Available online at www.sciencedirect.com

ScienceDirect

Current Opinion in Environmental Sustainability

Defining and advancing a systems approach for sustainable cities

Xuemei Bai[1], Alyson Surveyer[2], Thomas Elmqvist[3,12], Franz W Gatzweiler[4], Burak Güneralp[5], Susan Parnell[6], Anne-Hélène Prieur-Richard[2], Paul Shrivastava[2,7,8], José Gabriel Siri[9], Mark Stafford-Smith[10], Jean-Patrick Toussaint[2] and Robert Webb[11]

The sustainable development of cities is increasingly recognized as crucial to meeting collectively agreed sustainability goals at local, regional and global scales, and more broadly to securing human well-being worldwide. The UN Sustainable Development Goals (SDGs) include a goal on cities (Goal 11), with most other goals and targets have urban applications and multi scalar implications for their implementation. Further, the interdependencies — including synergies and trade-offs — among the various SDGs are greater in cities, presenting both challenges and opportunities. A systems approach is urgently needed in urban research and policy analysis, but such an approach rarely features in current analysis or urban decision-making for various reasons. This paper explores four questions: why a systems approach is necessary, what defines such an approach, why has this rarely been adopted in practice, and what can be done to promote its use. We argue that a systems approach can reveal unrecognized opportunities to maximize co-benefits and synergies, guide management of inevitable trade-offs, and therefore inform prioritisation and successful solutions. We present four key issues for the effective implementation of the SDGs and the *New Urban Agenda*, which emerged from UN Habitat III Conference, namely: (a) a radical redesign of the multilateral institutional setup on urban issues; (b) promoting regenerative culture, behaviour, and design; (c) exploring ways to finance a systems approach; and (d) a new and enhanced role for science in sustainable development. The latter issue could be addressed through Future Earth's Urban Knowledge-Action Network, which aims at co-designing and co-producing cutting-edge and actionable knowledge for sustainable cities bringing together researchers and urban decision-makers and practitioners.

Addresses
[1] Fenner School of Environment and Society, ANU College of Medicine, Biology and Environment, Frank Fenner Building, Linnaeus Way, Acton, ACT 2601, Australia
[2] Future Earth, Suite 1020, 1250 Guy Street, H3H 2T4 Montreal, Quebec, Canada
[3] Natural Resource Management at Stockholm Resilience Centre, Stockholm University, SE-106 91 Stockholm, Sweden
[4] Institute of Urban Environment (IUE), Chinese Academy of Sciences (CAS), 1799 Jimei Rd., 361021 Xiamen, China
[5] Texas A&M University, MS 3147, College Station, TX 77843, United States
[6] African Centre for Cities, Environmental and Geographical Science Building, Upper Campus, University of Cape Town, Rondebosch 7701, South Africa
[7] Concordia Univ, Canada
[8] ICN Business School, France
[9] UNU-IIGH Building, UKM Medical Centre, Jalan Yaacob Latiff, Bandar Tun Razak, 56000 Cheras, Kuala Lumpur, Malaysia
[10] Adaptation, CSIRO (and Chair | Science Committee | Future Earth), PO Box 1700, Canberra, ACT 2601, Australia
[11] ANU College of Medicine, Biology and Environment, The Australian National University, Australia

Corresponding author: Bai, Xuemei (xuemei.bai@anu.edu.au)
[12] Visiting address: Kräftriket 2B.

Current Opinion in Environmental Sustainability 2016, **23**:69–78

This review comes from a themed issue on **Open issue, part I**

Edited by **Eduardo S Brondizio, Rik Leemans** and **William D Solecki**

Received 07 September 2016; Revised 03 November 2016; Accepted 17 November 2016

http://dx.doi.org/10.1016/j.cosust.2016.11.010

Importance of the systems approach

Rapid urbanization is one of the most important social transformations in human history [1•], with cities playing an increasingly important role in global change through a multiplicity of social, economic, and biophysical processes across diverse spatial and temporal scales [2,3•,4]. The world's cities occupy just three per cent of the earth's land, but account for about 75 per cent of global final energy consumption and carbon emissions [5,6•]. Thus, the collective actions of cities will determine whether the world as a whole moves towards sustainability in all its manifestations — economic, social, and environmental.

Given the foreseeable challenges related to the increase in urban growth and urbanization, developing sustainable and resilient cities has become increasingly crucial, as recognized in Goal 11 of the United Nations Sustainable Development Goals (SDGs) [7], which calls for 'making cities and human settlements inclusive, safe, resilient and

sustainable'. Indeed, most SDG goals and targets are directly relevant to urban decision-makers [8]. Cities typically offer a good starting point for implementing most SDGs, as the local scale is where inequity and dysfunctionality, which is often concealed in national data aggregations, become apparent. Furthermore, the range and complexity of interdependencies between the various SDGs, including synergies and trade-offs, are greatest in cities.

Such complexity creates considerable challenges — but also significant opportunities — for urban research, decision-making, and practice. Political and institutional actions at the municipal scale have unique potential to catalyse national and global change. Whereas national governments act remotely, city governments are generally in direct contact with their constituents, and are embedded in their local urban geographic and social context. While often constrained by capacity limitations, there is a greater diversity of city governments with some can innovate and may have more flexibility to act responsively, as evidenced by the actions instituted by mayors globally. For example, the mayor of Bogotá, Colombia instituted a series of transport-related initiatives in the late 1990s, including an advanced bus rapid transit system (BRT), bicycle paths and pedestrian zones. The focus on sustainable urban design turned out to be the right intervention point, as manifested by the city's transformative changes, including lowered greenhouse gas emissions and reduced commuting times and traffic fatalities to decreases in crime, higher land values, and a perception of greater social justice [9].

Cities cannot act alone to achieve global urban change. Many of the decisions and feedbacks that give rise to urban dynamics take place beyond urban boundaries, and involve actors and institutions outside the city. These feedbacks can span several jurisdictions, operate simultaneously both locally and at a distance, often involve non-linear processes, and frequently give rise to unintended and displaced consequences. Such unintended consequences, or 'side effects', often arise due to a lack of appreciation for systemic interactions of actions taken at points widely separated in space and time, complicating interpretations of cause and effect [9]. Multi-scale governance capacity is one important means to address this issue and facilitate an appreciation for such systemic interactions that can then be acted upon.

