding, at time unconscious, of how the world around us functions and our place within it
System archetypes: core patterns of system's behaviour, in the form of commonly occurring combinations of reinforcing and balancing feedback, represented in a qualitative or semi-quantitative fashion.
Urban resilience: the ability of an urban system-and all its constituent socio-ecological and socio-technical networks across temporal and spatial scales to maintain or rapidly return to desired functions in the face of a disturbance, to adapt to change and to quickly transform systems that limit current or future adaptive capacity.
Participatory modelling: the process of incorporating stakeholders, including the public and decision-makers, into one or more stages of the modelling process, from data collection through to model construction, use and evaluation.

Three types of urban mental models

Addressing urban resilience requires that we first analyse how we understand a city. Most people are unlikely ever to think deliberately about what they understand a city to be. But when asked, they are likely to articulate some sort of understanding of a city either as a metaphor or as a more or less well-defined mental model. We refer to these as 'urban metaphors' and 'urban mental models' respectively. The distinction between a metaphors and a mental model is grey, but for the purpose of this work we refer to metaphors as figures of speech or images and to mental models as representation which include some sort of description of system functioning (see Table 1). Without being exhaustive, cities can be seen as:

- a 'natural' form of human aggregation: ecosystems, organisms, beehives, ant colonies
- an artificial system, antithetic to Nature: machines, infrastructure assemblages, built environments
- an economic entity: engines of prosperity, components (of globalization), competitive economic agents, cathedrals of consumption
- a locus of cultural development: brains, smart city, the place where an intellectual critical mass can flourish
- a locus of artistic development: the 'city beautiful', 'city spectacles'
- a locus of social alienation: rat race/rat maze, a black hole (a sink of resources), a trap (an inescapable monotony of routines devoid of meaningful human interaction).

How can the types of urban metaphors and mental models be used to support urban resilience? As we try to think

systematically about this, we relate the urban mental models to the three key concepts in urban resilience (desired function, adaptive capacity and system understanding), extracted from the definition in the introduction, and shown in Table 2.

Table 2

Mapping of models and metaphors against core urban resilience aspects	
Concept in urban resilience	Associated urban mental models
Type A. Desired function	Green Cities, The City Beautiful, Water Sensitive Cities, Walkable Cities, Low Carbon Cities
Type B1. Learning and adaptation mechanisms	Smart Cities, Cities as Machines, Cities as Brains, Tactical Urbanism, Smart Urbanism, Smart growth, Cities as Engines of Innovation, Socio-technical Transitions,
Type B2. Describing urban systems	Cities as Actors, Cities as Complex Adaptive Systems, Urban Metabolism, Cities as Ecosystems, Urban Transformation, Cities as Engines of Prosperity

We acknowledge that the difference between row 2 and row 3 is subtle and perhaps even subjective as we here single out learning processes as being separate from urban systems description rather than an integral part of it. Thus we see them as two varieties of the same type of urban mental model (Type B1 and B2). The reason for this separation is to highlight mechanisms for learning and/or adaptation as particularly important processes in cities.

Type A. Urban mental models that describe an outcome: as above, this is a range of urban metaphors and mental models that can be best described as desired end-goals in urban configurations. We call these ‘urban-state mental models’ and include, for example, the city beautiful, city spectacles, a locus of social alienation, a black hole, city as a trap, among others. ‘Urban-state mental models’ describe outcomes of urban processes, decision rules or management actions. As such, they are value laden, because some outcomes can be positive (city beautiful, cultural experience) and other may be negative (social alienation, rat race). We believe that it is important to keep looking for new desired urban configurations. This can be achieved by the urban governance system engaging the public to expand the list of mental models associated with desired functions in Table 2. We also recognise that some of the desired functions support adaptive capacity. For example green, low carbon, water sensitive and walkable cities are likely to reduce pressures on the city. However, all these are partial goals and we need mental models of city functions that embed all the desired aspects of a city, rather than only narrow definitions of urban outcomes. Without this, the city can’t be managed as a system, and it is then difficult for urban managers to provide anything but piecemeal solutions. To help urban managers, we need more holistic urban-state mental models of cities. It is also worth noting that it is not always possible to manage a city to delivery outcomes that suit everyone, i.e. there are winners and losers; and so these mental models are sometimes contested.

Type B1. Urban learning and adaptation mechanisms: several of the mental models describe aspects of how a city can adapt and learn, primarily by providing information and data to support decision making. With the exception of the term tactical urbanism, the available mental models to guide the learning processes, i.e. the smart cities, cities as machines etc. are largely focused on the technology and information, and under-represent the social aspect of learning, i.e. social capital. This is not to say that technology is not important for the city, but we argue that technology is insufficient by itself. The city as brains metaphor stands out as it focuses on the creative and cultural aspects of a city.⁷ According to current knowledge, urban change processes are both social and technological in nature,⁸ and so we think urban-learning mental models should be.⁶ Combining the concept of tactical urbanism with the metaphor of a city as a brain, may provide useful results.

Type B2. Describing urban systems: some urban mental models are more explicit at representing a city as a system and how it functions. These include cities as: ecosystems, organisms, beehives, artificial systems, infrastructure assemblages, economic entities and engines of prosperity, among others. These may potentially be turned into computational models. We have also identified urban metaphors that describe the physical processes of the city (urban metabolism), the city in the context of the regional and the global economy (the city as actors), and cities as places where technological innovation occurs (socio-technical systems). The city as a complex adaptive systems (CAS) is a fairly theoretical urban mental model, that provides some guidance in how to explore cities, yet most descriptions of cities as CAS struggle in practice with defining the system, both in terms of boundaries as well as in terms of the required level of detail. Nearly all urban systems mental models are focused on solving specific problems, yet no urban mental model describes the urban system in its entirety.

