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Sustainability and resilience for transformation in the urban century

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We have entered the urban century and addressing a broad suite of sustainability challenges in urban areas is increasingly key for our chances to transform the entire planet towards sustainability. For example, cities are responsible for 70% of global greenhouse gas emissions and, at the same time, 90% of urban areas are situated on coastlines, making the majority of the world's population increasingly vulnerable to climate change. While urbanization accelerates, meeting the challenges will require unprecedented transformative solutions for sustainability with a careful consideration of resilience in their implementation. However, global and local policy processes often use vague or narrow definitions of the concepts of 'urban sustainability' and 'urban resilience', leading to deep confusion, particularly in instances when the two are used interchangeably. Confusion and vagueness slow down needed transformation processes, since resilience can be undesirable and many sustainability goals contrast, or even challenge efforts to improve resilience. Here, we propose a new framework that resolves current contradictions and tensions; a framework that we believe will significantly help urban policy and implementation processes in addressing new challenges and contributing to global sustainability in the urban century.

By 2030, the deadline for achieving the UN Sustainable Development Goals (SDGs), urbanization is expected to surpass 60% of the global population[1]. Estimates by the UN[1] suggest that there are currently over 4 billion global urban dwellers, including over 863 million informal settling dwellers, and that this is increasing by nearly 1 million every 10 days[2]. Urban areas contribute more than 75% of global GDP, but are also responsible for most of global energy demand and carbon emissions. The current and future regional and global significance of cities[3–5], is in stark contrast with the turn of the twentieth century, when the urban population was only 215 million, just 13% of the global population[1]. Hence, the current century should rightly be labelled the urban century, where cities will require a fundamentally new holistic perspective for understanding the challenges, aligning different priorities and goals, and for strategically planning for policy and governance of better urban futures.

Cities have proven to be remarkably resilient complex systems: many cities have existed for thousands of years and have persevered in the face of natural and human-induced disasters to become stronger and in some cases more resilient (for example, ref. [6]). However, the context is changing and the Anthropocene[7] will see multiple new risks and challenges for urban areas[4,5]. The UN International Strategy for Disaster Reduction recently concluded that cities are increasingly vulnerable to global environmental change: drought, flooding, heat stress, extreme rainfall events and other natural catastrophes[8,9]. When hit by natural disasters, urban areas tend to suffer greater fatalities and economic losses when compared with rural areas due to the concentration of people, buildings, services and assets, as well as the tightly interconnected infrastructures[10]. The high concentration and connectivity of infrastructures in urban areas (water supply network, sewage systems, transportation, subways, roads and railways, energy supply network, telecommunication system, green infrastructures) and even more so in megacities, put them particularly at risk of cascading system failures[11]. In the US, for example, recent devastating hurricanes including Hurricane Florence in 2018 and Harvey, Irma and Maria in 2017, demonstrate the vulnerability of even wealthy, developed coastal cities. A large proportion of the urban and therefore global human population are located in low-lying coastal zones and are at risk from urban development intensification exposing people and social, ecological and technological assets to coastal storms and the effects of sea level rise[12,13]. Moreover, increased global interconnectivity, through for example the global financial system, trade networks and global supply chains[14], means localized impacts in one city reverberate globally. This connectivity is affecting cities in multiple ways, including their ability to support networks of cities in delivering on sustainability goals.

Each of the three main pillars of sustainability—economic, environmental and social—are now enshrined in the 2030 UN Sustainable Development Agenda, which includes an SDG that focuses explicitly on urban areas (SDG 11; https://www.un.org/sustainabledevelopment/cities/). All SDGs have some level of dependence on urban sustainability. For example, the energy, food and water systems needed to supply current and future cities and to manage the resultant waste products, strongly suggests that cities must be at the centre in the efforts to achieve global sustainability[15,16].