Cities are complex social–ecological–technological systems where numerous actors and processes interact, often across geographic, institutional and governance scales [10•]. Such complex causal structures often imply trade-offs between the positive and negative consequences of policy actions, and a strong path-dependency exemplified by the near irreversibility of the built environment and land-use pattern. The latter are often unanticipated because of siloed views of the system or incomplete understanding of complexity, producing negative policy surprise. For instance, urban planning influences the amount of green space in a city, altering urban heat island effects and consequently energy demands from buildings. Yet these factors are also affected by building design and energy efficiency and, inevitably, building codes [11••]. Another example of a 'side effect' due to the siloed approach to systemic urban problems would be road building programs intended to relieve chronic traffic congestion but instead result in suburban sprawl and further increase traffic congestion [12]. As such, achieving sustainability in cities requires that interlinked planning and regulatory actions be tackled simultaneously and considered for their long-term impacts, and preventative rather than remedial actions are required. The traditional fragmented approach foregoes numerous synergistic benefits arising from coordinated action across sectors; as such, individual sensible actions often fail to have the intended effect if changes on other parts of the system are not implemented at the same time (e.g. widened roads just result in more traffic, unless public transport is enhanced in a coordinated way). Indeed, in a world with 17 SDGs, the potential for harnessing positive synergies, may be an even greater motivating factor for using a systems approach than the identification of negative/cautionary trade-offs [13•,14].

A systems approach is economically sustainable as it is inclusive of different types and a wider range of economic values attached to goods and services provided by urban system functions. These values include, for example, recreational values of urban parks, cultural values of urban areas and buildings, value created by urban regulation functions which are a precondition for mobility and communication and exchange activities, or value of providing services such as water purification and waste management. Although these economic values are sometimes incommensurable, taking them into account and including them in decision making, demonstrate a systems approach and makes a city system less polluting, less unequal, and ecologically and economically more sustainable. '*Valuation processes can be seen as a form of regulatory adaptation by serving as a mechanism to provide feedback in a system where production and consumption, trade and exchange are so distant and complex that they undermine perceptions of the impacts of habits and behaviour on the environment* [15].'

City governance increasingly involves separation and specialization of bureaucratic departments. Each of these departments deal with a specific urban sector, such as water, transportation, electricity, parks, food, health, etc., with little to no coordination let alone communication among them. This fragmented institutional structure reflects both the need for increasingly specialized knowledge and the sheer scale of the challenges of modern

urban management [16]. Yet such approach ultimately leads to problem translocation, as actions confined within a particular sector often do not result in the desired outcomes due to negative externalities manifested in other parts of the city or even beyond the city. What's more, blame avoidance and scapegoating among different sectoral units tend to be widespread in fragmented governance structures. Silo-thinking in urban governance and institutions preclude thoughtful management of interactions across scales, among sectors and over time; thus, preventing generation and implementation of holistic solutions.

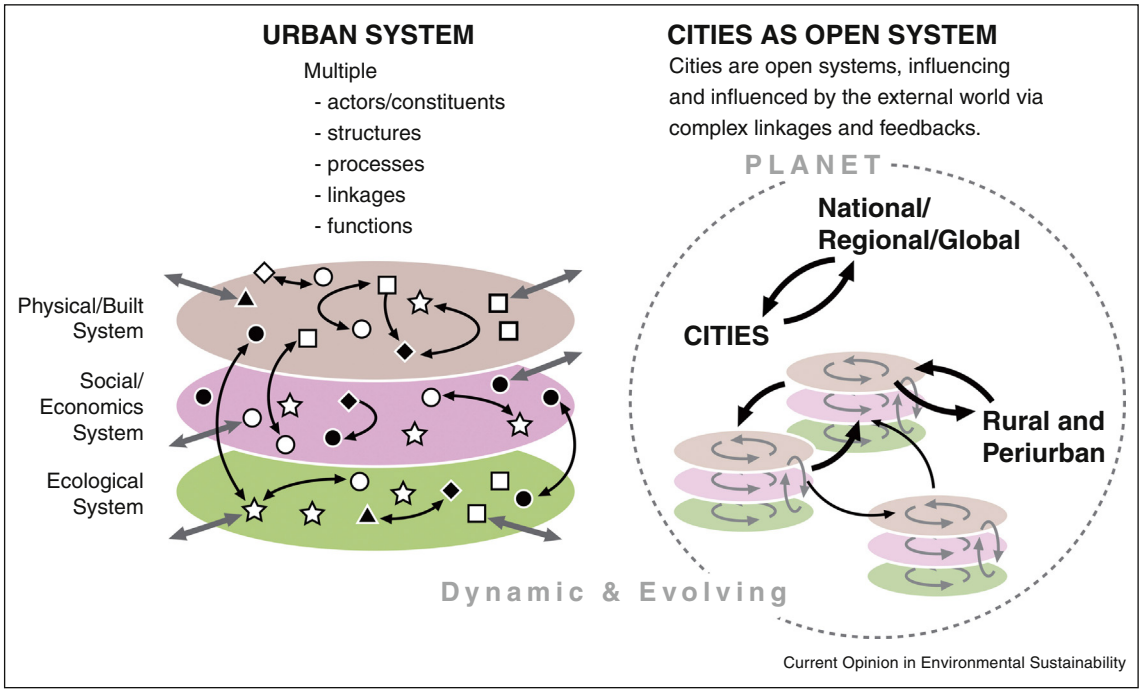
Institutional and governance fragmentation is equally reflected in urban research, where efforts often focus on identifying cause-and-effect relationships within the boundaries of individual sectors, for example, land use, transport, air pollution, sewage, and so on (but see [17]). Although much research has been devoted to sector-level analyses, little attention has been paid to the interactions among disparate urban sectors (infrastructural or institutional). For example, evidence increasingly shows that sustainable positive health outcomes in the urban context require a systems approach that integrates perspectives from urban planning, design, mobility, sanitation, and environmental science [18,19,20•]. With this perspective in mind, Future Earth's Urban Knowledge-Action Network, launched at the Habitat III Conference, could represent an integrative and transdisciplinary approach to engage researchers, policymakers and other stakeholders on urban issues at various levels, thus facilitating the knowledge co-production needed to address urban challenges. The Urban Knowledge-Action Network (Urban KAN) aims at connecting scientists from all fields to leaders in the public and private sectors, civil society, funding agencies and other arenas in order to apply a systems approach to co-design relevant research questions that will lead to producing actionable knowledge at the urban level. This paper is one of the first efforts of the Urban KAN.