From a system perspective, these three types of urban mental models differ significantly. The Type B1 and B2 ‘urban-system mental models’ are process oriented and describe complex webs of cause and effect mechanisms. As such, they suggest causal process and thus potential levers for policy intervention. However they are value free, as they say little about what experience they may provide to the citizens. On the other hand, as ‘urban-state mental models’ can be outcomes of simplistic decision rules, they may be responsive to social processes or governance choices, not first causes. It should also be recognised that the ‘urban-state mental models’ may be perceived as the outcome of cause and effect relationships that are not always based on solid scientific evidence, so that their validity could be challenged. Furthermore, simple decision rules in complex

adaptive systems will tend to have both intended as well as unintended consequences that are often unpredictable. So whilst the Type A type of mental model may be useful, they should be used with caution.

Mental models as building blocks for computational models

Mental models are useful building blocks on which directed urban planning can be supported. However, limitations in human cognition and the immense complexity of urban processes, require computational models in order to provide adequate decision support. See Table 1 for a distinction between mental and computational models. All models reside, implicitly or explicitly, partially or fully, in someone's mind or in the minds of several people, so they are all 'mental' models. A few of them are turned into computational models to expand beyond the limited cognitive functions of humans. This contrasts with a common view of numerical and mental models as an alternative representation of a process. We believe there are a number of benefits in this interpretation:⁹

1. it demystifies the essence of computer modelling in communicating model results to stakeholders;
2. it demystifies the predictability power of computer models;
3. it clarifies why computer models are not value-free and, like any mental model, necessarily come with underlying worldview, perceptions, and narratives.

Computational models can play different roles to support resilience based assessments and planning, i.e. models can be used to:

1. Develop and communicate a system description by making explicit a set of coherent assumptions about a system's components and processes.
2. Facilitate conversation, and thus develop a shared understanding of issues and solutions by representing divergent views and invite scrutiny and comparison with evidence.¹⁰
3. Inform what to measure and monitor and how to identify performance metrics or indicators.

To explore the suitability of urban mental models as building blocks for urban computational models to support resilience based urban planning, in Table 2 the relationship between urban metaphors, the embedded worldviews, and their implications for urban resilience are explored.

Table 3

The relationship between selected city mental models and implication for a city's resilience			
Metaphors. Cities as..	Worldview / Emphasis on	Computational Model	Implication for resilience
Ecosystems, Organism, Ant colonies, Beehives	Nature-inspired models of development in urban planning and design; Emergent properties; relationships and interactions between parts. Processes are circular, balanced and ordered. Humans' role de-emphasised.	Ecosystem modelling. Scale-free models. Urban metabolism (energy equivalents or material and energy flows)	Fragile (stable- state) or adaptable depending on worldview ('ductile' vs 'elastic' (15)); Can be a parasite of the surrounding environment. Cities go through the process of change, renewal, and destruction as other life forms. City design should aim for stability and adjust urban metabolic flows to idealized models of ecosystems. Ecological footprint. Technological modernisation may lead to rebound effects. Steady-state economy; Degrowth. Needs to safeguard flows of ecological resources.
Complex systems, Unified aggregates	Emergent processes; socio-ecological flows. Open system. Creative. Humans are integral part of the city.	Network theory; Agent Based Models; Scale-free models.	Adaptation; tipping points; alternative stable states; collapse; boundary limits. City design should aim for greater resilience to the inevitable internal and external shocks.
Cities as brains	Creative; cultural; Policy, technological and scientific innovations	Evolutionary computation	Fundamental for creative adaptation, but cannot survive by itself, needs energy and resources from the surrounding environment
Machines, satellites, artificial	Can be controlled and planned with expertise. Or achieved by markets. Opposite to Nature. Optimisation. Reductionist: the sum of the technical and socioeconomic processes that occur in cities. The relationship between the city and surrounding as governed by physical laws. Inadequate attention to socio-political processes (stakeholders as agents involved in material flows. "ordered system for transforming low-entropy raw materials and energy into high-entropy waste and unavailable energy".	Input-output models. Ecological economics. System dynamics. Urban metabolism (energy equivalents or material and energy flows). Infrastructure analysis.	Fragile, it can break and may or may not be fixed. Can reduce waste and improve efficiency; Optimisation may reduce resilience. Self-sufficiency. Urbanization and economic growth have an overall negative impact on the environment. Self-sufficiency, dematerialisation, need to reduce metabolic rate. Steady-state economy; De-growth. Needs to safeguard flows of ecological resources, infrastructure and services. Strategies to reconfigure cities and their infrastructures in ways that help to secure their ecological and material reproduction.
Cities as engines of prosperity (13), Components of globalization	Economic growth, sources of wealth but also power and unequal access to resources. Stakeholders as agents involved in economic flows. Neoliberalism. Diversity in metabolic rate (within and between cities) leads to inequality.	Various models of economic growth and technological innovation	Development will allow cities to continue to grow economically while quite literally transcending environmental constraints, obviating the need for wider societal change. Economic sustainability.
Smart cities	Techno-centric view of cities, where it is assumed collection of data combined with AI can resolve		