The increasing complexity, deep uncertainty and scale of global needs for urban development in the urban century will demand radically new approaches if we are to achieve a transformation to planetary sustainability[7,17–20]. Even long before the concepts of the Anthropocene and the urban century made it to the top of the agenda, cities employed the concepts of 'urban sustainability',

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'urban resilience' and 'urban transformation' as frames of reference to inform for example, urban regeneration programmes. Together, these concepts have been used to capture and highlight important aspects needed for guiding urbanization and urban change. However, in the current context of rapidly increasing complexity and deep uncertainty, there is a risk that the concepts are not being used to their full potential. Current interpretations often lead to striking confusions and overlap[21]. When analysing the intergovernmental documents underlying the Sustainable Development Goals and particularly the 'urban' SDG, Goal 11 and the New Urban Agenda, it is apparent that the concepts of resilience and sustainability are, in the urban context, poorly or too narrowly defined and even used interchangeably[21].

The misconceptions are at least partly a result of current scientific discourses on sustainability, resilience and transformations. These discourses are riddled with misconceptions and vague interpretations[22]. In the academic literature, urban sustainability has been discussed in 679 publications since 1967, urban resilience in 272 since 1973 and urban transformation in 214 since 1994 (based on a Web of Science search 22 December 2018). However, very few publications explicitly position the concepts relative to each other (for a general discussion about links between sustainability and resilience, see refs. [22–30]). Also, in their review papers on urban transformations, Wolfram, Frantzeskaki and Maschmeyer[31,32] emphasize that research on urban transformations identifies similar processes and drivers of change regardless of their orientation towards sustainability or resilience.

The root of the problem

Here, we explore how the concepts of urban sustainability, resilience and transformation have so far been commonly interpreted in policy, practice and academic literature. We expose the ambiguities embedded in these interpretations and offer suggestions on how to resolve these issues (definitions can be found in Table 1).

From policy and practice. In the policy documents underlying the New Urban Agenda[33], development towards urban sustainability is often narrowly interpreted as just increased resource efficiency, for example regarding energy use, whereas resilience is often interpreted as the ability to recover following disasters and transformation as any large-scale changes in the urban system (Table 1).

Further, in the New Urban Agenda[33] resilience is the most frequently used concept, mentioned 17 times, compared with 11 mentions of sustainability. Resilience and sustainability are mentioned in the same sentence eight times, reflecting a common assumption that sustainability and resilience, even if interpreted as distinctly different, often are viewed as positively correlated[34]. In this way, policies for a resilient city risk being interpreted as policies for a sustainable one. We view this as a fallacy.

The common mode of urban development generates urban sprawl and other inefficiencies. Urban sustainability often aims to avoid inefficiencies, for example through optimization of existing infrastructures and adapting institutions. Yet, designing for maximized efficiencies in transportation and communication networks, or energy systems, ignores a key characteristic of resilient systems: redundancy. A tenet of complex systems thinking is that a singular focus on efficiency can erode desired resilience by reducing redundancy. For example, maximizing efficiency in energy delivery systems result in vulnerability to for example, natural disasters when they lack parallel or redundant back-up systems. Sustainability goals and resilience goals, if not examined carefully, can therefore be at odds with one another where maximizing efficiency at the same time reduces resilience (Fig. 1). For example, contradictions between resilience and sustainability goals may result in planning programmes where densification plans in cities may improve energy sustainability but compromise the availability and sometimes even the quality/health of urban ecosystems, which are vital for urban resilience to climate change[35]. In Fig. 1 we highlight the potential consequences of such a narrow definition of sustainability leading to situations where policy and planning for increasing sustainability (that is, efficiency), often may lead to reduced resilience[36].

One way of getting out of this dilemma is to widen and deepen the definitions and be specific about the application. Policy and practice already offer recommendations for normative and aspirational 'sustainability'. For example, the classic Brundtland Report's definition of sustainable development focuses on targets, that is, how to manage current resources in a way that guarantees the welfare of future generations, ensuring that it is equally distributed[37]. Sustainable development is inherently normative and positive in the more recent Sustainable Development Goals where it is stated that "ending poverty and other deprivations must go hand-in-hand with strategies that improve health and education, reduce inequality and spur economic growth—all while tackling climate change and working to preserve our oceans and forests" (https://sustainabledevelopment.un.org/sdgs). Sustainability provides a normative framework, a skeleton to support a discourse about the interaction between human societies and the environment[29]. Our baseline is that a functioning biosphere is a precondition for human wellbeing and societal development[38] and we are therefore in favour of definitions emphasizing development that meets the needs of the present while safeguarding Earth's life-support system, on which the welfare of current and future generations depends[37,39]. Ely and colleageus[40] argue that the notion encompasses multiple understandings and interests, hence, addressing it in its plural form as 'sustainabilities' further strengthens its normative position.