Defining a systems approach in cities

Systems thinking allows us to imagine cities in their multifarious manifestations, as geophysical spaces, physical infrastructures, economic relationships, social entities, and cultural practices. The systems approach entails recognizing several important system characteristics of a city, as illustrated in Figure 1:

- Cities are open systems, continually exchanging resources, products and services, waste, people, ideas and finances with the broader world [21••,22].
- Cities are complex, self-organizing, adaptive, and constantly evolving [23–28].

Figure 1



Urban system structure and interlinkages, with the left component focusing more on the internal structure, and the right one highlighting external linkages and interactions of cities. The symbols represent actors/constituents, structure, and processes across physical/built, social/economics, and ecological subsystems. The arrows represent complex processes and linkages within and between cities, and between cities and their hinterlands. The actors and constituents are typically self-organizing, and the structure, processes and linkages and functions are dynamic and evolving, with non-linear pathways.

- Cities encompass multiple actors with varying responsibilities, capabilities and priorities, as well as processes that transcend the institutional compartmentalization of city administration [29••,30].
- Cities are embedded in broader ecological, economic, technical, institutional, legal and governance structures that often constrain their systemic function, which cannot be separated from wider power relations [31–37].
- Urban processes — physical, social, and economic — are causally interlinked, with interactions and feedbacks that result in both intended and unintended consequences [17,38,39].

Such characteristics need to be accounted for in decision-making. In terms of implementing systems approaches in urban practice, the following high-level principles, although not exclusive to systems approach, are important:

- Context: A systems approach begins by a sound understanding of the genesis of current systems structure-social, economic, ecological, political, and dynamics within and beyond the city.
- Vision: A systems approach in cities should allow for exploration of plausible and desirable visions of possible futures by the variety of stakeholders affected by urban system functioning. A process of co-design and co-production can give rise to novel ideas and the emergence of solutions, as well as increase the likelihood of collective buy-in on shared goals.
- Goals: A systems approach should have a clear set of goals. In particular, it is critical to specify a clear objective and priorities, and identify what must be included and what can be excluded, across what spatial and temporal scales. Such specifications and priorities are important in practice, to avoid being overwhelmed by the complexity or falling into the *paralysis by analysis*. Lack of clarity or agreement on these points and the normative assumptions underneath, often leads to confusions and conflicts, which tend to replicate themselves in the system.
- Actors: A systems approach must engage a wide cross-section of urban decision-making agents and stakeholders, across the public, private, community and household sectors. Involving higher-level governance structures, for example, is important if innovative practice arising from a systems-based project is to be up-scaled [40].
- Diversity/interdependencies: A systems approach should acknowledge, on the one hand, that urban system functions derive from a diversity of constituents, which needs to be recognized and accounted for and, on the other, that complex feedback mechanisms may drive inequity. Effective application of the systems approach can empower disadvantaged groups by addressing the systemic causes of inequities and disparities.
- Flexibility/adaptability: Solutions derived from systems approach are not fixed in time or space, but need to be flexible to account for new challenges and opportunities [41]. Issues must be effectively — and adaptively — framed, adjusted regularly on the basis of new challenges, experience, learning.

In practice, the approach will vary depending on the task at hand, and will be constrained by the specific governance structure and larger set of systems in which a particular city is embedded. Box 1 illustrates a systems approach to issues of urban health and wellbeing.

Box 1 Definition of a systems approach for urban health and wellbeing [42].

A systems approach to urban health and well-being would (i) perceive the city as a complex adaptive system; (ii) integrate human health concerns into urban system function (structure and processes), and; (iii) address collective knowledge creation in science and society (International Council for Science ICSU Urban Health and Wellbeing Programme).

From the standpoint of society, taking a systems approach would mean: (1) co-producing knowledge for and about urban areas across broad domains of expertise and practice (e.g., research and urban governance); (2) recognizing how particular urban system functions and lifestyles are connected to particular outcomes (including environmental, social, economic and health-related); (3) raising awareness and understanding of the interconnections and relationships between and among particular urban outcomes; (4) creating demand and opportunities for entrepreneurship and business and civil society engagement in service of desirable sustainable development outcomes; (5) creating networks of systems thinkers and agents of change who recognize similar goals related to sustainable urban development.

For research, a systems approach means:

(1) the development of new conceptual models of the processes leading to sustainable environmental, development and health in urban settings that incorporate dynamic relations.
(2) the use of systems tools and formal simulation models, such as agent-based models, systems dynamic models, or other systems modelling tools to better understand the functioning of the integrated urban, environmental, social and health systems or predict changes to economic, social development, environment and health under various hypothetical interventions;
(3) the integration of various sources and types of data (including spatial, visual, quantitative and qualitative data) in the conceptual models and/or the formal simulation models as well as the identification of important data gaps that need to be filled in order to advance understanding of how the system works.
(4) addressing co-design/co-production of knowledge with non-research stakeholders. Systems approaches are indeed about (a) conceptualization/framing from a systems perspective; (b) analytical methods to manage complexity, and; (c) integration of various sources of data, but they are also indispensably about; (d) broad engagement across (inter-disciplinary) and beyond (trans-disciplinary) and sector boundaries.
(5) thinking explicitly about suites of linked responses rather than singular silver bullets.

Barriers to implementing a systems approach in cities

Current practices of urban governance tend to be inefficient, rarely taking full advantage of potential synergies and often producing unsatisfactory outcomes. Among the major barriers to adoption of systems approaches are:

a. **Institutional evolution/behaviour:** There are historical and practical reasons for the fragmentation in urban governance (and indeed in governance at large) and research, which hinders systems approaches [16,43,44]. In particular, the increasing scale and complexity of cities has led either to the development of specialized institutions, each dealing with a particular feature of urban life or competing and overlapping responsibility for managing the city with no clear points of accountability. It is important to understand what evolutionary pressures generate siloed behaviour and, in contrast, how restructuring governance can enable behavioural and institutional change towards systemic thinking. In the meantime, the potential roles of non-governmental actors, e.g., representing the corporate sector, communities and civil society, are insufficiently understood, are poorly recognized and may be under or, as in the case of incapacitated states, over utilized [45,46].