From research. In recent reviews[22,23,30] the authors discuss definitions of urban sustainability and urban resilience, identifying inconsistencies and short-comings, particularly regarding scale (see further below in section 'Across scales') and provide their own definitions (Table 1). Although their definitions of resilience may bring more clarity by incorporating, for example, references to scales, they still tend to view resilience as normative. We argue along with others[29], however, that resilience is in essence non-normative and a deconstructable attribute of a system that is neither good nor bad per se. Consequently, resilience has the scope for both 'desired' and 'undesired' dimensions suggesting it has the potential to guide management, or planning approaches, towards enhancing resilience when desired or reducing it when undesired. Undesired resilience can conflict with sustainability goals, while desired resilience can be harnessed to make sure development stays on more sustainable trajectories (Fig. 2). There is a risk that short-term efforts for sustainability may reinforce undesired resilience, for example when efficiency is achieved through huge investments in specific energy, water and food delivery systems. The negative externalities of every one of those systems compromises the long-term resilience and generates reinforced feedback loops of undesired resilience for example, water systems that are energy intense without considering the resilience of energy systems. Therefore, resilience thinking explicitly points at the need for transformation, particularly of urban structures as a way to maintain functions under new conditions, and in this way, highlighting opportunities for linking both concepts for action[36,41]. The desirability of resilience would depend on careful analysis of resilience 'of what, to what and for whom' since many examples can be found of highly resilient systems locked into undesirable, unjust system configurations[42].

In our definition of resilience in Table 1, we emphasize maintaining functions and have deliberately omitted maintaining structures, which is present in most previous definitions of resilience (for example, refs. [36,43]). The reason for this is that structures in the urban system are often man-made, hard infrastructure that represent inertia and prevent innovation, development and transformations. By

Table 1 | Views on urban sustainability, urban resilience and urban transformations given in policy and research

	Common views in policy documents	Recent views in academic literature	Our proposed views
Urban sustainability	Increase in efficiency of resource use, optimization, important dimensions of equity and social justice sometimes not included.	Active process of synergetic integration and co-evolution between the subsystems making up a city without compromising the possibilities for development of surrounding areas and contributing by this means towards reducing the harmful effects of development on the biosphere[23].	Manage all resources the urban region is dependent on and enhance integration of all sub-systems in an urban region in ways that guarantee the wellbeing of current and future generations, ensuring distributional equity. Sustainability is a normative concept, representing the vision for society.
Urban resilience	Recovery from disaster events.	The ability of an urban system and all its constituent socio-ecological and socio-technological 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[30].	The capacity of an urban system to absorb disturbance, reorganize, maintain essentially the same functions and feedbacks over time and continue to develop along a particular trajectory. This capacity stems from the character, diversity, redundancies and interactions among and between the components involved in generating different functions. Resilience is fundamentally non-normative and an attribute of the system and applicable to different subsystems.
Urban transformation	Large-scale changes in system properties, infrastructures and system structure overall.	Shifts of urban systems from one state to another that entails radical changes in technology, society, economy and ecosystems[63]. A related concept, urban transitions, has been linked to both systems' level and agency processes[75] focusing on the ability of multiple actors to initiate, accelerate and facilitate transformative processes in cities by scaling, replicating and embedding in local practices and institutions, generating solutions that directly and effectively address sustainability in cities[76,77].	A systemic change of the urban system. It is a process of fundamental irreversible changes in infrastructures, ecosystems, agency configurations, lifestyles, systems of service provision, urban innovation, institutions and governance.

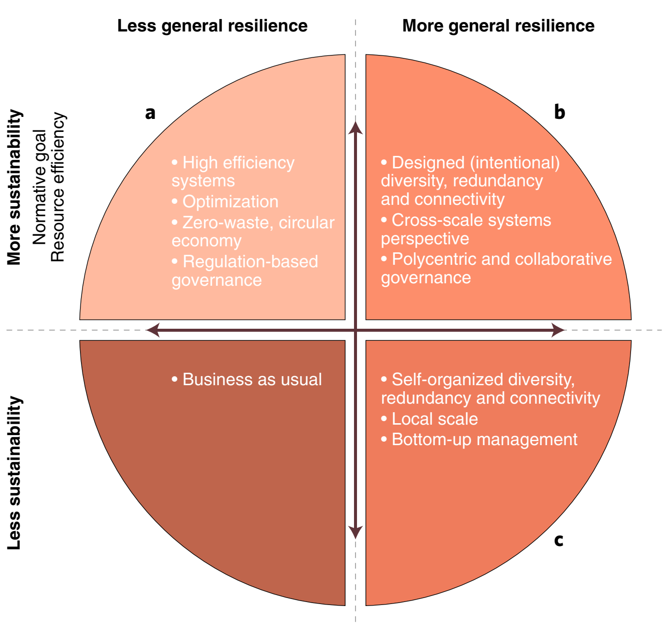

Fig. 1 | The relationship between sustainability (narrowly defined as increased efficiency) and general resilience. a–c, The main drivers/outcomes of different combinations of resilience and sustainability thinking. Examples from the energy sector could be: large-scale carbon-capture technology (**a**), individual distributed solar technology connected in large regional grids (**b**) and no-grid individual household renewable energy sources (**c**).

contrast, in ecological systems, structures may underlie resilience capacity, mainly being the product of evolutionary processes and ecological processes such as succession.

When most people think of resilience, it is generally in response to sudden shocks or continuous stresses[44,45]. However, as stated above, the resilience concept goes far beyond the mere recovery from disturbances: it explores the persistence, perseverance and potential alternative configurations of a complex system subject to changing conditions, and links to the adaptive and transformative capacities of subsystems interacting across scales and over time[43,46–51]. Following this line of reasoning, we refine the conceptualization of resilience (Table 1) by arguing that it is a system property to maintain function in the eve and aftermath of a disturbance, allowing structures of the system to undergo a transformation. The application of resilience thinking therefore requires an understanding of the desired functions and the drivers or conditions affecting feedback loops for urban systems to reorganize and innovate. For example, the backloop of social innovation[47] is important in considering urban strategies and plans for resilience in both social and ecological terms.

Across scales. The reference to spatial (and temporal) scales when defining resilience in the work of Meerow and colleagues[27,30] and Zhang and Li[23] (Table 1) is both new and important. We commend this, since resilience is a system property and not confined to a single scale of a city or even subsystem[48]. Too frequently, the resilience concept has been applied to a specific urban systems' scale with numerous attempts made to analyse sustainability, or resilience, of individual cities[52] and has often been constrained to either single or