b. **Failure to recognize the systemic nature of cities:** the traditional view of cities in primarily geographic terms is inadequate. While the concept of 'place' in terms of the unique character, context, and capacities of specific localities is a critical corollary to the systems approach, cities are too often conceptualized as places like any other [23,47,48]. In fact, the urban environment represents a critical juxtaposition of multidimensional causal structures, which cannot be characterized in one-dimensional terms. As long as such characterizations prevail, it is difficult to demonstrate the need for systems approaches. Furthermore, silos in urban research and management tend to reinforce sector based actions than an integrated one, as disciplinary or sectoral expertise is seen by practitioners as sufficient to resolving problems in their own fields.

c. **Inadequacy of mental models**: The behaviour of complex systems is inherently difficult to understand and manage. Existing concepts and labels that are used to categorize and understand urban phenomena often turns out to be inadequate and unhelpful [49], and new models are often called for [50]. The mental and logistical effort required to expand mental models by creating linkages across sectors and learning from new partners with different worldviews, and the time required for this, hinder the adoption of systems approaches. This increased investment is usually in stark contrast to urban managers' needs for immediate actions and simple narratives. Yet inadequate mental models would inevitably give rise to unintended undesirable consequences and thus are liable to result in wasted efforts and resources. New and shared mental models of urban systems and effective communication of them are often necessary for transformational change.

d. **Lack of incentives:** There is a general lack of incentive or institutional support for urban decision-makers to think beyond individual sectors and adopt systems approaches. Managers focus on sectoral goals where cross-sectoral negative externalities are typically not taken into consideration, thus effective leverage points that may become apparent only through a synergistic effort are rarely recognized and acted upon. For example, mainstreaming ecosystem-based adaptation remain a challenge, despite evidences supporting such [51]. In some developing cities, the lack of incentive for systems-informed decision making is not because of vested interests of specialist gatekeeping. Rather, it centers on the inability to bridge the gap between low levels of capacity and training among politicians and civil servants, the paucity of reliable information that is required for responsible multidimensional systems analyses.

e. **Inadequate decision-support systems:** There is a need for new data collection, much wider scientific deliberation about metrics that are available or chosen as indicators for sustainable development and the data collected on the basis of these choices, and a better capacity for spatial and statistical disaggregation of urban data. Modelling serves as a vehicle to facilitate informed conversation, and thus shared understanding of a problem and potential solutions [52]; dynamic modelling and simulation is a valuable tool that provides insight into systems functioning, and the identification of the most worthwhile policy options [28]. However, modelling to support decision-making is often flawed by limited and non-representative data and capacity for disaggregation at appropriate spatial and statistical levels, and often confined to sectoral expertise. In most African and many Asian cities, the data is simply not available [53]. It is critical to bring diverse stakeholders into the modelling process early on, both to ensure buy-in/ownership and to take advantage of their unique perspectives and knowledge of the urban system, without which mischaracterization of the system and negative unintended outcomes are likely. Additionally, limited financing mechanisms and institutions able to support transformative changes and lack of effective cross city/project learning exacerbate the latter.

f. **Path-dependency and lock-in:** Urban physical, institutional, and cultural development is typically path-dependent, often leading to lock-in of infrastructure, inertia in practice, persistence of social stratification and limited social buy-in to the sustainability agenda [54]. Once in place, it is hard to reverse such urban

features, even where a systems approach would indicate better solutions.

The way forward: promoting a systems approach

Some cities have recognized the importance of adopting systems approaches in urban decision-making, and have thereby generated positive outcomes. For example, Yogyakarta City in Indonesia adopted a participatory approach that mobilizes multiple stakeholders across the water supply, waste management, sanitation, and health sectors to identify and implement appropriate dengue management interventions in the city and surrounding area, with corresponding reductions in disease [11••]. In China, increasing urban flood risk has led to the cities to look beyond traditional infrastructure solutions and explore the concept of 'sponge city', where nature based solutions are combined with various technological solutions to enhance the ability for cities to absorb rainfall and reduce flood. In Bandar Lampung, Indonesia, analyses of flood safety and security revealed that unregulated dumping of waste in drainage channels, canals and rivers (infrastructure networks) had severely compromised the existing urban drainage system, contaminated the freshwater, and led to an increase in the prevalence of waterborne diseases. In response, the city developed a city-wide integrated solid waste management plan to decrease the risk of flooding and spread of waterborne diseases [55].

For the systems approach to become a norm in urban practice, some fundamental changes that address the kind of barriers discussed above will be needed. While solutions will vary, we consider a few strategic responses critical in this respect, and these are shown in Table 1 matched to the barriers identified in the previous section, that each addresses.

Table 1

Proposed changes (letters) to address the major barriers to adoption of systems approaches. Each letter corresponds to the following proposed changes (as presented in the paper) — A: Radical redesign of urban institutional structures and processes; B: Promoting regenerative cultures, behaviours and design; C: Financing of systems approaches in urban governance; D: Stronger science-policy-practice linkages

Barriers to adoption of systems approach	Proposed changes
Institutional evolution/behaviour	A, B, D
Failure to recognize the systemic nature of cities	A, D
Complexity of required mental models	A, D
Lack of incentives:	A, B, C
Inadequate decision-support systems	C, D,
Path-dependency and lock-in	A, B

Radical redesign of urban institutional structures and processes

In large-scale policy and practice processes, such as the Rockefeller 100 Resilient Cities project (Rockefeller 100 Resilient Cities project; URL: http://www.100resilientcities.org/) there has been a growing need to understand the governance implications of a shift towards sustainable, resilient cities. A complex systems framework, along with an understanding of urban resilience and sustainability as features that promote plurality and redundancy in institutional structures and diversity in development and transformation pathways, can introduce new perspectives into urban planning and practice [56]. For example, the tension between efforts to increase efficiency in urban systems and the consequent loss of redundancy and resilience represents a challenge that is difficult to address with current paradigms of urban planning and practice. One way of addressing the conflict is to acknowledge the importance of a coordinated plurality of institutional arrangements and community initiatives. For example, planners might search for sustainable and resilient solutions to urban problems through a co-production process running parallel to streamlined planning efforts, allowing for multiple solutions to be experimented with across the urban landscape (i.e., through collaborative and polycentric governance).

Centralized urban governance can permit bold actions to be quickly taken, but often requires enhanced accountability. In contrast, a more decentralized governance framework involving the devolution of power to citizens and the promotion of polycentric governance structures has the potential to enhance resilience, as no single entity would control the whole system (i.e. subsidiarity principle). Rather, governance would occur in networks of interlocking arrangements that enhance resilience from the bottom up. For such decentralized governance systems to work, workplace approaches would need to be devised to encourage coordinated action towards shared systemic goals and principles. In addition, the benefits of polycentrism are only realised if there are explicit processes in place to ensure there is learning across the diversity of experiments. One important pressing research task is to understand under which conditions and to what extent polycentric governance facilitate developing systems-analytic perspective on the part of decision makers [57–59]. This would include a better understanding of the type of activities that might be best governed (or in some cases ungoverned, that is, participatory, collaborative, polycentric, governance) at what levels and in what ways, as there are valid governing practices at all scales from international to local.

To achieve sustainability and resilience, urban planning need to incorporate a large nested hierarchy of spatial scales, taking into account the external connections and impacts of cities. Collaboration across a global system of cities could and should provide a new component of a governance framework to manage resource chains for

sustainability and resilience. In this way, planners and policy makers can create a more inclusive process to determine which potential pathways will offer the most desirable sustainability and/or resilience outcomes [55].

Promoting regenerative cultures, behaviours and design

Culture is an essential but under explored or utilized dimension of health and sustainability. 'Culture' refers to both the aggregated patterns of daily life, commerce, and governance, that is, the way things are done in practice in a particular place, and to 'arts-based culture' where artists, architects, and designers shape public perception and experience. Urban resilience requires a culture of sustainability. Urban planning has been recognized as an instrument for promoting sustainable development. Several central business districts in Finland were designed to facilitate environmental sustainability [60]. The İstanbul Water Front used social and cultural elements to regenerate urban areas with positive impact on the historic environment, local community and economy [61]. Red Town area of Shanghai was developed using arts for regenerating the city. It represented a shift from purely technical and episodic artistic interventions, to organized construction of creative industry spaces [62]. Regenerative ecological industrial development represents an emerging paradigm for sustainable renewal of communities devastated by the multiple crises in our ecological, economic, social and cultural systems.

Regenerative design applies 'systems thinking' to design processes and outcome instead of the tendency to design objects in isolation. Its goal is to integrate natural and human systems in ways that minimize disruptions in the ecosystem, and restore or revitalize sources of energy and materials within the system. This is a cradle to cradle philosophy of design with a closed loop input–output model [63]. Our challenge likewise is to find occasions for melding social, cultural, artistic sensibilities and aesthetic inquiry with scientific and technological pursuit of efficiency and objectivity, to create both rationally sound and emotionally compelling sustainable urban communities.

Designing spaces with intended behaviours can induce pro socio-environmental behaviours and reinforce such values. A number of experiments have been implemented in designing public spaces to invoke socially and ecologically friendly behaviours. For example, many studies show that stair use will increase when the aesthetics of a stairwell are pleasing, this is an alternative which Dalhousie University in Halifax has been contemplating for one of their buildings [64]. The Echigo Tsumari Art Fields use landscape art installations to recover memory and history of their region to offer a community narrative and attract visitors and volunteers to their community. Thus viewing humans, communities and cultures, as integral elements of systems design is critical for urban development.

Financing of systems approaches in urban governance

Systems approaches do not necessarily require additional funding. In fact, a careful systems consideration and approach might save cost in practice by eliminating duplication and unnecessary repetition abundant in siloed infrastructure management or by aligning initiatives by multiple partners. For example, it is estimated that the long-term development visions of Chinese cities are adding up towards supporting a population of more than 3 billion, which is more than twice the nation's total population. Better inter-city coordination, which is one of the important elements of systems approach at a larger scale, would prevent over competition and direct the investment into more effective urban planning and governance. The challenge, however, is that such savings might only be realised over the long run and beyond the immediate project level.

Nonetheless, a more innovative financing mechanism for urban research and practice can be an important instrument for change [65]. To begin with, designing different funding mechanisms is critical as systems approaches will not be widely adopted without interdisciplinary research funding and proper incentives for coordinated decision-making at urban scale. For example, a small percentage of urban development funds should be dedicated to studying the behaviour of urban systems (i.e., how urban areas function in all their complexity), and long-term evaluation and monitoring of system level costs and benefit. Such dedicated funds might be pooled to support larger research projects that are targeted at fundamental problems that might be beyond the immediate concern of a typical urban development project. In addition, investment in developing systems monitoring and decision supporting tools will enable the true impact of urban activities as well as the potential benefits of a systems approach to be measured and clearly demonstrated. There is as well a need to not only rethink about financing the systems response but about reshaping how the research bodies and institutions own mental models in order to help create a systemic culture for researchers and practitioners.

Stronger science–policy–practice linkages

To achieve the urban SDG, a closer science–policy–practice linkage that builds systems capacity and evidence needs to be promoted. There is much expertise on urban areas, but typically it is fragmented by disciplines and sectors, and the extent to which researchers are engaged in the policy-making processes remains unclear [10,66]. There are knowledge gaps in terms of understanding the interface, interactions, and interdependencies among factors that both drive and are driven by urbanization as well as among different sectors within

an urban system. As such, decision-making cannot be informed in ways that maximize the synergies or minimize tradeoffs between these different sectors. Cities learn from each other much more effectively than they could from scientific literature (which is positive), but research can help facilitate and accelerate such cross learning. There are many innovative practices adopted by cities that have the potential to be up-scaled into systemic changes, but, first, an effective mechanism to extract and share learning is needed [30,67].

An integrative, interdisciplinary and transdisciplinary community of scholars, able to engage decision-makers and other stakeholders on urban issues at all relevant levels (local, national, regional, global), needs to be fostered. As Frantzeskakia and Kabischb [68] point out, urban environmental problems are not only for experts to solve but are relevant to a wide array of actors at various urban scales. Thus, the knowledge required to solve such challenges need to arise from co-designed and co-produced narratives with a solution-oriented approach. Therefore, an effective mechanism that helps mobilize a wide array of urban stakeholders is called for to facilitate knowledge co-production, which will in turn enhance the role of science in urban policy processes [69••]. In 2016, at the Habitat III conference, Future Earth (www.futureearth.org) launched the Urban Knowledge-Action Network (Urban KAN), which will connect scientists from a broad range of disciplines (natural, social, humanities, architecture, design, etc.) to leaders in the public and private sectors, civil society, funding agencies and other arenas to build solutions for creating more liveable, sustainable and equitable cities. It aims at applying a systems approach to urban policy, practice, and knowledge co-development to co-design relevant research questions that will lead to producing actionable knowledge. It will also foster a cohort of urban decision-makers and practitioners that connect to researchers to implement reliable and effective solutions for cities. As such, because of its focus on bridging the gaps between different disciplines, sectors, and communities, Future Earth, through its Urban KAN, offers an elegant and unique way to mobilize the stakeholders needed to address the complex challenges that cities are faced with, including that of implementing a systems approach.