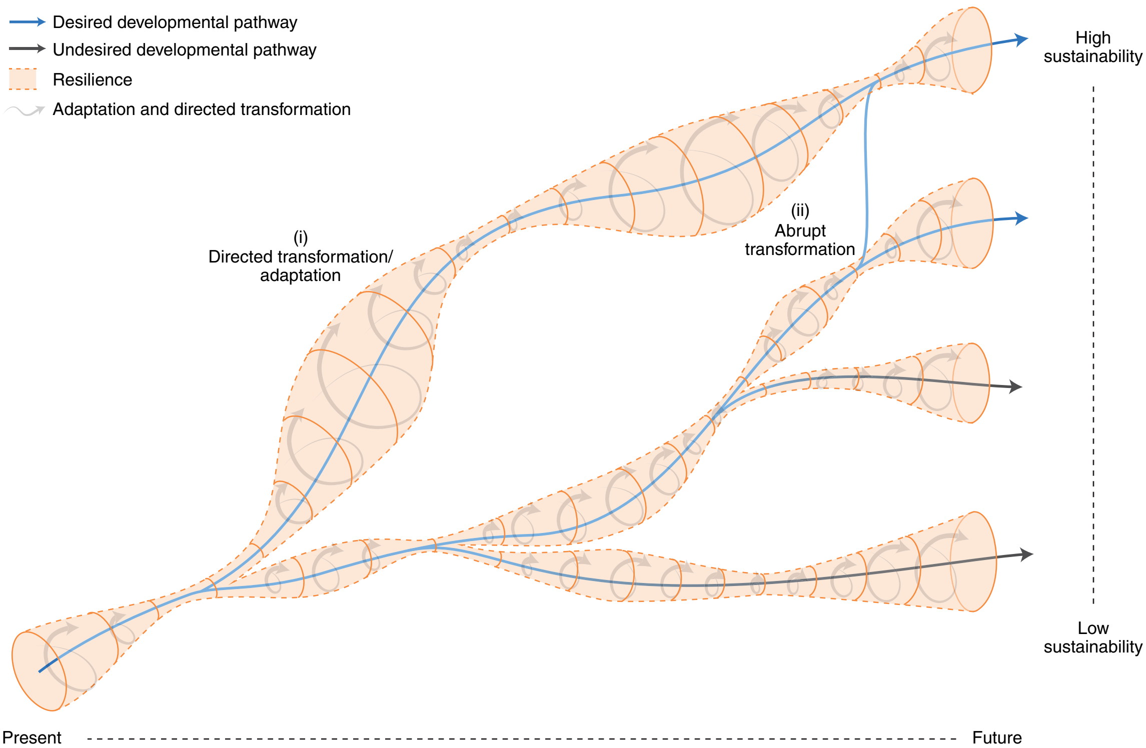

Fig. 2 | Interlinkages between sustainability, resilience and transformations. See text and Box 1 for further explanation.

narrowly defined issues (for example, population, energy and security)[53,54]. These attempts are misleading: urban systems are open systems and have multiple scales from household to neighbourhood and from city to region[55]. The current focus on a single scale may, for example, lead to efforts to build resilience in a particular neighbourhood, without considering effects on other neighbourhoods within a city, such as building flood walls to protect high value real estate in one neighbourhood of a coastal city that could increase flood risk in other unprotected vulnerable neighbourhoods. Similarly, such approaches may ignore that lower scales or subsystems sometimes need to be transformed to ensure more general, larger scale resilience beyond the city scale. Cross-scale dynamics challenge integration of resilience and sustainability further.

Similarly, efforts on devising and implementing transformative plans and policies in a city to achieve specific policy goals may not consider sustainability and resilience as interconnected but rather as separate urban planning aspirations. This may, for example, result in efforts to change urban design and urban form to encourage sustainable lifestyle choices such as organic food consumption, vegetarian diets and low carbon mobility without considering the impacts to other systems such as agriculture, mobility and energy resulting in sustainability at a local level and unsustainability at a global level captured by the concept of urban land teleconnections (for example, ref. [3]).

Further, strategies intended to make a city more resilient to increased variability in heat and heat extremes due to regional climate change must achieve this at neighbourhood and city scales, while also considering regional and even global system dynamics that may impact the efficacy of any specific strategy and for any particular neighbourhood. To become meaningful, urban resilience should address scale issues appropriately, which would include both larger and smaller scales than an individual city (for example, refs. [56,57]).

There are also different types of resilience, which is similarly often overlooked in general normative resilience goals. For example, resilience to climate change could mean social resilience or community resilience, or technological infrastructure resilience or ecological resilience if applied through a framing where social, ecological and technological sub-systems may differ in ways that challenge any kind of general system level resilience. For example, managing for improving ecological resilience might be more about promoting biodiversity and green space connectivity in urban planning, where social/community resilience may or may not require ecological resilience. Similarly, designing and planning for infrastructure resilience may target investments in ways that reinforce inequity and injustice, drive gentrification, displacing minority and low-income residents, disrupting social networks and cohesion critical for social or community resilience. Aligning not only scalar aspects of resilience but also multiple sub-systems of resilience is a remaining challenge and should not be overlooked[58].

A new framework

In Table 1 we offer definitions of the three concepts that we think address and clarify most of the confusion and misunderstanding so far on the distinction and complementarity between sustainability, resilience and transformation. As we live in the Anthropocene and in the urban century, we also offer a view on how the three concepts relate to each other in a way that could support policy and practice and also be suitable for addressing new and pressing challenges.