Conclusion

Urbanization is increasingly recognized as one of the biggest challenges of our time as well as one of the most effective leverage points for achieving the Sustainable Development Goals. Cities as systems demonstrate a high level of complexity of interdependencies — including synergies and trade-offs — that represents both challenges and opportunities. We argue that a systems approach can reveal unrecognized opportunities to maximize co-benefits and synergies, guide management of inevitable trade-offs, and therefore is far more likely to deliver successful solutions than reactive interventions undermined by inadequate supporting action plans. This systemic approach could help avoid unintended consequences, which in turn can drive building more economically, socially, and environmentally sustainable and equitable cities.

Building sustainable and equitable cities is at the heart of the *New Urban Agenda* [70], which has been adopted at the UN Habitat III Conference in October (Quito, Ecuador). Although lacking in many current urban decision-making processes, the *New Urban Agenda* recognizes the importance of adopting systems approach that involve the different sectors and stakeholders. For the effective implementation of the SDGs and the *New Urban Agenda*, we consider the following aspects as key to implementation of a systems approach: (a) redesign the urban institutional setup; (b) promote regenerative culture, behaviour, and design; (c) explore ways to finance systems approach; and (d) facilitate a new and enhanced role of sciences in policy and practice (science–policy–practice continuum). The Urban Knowledge-Action Network of Future Earth is designed to respond to these challenges and to provide the knowledge to implement the urban-related aspects of the SDGs and the *New Urban Agenda*.

Acknowledgements

This paper was originally developed as a Future Earth white paper in response to the draft New Urban Agenda, which was adopted at the Habitat III. The authors are grateful for the helpful discussions and comments provided by Simon Toze, Corrie Griffith, Patricia Romero Lankao, Peter Head, Eugenie Birch, Christina Cook on an earlier version of the paper; and for the help with the graphics by Clive Hilliker.

References and recommended reading

Papers of particular interest, published within the period of review, have been highlighted as:

- • of special interest
- •• of outstanding interest

1. • Bai X, Shi P, Liu Y: **Society: realizing China's urban dream**. *Nature* 2014, **509**:158-160.

This paper discusses how rapid urbanization can be one of the biggest social transformation and experiment in human settlement in history. The authors argue that city level practice will make or break the national government policy attempting to guide the urbanization process.

2. Seto KC, Güneralp B, Hutyra LR: **Global forecasts of urban expansion to 2030 and direct impacts on biodiversity and carbon pools**. *Proc Natl Acad Sci* 2012, **109**:16083-16088.

3. • Revi A, Satterthwaite D, Aragón-Durand F, Corfee-Morlot J, Kiunsi RBR, Pelling M, Roberts D, Solecki W, Gajjar SP, Sverdlik A: **Towards transformative adaptation in cities: the IPCC's Fifth Assessment**. *Environ Urban* 2014, **26**:11-28.

This Chapter of the Fifth Assessment Report (AR5) of the IPCC provides a systematic overview of adaptation in cities, including adaptation in different urban sectors and the role of various stakeholders in achieving transformative adaptation.

4. Grimm NB, Faeth SH, Golubiewski NE, Redman CL, Wu J, Bai X, Briggs JM: **Global change and the ecology of cities**. *Science* 2008, **319**:756-760.

5. Grubler A, Bai X, Buettner T, Dhakal S, Fisk DJ, Ichinose T, Keirstead JE, Sammer G, Satterthwaite D, Schulz NB *et al.*: **Urban energy systems**. *In Global Energy Assessment — Toward a Sustainable Future*. Cambridge University Press and the

International Institute for Applied Systems Analysis; 2012:. pp 1307–1400.

6. • Seto KC, Dahkal S, Bigio A, Blanco H, Delgado DC, Dewar D, Huang L, Inaba A, Kansal S, Lwasa S *et al.*: **Human settlements, infrastructure and spatial planning**. In *Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.* Edited by Edenhofer OR, Pichs-Madruga Y, Sokona E, Farahani S, Kadner K, Seyboth A, Adler I, Baum S, Brunner P, Eickemeier B. Cambridge University Press; 2014:923-1000.

This Chapter of the Fifth Assessment Report (AR5) of the IPCC provides an overview of current urban research related to climate change and key knowledge gaps (e.g. limited evaluations of city climate action plans, lack of scientific understanding of how cities can prioritize mitigation actions, strategies, investments, and policy responses and important uncertainties about future urbanization scenarios considering urbanization's large role in determining emissions pathways).

7. UNDP: *UNDP Support to the Implementation of the 2030 Agenda*. UNPD; 2016.

8. Le Blanc D: **Towards integration at last? The sustainable development goals as a network of targets**. *Sustain Dev* 2015, **23**:176-187.

9. Duarte F, Rojas F: **Intermodal connectivity to BRT: a comparative analysis of Bogotá and Curitiba**. *J Public Transp* 2012:15.

10. • McPhearson T, Pickett STA, Grimm NB, Niemelä J, Alberti M, Elmqvist T, Weber C, Haase D, Breuste J, Qureshi S: **Advancing urban ecology toward a science of cities**. *BioScience* 2016, **66**:198-212.

This paper looks at urban ecology as a field of science overarching multiple disciplines and practical applications and argues that the field should mature as an integrated science of urban systems to better inform decision makers who need understanding of complex interactions between social, ecological, economic, and built infrastructure systems.

11. •• de Oliveira JAP, Doll CNH, Siri J, Dreyfus M, Farzaneh H, Capon A: **Urban governance and the systems approaches to health-environment co-benefits in cities**. *Cad. Saúde Públ* 2015, **31(Suppl. 1)**:25-38.