It has become clear that resilience needs to be understood within the constantly changing dynamics of complex adaptive systems[57]. Earlier writings have already pointed out that the nature of stable states changes over time[48]. Instead of having multiple stable states, we describe urban systems as having multiple possible development pathways or trajectories (blue lines in Fig. 2)[59,60]. Resilience is understood as the capacity to adhere to, or simply strengthen, a specific pathway (Table 1). In Fig. 2 this is visualized as a tunnel surrounding a trajectory, where the width represents the tolerance of the system to external disturbances, experimentation, mistakes and errors, that is, capacity to deal with uncertainties, continue to develop while maintaining functions and stay on the same trajectory.

Box 1 | Directed and abrupt transformation

The notion of 'directed transformations' ((i) in Fig. 2) represents proactive actions that are dependent on some degree of system resilience to buffer effects of external disturbances, experimentation, mistakes and errors, that is, capacity to deal with uncertainties. It could also be represented by urban challenges where strong path-dependencies and investments in infrastructure to fulfil one function have created a lock-in situation lasting decades to centuries. Transformations in such cases represent how inventions of new functions of existing infrastructure are made and implemented to meet new demands (compare with urban tinkering approaches[78]). Transformations typically involve changes in features like power relations, resource flows, meaning and values, roles and routines—and the interactions between them[79,80]. A key to achieving sustainability is that these transformations also involve a fundamental shift in human environmental interactions and feedbacks.

An example of directed transformation is how abandoned urban railway systems in many cities around the globe have transformed into highly popular and frequently visited linear parks (for example, the High Line in New York). Such transformations include not only changes in landscape but also changes in the use and function of abandoned infrastructures, creating new urban economies and new urban flows of people and services.

'Abrupt transformation' ((ii) in Fig. 2) is much more fundamental and involves maintaining a function (for example, transport and mobility) but shifting structures (for example, from a ground street-based transport system to a cable-car or air-based system). These more fundamental changes are often influenced by and could themselves influence drivers and connections at local, regional and global scales (Fig. 3). Social innovation is demonstrated to play an important role in abrupt transformations by showing alternative uses and configurations or reconfigurations of structures for maintaining a function or service in a system[49,77].

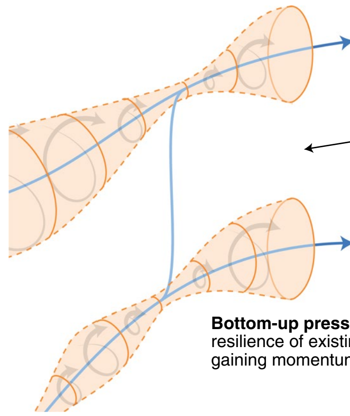

Fig. 3 | Important factors involved in abrupt changes with a system transformation from one trajectory to another.

The width of the tunnel can be managed, by applying resilience thinking and either (i) widened to make sure a system stays on a desirable trajectory and allow for necessary transformations (adaptation and directed/facilitated transformation) or (ii) narrowed to facilitate a fundamental abrupt transformation to a more desirable trajectory (Box 1 and detail in Fig. 3). Directed transformation is here viewed as proactive and distinguished from adaptation viewed as being a more reactive response. Directed transformation is further distinguished from abrupt transformation by scale and abrupt transformation representing a leap from one less sustainable trajectory to another more sustainable, possible when resilience is managed and reduced (Fig. 2, Box 1).

The capacity to adapt and transform are key concepts of resilience thinking[43,48], but so far rarely treated together with sustainability, even though these concepts together can help us understand capacities needed to release lock-ins and create and embark on new desirable trajectories towards a 'good' Anthropocene[61,62].

Governance challenges

Governance for sustainability will require active management of resilience by either reducing or strengthening resilience. We argue that such active management of resilience must be set in a multi-scale, complex systems framing to guide transformations and system development. Especially when the aim is to effect transformation at a specific scale or one aspect of the system (for example, transportation or food systems), resilience management needs to include a balance between building resilience around a transformation target while reducing the resilience of the (sub)system itself. We further propose that transformation actions/approaches for sustainability include frameworks and planning tools to identify and further reduce unwanted resilience and enhance desired resilience. For example, resilience must be reduced to allow for breaking free from lock-ins of undesired resilience such as urban poverty, while in other situations, strengthening (social) innovations to take hold of desired resilience. Urban experimentation approaches can be devised to co-create narratives, positive visions and solutions of urban sustainability and urban resilience to steer clear from these lock-ins and strengthen narratives around a good Anthropocene[62–67].