This paper highlights the importance of using a systems approach in order to improve urban and thus dealing more effectively with the complex interactions between environmental change and urban health. The authors suggest five actionable transitional steps in order to facilitate the transition to good governance, from better coordination among urban sectors to bringing together a wide-array of stakeholders in the decision-making processes.

12. Newman P, Kenworthy J: *The End of Automobile Dependence: How Cities are Moving Beyond Car-Based Planning*. 2015.

13. • Smith TF, Brooke C, Measham TG, Preston B, Gorddard R, Beveridge B, Morrison C (Eds): *Case Studies of Adaptive Capacity: Systems Approach to Regional Climate Change Adaptation Strategies*. Sydney Coastal Councils Group Inc.; 2008.

This paper discusses the utility of applying the concepts, principles, and methods of systems thinking to the study of complex urban health. Using specific examples, it provides recommendations on how to better incorporate systems thinking methods in urban health research and practice.

14. Fiksel J: **Sustainability and resilience: toward a systems approach**. *Sustain Sci Pract Policy* 2006:2.

15. Brondizio ES, Gatzweiler FW: **Socio-cultural context of ecosystem and biodiversity valuation**. In *The Economics of Ecosystems and Biodiversity. Ecological and Economic Foundations.* Edited by Kumar P. Earthscan; 2010.

16. Silva CN: **Governing metropolitan Lisbon: a tale of fragmented urban governance**. *GeoJournal* 2002, **58**:23-32.

17. Güneralp B, Seto KC: **Environmental impacts of urban growth from an integrated dynamic perspective: a case study of Shenzhen, South China**. *Glob Environ Change* 2008, **18**:720-735.

18. Bai X, Nath I, Capon A, Hasan N, Jaron D: **Health and wellbeing in the changing urban environment: complex challenges, scientific responses, and the way forward**. *Curr Opin Environ Sustain* 2012, **4**:465-472.

19. Roux AVD, Roux AVD: **Health in cities: is a systems approach needed?** *Cad Saúde Públ* 2015, **31**:9-13.

20. • Tozan Y, Ompad DC: **Complexity and dynamism from an urban health perspective: a rationale for a system dynamics approach**. *J Urban Health Bull N Y Acad Med* 2015, **92**:490-501.

This paper discusses the utility of applying the concepts, principles, and methods of systems thinking to the study of complex urban health. Using specific examples, it provides recommendations on how to better incorporate systems thinking methods in urban health research and practice.

21. •• Bai X: **Eight energy and material flow characteristics of urban ecosystems**. *Ambio* 2016, **45**:819-830.

This paper discusses how the urban energy and material flow studies can reveal some fundamental characteristics of cities as human dominant, complex, adaptive and evolving ecosystems. The paper calls for a conceptual bridging between the urban metabolism and urban ecosystem research communities to achieve a better understanding of urban systems.

22. Kennedy CA, Stewart I, Facchini A, Cersosimo I, Mele R, Chen B, Uda M, Kansal A, Chiu A, Kim K *et al.*: **Energy and material flows of megacities**. *Proc Natl Acad Sci* 2015, **112**:5985-5990.

23. Batty M, Barros JSA: **Cities: continuity, transformation and emergence**. In *Complexity and Co-evolution: Continuity and Change in Socio-economic Systems.* Edited by Garnsey E, McGlade JA. Edward Elgar Publishing Ltd.; 2006:61-76.

24. Bai X: **The process and mechanism of urban environmental change: an evolutionary view**. *Int J Environ Pollut* 2003, **19**:528-541.

25. Fujita M, Mori T: **Structural stability and evolution of urban systems**. *Reg Sci Urban Econ* 1997, **27**:399-442.

26. Ma S, Wang R: **Social–economic–natural ecosystems**. *Acta Ecol Sin* 1984, **4**:1-9.

27. Portugali J (Ed): *Self-Organization and the City*. Springer; 2000.

28. Portugali J, Benenson I: **Human agents between local and global forces in a self-organizing city**. In *Self-Organization of Complex Structures: From Individual to Collective Dynamics.* Edited by Schweitzer F. CRC Press; 1997:537-546.

29. •• Loorbach D, Wittmayer JM, Shiroyama H, Fujino J, Mizuguchi S (Eds): *Governance of Urban Sustainability Transitions*. Springer; 2016.

This book presents how cities can achieve the great sustainability challenges by considering new and innovative methods based on a transitions management. It examines how cities in Europe and Asia are implementing the latter both conceptually and practically.

30. Bai X, McAllister RR, Beaty RM, Taylor B: **Urban policy and governance in a global environment: complex systems, scale mismatches and public participation**. *Curr Opin Environ Sustain* 2010, **2**:129-135.

31. Grimm NB, Grove JG, Pickett STA, Redman CL: **Integrated approaches to long-term studies of urban ecological systems urban ecological systems present multiple challenges to ecologists — pervasive human impact and extreme heterogeneity of cities, and the need to integrate social and ecological approaches, concepts, and theory**. *BioScience* 2000, **50**:571-584.

32. Bai X: **Integrating global environmental concerns into urban management: the scale and readiness arguments**. *J Ind Ecol* 2007, **11**:15-29.

33. Ramaswami A, Weible C, Main D, Heikkila T, Siddiki S, Duvall A, Pattison A, Bernard M: **A social–ecological–infrastructural systems framework for interdisciplinary study of sustainable city systems**. *J Ind Ecol* 2012, **16**:801-813.

34. Elmqvist T, Fragkias M, Goodness J, Güneralp B, Marcotullio PJ, McDonald RI, Parnell S, Schewenius M, Sendstad M, Seto KC *et al.*: **Stewardship of the biosphere in the urban era**. In *Urbanization, Biodiversity and Ecosystem Services: Challenges and Opportunities.* Edited by Elmqvist T, Fragkias M, Goodness J, Güneralp B, Marcotullio PJ, McDonald RI, Parnell S, Schewenius M, Sendstad M, Seto KC.*et al.*: Springer; 2013:719-746.

35. Pickett STA, Cadenasso ML, Grove JM, Nilon CH, Pouyat RV, Zipperer WC, Costanza R: **Urban ecological systems: linking**

terrestrial ecological, physical, and socioeconomic components of metropolitan areas. In *Urban Ecology.* Edited by Marzluff JM, Shulenberger E, Endlicher W, Alberti M, Bradley G, Ryan C, Simon U, ZumBrunnen C. Springer; 2008:99-122.