However, to make progress, the barriers that have so far hindered more comprehensive applications of resilience must be understood. Current governance systems do not match the functional scales of today's globalized cities. Limited administrative and jurisdictional scales and sectoral divisions together with the often relatively short-sighted political cycles and concerns may offer some explanation for the narrow, limited applications of resilience[68]. In terms of managing and actively building resilience, working within system boundaries (administrative boundaries, sectoral mandates and so on) offers more opportunities for directly transforming urban systems. The problem is that many of the large-scale functional connections linking cities to their regions and the Earth System have no directly responsible actor or governing body (for example, ref. [69]). Functional connections are often opaque and involving multiple relatively autonomous actors with limited resources for, and interest in, collaboration[2].

In addition, given that resilience and sustainability require contextual translations to inform better urban policy and planning, we propose knowledge co-production with multiple urban actors as a process to invite, facilitate and enable locally informed and globally related meanings of urban resilience and sustainability. Such a process could be particularly important for exploring where designed redundancy and diversity would make most sense, for example, opening up for flexible contracts for co-management of urban commons[70,71] and thus mobilizing different types of knowledge and promoting multiple alternative opportunities for learning about the system. Such intentional redundancies may provide the necessary enabling institutional context for transformation trajectories towards sustainable outcomes and help avoid lock-in and efficiency traps in urban development.

In this context, plurality and redundancy of institutional arrangements for managing different functions imply that planners should search for solutions to achieve sustainability through processes of co-creation in parallel to streamlined planning processes so that multiple solutions can be experimented with across the city. Inclusivity among multiple stakeholders is critical to avoid unwanted outcomes. In this way, planners and policymakers can create a more inclusive process to determine which potential pathways will offer the desirable sustainability and/or resilience outcomes[22].

At the same time, knowledge co-production amongst cities and city-networks may bring about new urban solutions applicable across scales and across geographies for urban resilience and urban sustainability. Examples of such global processes of co-production are already emerging from city networks such as 100 Resilient Cities, using urban experiments to bridge the implementation gap of resilience strategies and a common indicator framework for assessing urban resilience dimensions in the participating cities. Alternative sustainability pathways can be influenced by the evidence of sustainable solutions in other cities that contribute to setting these pathways in motion[72]. Alternative pathways can reinforce each other's resilience, erode it and initiate transformation and suggest directions for it.

Futures in the urban century

In recognition of a world where human influence is increasingly pervasive[7] and not least where cities are hybrids of social–ecological–technological system structures and processes[73], we need a system framing that explicitly acknowledges and builds on change and addresses deep uncertainty. The trajectories that we present in Fig. 2 are a first step towards a new conceptualization of sustainability, resilience and transformations that we suggest better supports the need for change and fundamental transformative solutions in the urban century.

Solutions—transformative or otherwise—are, however, not ready packages that can be implemented anywhere and be expected to work[5]. Instead, the framework we have presented points to the need for approaches and ways to continuously engage with problem solving and system reorganization. Further, by applying resilience thinking (and resilience principles sensu ref. [49]), sustainability may be considerably strengthened through interlinking and analysing numerous alternative sustainability initiatives at multiple scales, initiatives that otherwise would may have aimed for increased efficiency and optimization often within narrow sectors. Clearly, sustainability-oriented goals can help identify undesired resilience and suggest opportunities for structural transformations of the urban system.

To achieve all this, there are multiple challenging questions we need to address, where we still only have incomplete knowledge:

- Does urbanization result in diversification or simplification of the intertwined system of people and planet?
- Is the increasing connectivity of cities becoming a force on its own in governing human affairs and in shaping the biosphere?
- What is the role of connectivity in urban resilience, is over-connectivity causing new types of vulnerabilities?
- What is the role of cities in shifting global development towards more attractive trajectories, to become a stabilizing, resilience-building force of the Anthropocene?

Ultimately, urban sustainability, urban resilience and urban transformations are about the significant role of urban areas, urban development, urban decision-making and urban governance as pervasive human activity of the Anthropocene, in shaping our biosphere and Earth System dynamics[3,18,74].

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Competing interests

The authors declare no competing interests.

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