36. Padoch C, Brondizio E, Costa S, Pinedo-Vasquez M, Sears RR, Siqueira A: **Urban forest and rural cities: multi-sited households, consumption patterns, and forest resources in Amazonia**. *Ecol Soc* 2008:13.

37. Mitlin D, Satterthwaite D (Eds): *Urban Poverty in the Global South: Scale and Nature*. Routledge; 2013.

38. Bai X, Chen J, Shi P: **Landscape urbanization and economic growth in china: positive feedbacks and sustainability dilemmas**. *Environ Sci Technol* 2012, **46**:132-139.

39. Glaeser EL, Kahn ME: **The greenness of cities: carbon dioxide emissions and urban development**. *J Urban Econ* 2010, **67**:404-418.

40. Bai X, Roberts B, Chen J: **Urban sustainability experiments in Asia: patterns and pathways**. *Environ Sci Policy* 2010, **13**:312-325.

41. Leichenko R: **Climate change and urban resilience**. *Curr Opin Environ Sustain* 2011, **3**:164-168.

42. ICSU: *Report of the ICSU Planning Group on Health and Wellbeing in the Changing Urban Environment: a Systems Analysis Approach*. International Council for Science; 2011.

43. Newman P, Thornley A: **Fragmentation and Centralisation in the Governance of London: influencing the Urban Policy and Planning Agenda**. *Urban Stud* 1997, **34**:967-988.

44. Biermann F, Pattberg P, van Asselt H, Zelli F: **The fragmentation of global governance architectures: a framework for analysis**. *Glob Environ Polit* 2009, **9**:14-40.

45. Beall J, Parnell S, Albertyn C: **Elite compacts in Africa: the role of area-based management in the new governmentality of the Durban city-region**. *Int J Urban Reg Res* 2015, **39**:390-406.

46. Simone A (Ed): *For the city yet to come: Changing African life in four cities*. Duke University Press; 2004.

47. Seitzinger SP, Svedin U, Crumley CL, Steffen W, Abdullah SA, Alfsen C, Broadgate WJ, Biermann F, Bondre NR, Dearing JA *et al.*: **Planetary stewardship in an urbanizing world: beyond city limits**. *Ambio* 2012, **41**:787-794.

48. Batty M: *The New Science of Cities*. The MIT Press; 2013.

49. Schindler S: **Producing and contesting the formal/informal divide: regulating street hawking in Delhi, India**. *Urban Stud* 2014, **51**:2596-2612.

50. Occelli S, Rabino GA: **Cognitive modeling of urban complexity**. In *Complex Artificial Environments.* Edited by Portugali J. Springer; 2006. pp 219–233.

51. Wamsler C, Pauleit S: **Making headway in climate policy mainstreaming and ecosystem-based adaptation: two pioneering countries, different pathways, one goal**. *Clim Change* 2016, **137**:71-87.

52. Guhathakurta S: **Urban modeling as storytelling: using simulation models as a narrative**. *Environ Plan B: Plan Des* 2002, **29**:895-911.

53. Simon D, Arfvidsson H, Anand G, Bazaz A, Fenna G, Foster K, Jain G, Hansson S, Evans LM, Moodley N *et al.*: **Developing and testing the urban sustainable development goal's targets and indicators — a five-city study**. *Environ Urban* 2015, **28**:49-63.

54. Wu F, He S, Webster C: **Path dependency the neighbourhood effect: urban poverty in impoverished neighbourhoods in Chinese cities**. *Environ Plan A* 2010, **42**:134-152.

55. da Silva J, Kernaghan S, Luque A: **A systems approach to meeting the challenges of urban climate change**. *Int J Urban Sustain Dev* 2012, **4**:125-145.

56. Wilkinson C: **Urban resilience what does it mean in planning practice?** *Plan Theory Pract* 2012, **13**:319-324.

57. Marshall G: **Nesting, subsidiarity, and community-based environmental governance beyond the local scale**. *Int J Commons* 2007, **2**:75.

58. Marshall GR: **A social–ecological systems framework for food systems research: accommodating transformation systems and their products**. *Int J Commons* 2015, **9**:881.

59. Ostrom E: **Nested externalities and polycentric institutions: must we wait for global solutions to climate change before taking actions at other scales?** *Econ Theory* 2012, **49**:353-369.

60. Säynäjoki E-S, Heinonen J, Junnila S: **The power of urban planning on environmental sustainability: a focus group study in Finland**. *Sustainability* 2014, **6**:6622-6643.

61. Gunay Z, Dokmeci V: **Culture-led regeneration of Istanbul waterfront: Golden Horn Cultural Valley Project**. *Cities* 2012, **29**:213-222.

62. Wang J: **''Art in capital'': shaping distinctiveness in a culture-led urban regeneration project in Red Town, Shanghai**. *Cities* 2009, **26**:318-330.

63. McDonough W, Braungart M: **Design for the triple top line: new tools for sustainable commerce**. *Corp Environ Strategy* 2002, **9**:251-258.

64. Tusquets O, Diot M: *The Staircase The Architecture of Ascent*. Thames & Hudson Ltd.; 2013.

65. Barnes PM: Instruments of change — motivating and financing sustainable development, In Theodor Panayotou, 1998. Earthscan, xii+228 pp, £19.95. ISBN 1-85383-467-X. Sustain. Dev. 1999, 7:205–205.

66. Acuto M, Parnell S: **Leave no city behind**. *Science* 2016, **352**:873.

67. Nevens F, Frantzeskaki N, Gorissen L, Loorbach D: **Urban transition labs: co-creating transformative action for sustainable cities**. *J Clean Prod* 2013, **50**:111-122.

68. Frantzeskaki N, Kabisch N: **Designing a knowledge co-production operating space for urban environmental governance — lessons from Rotterdam, Netherlands and Berlin, Germany**. *Environ Sci Policy* 2016, **62**:90-98.

69. •• McPhearson T, Parnell S, Simon D, Gaffney O, Elmqvist T, Bai X, Roberts D, Revi A: **Scientists must have a say in the future of cities**. *Nature* 2016, **538**:165-166.
This paper calls for a stronger urban science–policy linkages, including a greater role of science and scientists in international policy processes, and in the implementation of New Urban Agenda adopted at the Habitat III Conference.

70. The New Urban Agenda. Habitat III; 2016.