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Lessons from complexity science for urban health and wellbeing

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1 Background

Until the first half of the 20th century, life expectancy at birth for most countries of the world did not extend beyond 40 years. Since then, life expectancy at birth and average income per capita increased substantially and by 2000, average life expectancy for all countries in the world was above 40 years, with per capita income showing a similar trend (Gapminder.org).

Although urbanization is generally associated with growing levels of income and economic prosperity, public health improvements do, so far, not show any consistent, causal links to urbanization. In contrast, urbanization has been associated with reduction of malnutrition, while at the same time posing higher risks of obesity in children. Additional evidence shows that risk factors for chronic non-communicable diseases (NCDs) are more prevalent in cities than in rural areas, which suggests that urbanization as a development strategy should be accompanied by an informed and responsive health policy.

As the global human population has become predominantly urban, environmental and health risks of urban life are receiving more attention from policy makers, urban planners, scientists and the general public. The speed of urbanization presents challenges in developing and maintaining a thorough understanding of cities and their emergent urban health challenges. As a consequence, the World Health Organization (WHO) and United Nations Human Settlements Programme (UN-HABITAT, 2010: viii) stated that “The rapid increase of people living in cities will be among the most important global health issues of the 21st century.” Despite improvements in the availability of and access to health services in cities, widespread public health risks remain: infectious diseases (e.g. tuberculosis), water and air pollution, increased numbers of homeless, barriers to access medical services for ethnic minorities and the poor, terrorism, and inequality (McKinsey 2011).

1.1 Cities as complex systems

In order to understand the range of potential health impacts of urbanization we conceptualize cities as complex systems. As such, they are both origin and solution of multifaceted challenges for urban health and wellbeing. From a complexity perspective, it is useful to approach urban health and wellbeing issues from two angles:

1. How to make progress in understanding health and wellbeing by disentangling the complexities (multiple and dynamic cause-effect chains) which cause certain phenomena of urban health and wellbeing to emerge, and
2. How to increase our understanding of drivers of complexity in order to deliver those requirements for implementation.

These two questions also highlight the importance of the link between knowledge about health and knowledge about (how to change) behavior: *Knowledge* of what factors and which behaviors cause illness does not automatically translate into a *change of behavior*. The interactions between health and behavior themselves are complex. The rapid change of urban environments is a stress factor affecting human health. Adaptation-pressures to rapidly changing physical urban environments trigger stress responses aiming at maintaining balanced internal conditions and human wellbeing. This aspect is captured by the concept of allostatic load, i.e. "the wear and tear on the body" that accumulates as an individual is exposed to repeated or chronic stress, which can go beyond chronic stress and lead to a wide range of failures to cope with daily life (Institute of Medicine 2001). The changing ecological, physical and associated microbial environments in urban areas have an additional impact on the human immune-regulatory system, which is intertwined with physiological and psychological systems (Rook 2013). More generally, the intricate links between human and ecosystem health, as

conceptualized in the ‘Ecological Public Health’ concept (Rayner and Lang, 2012) represent complex interactions between humans and the urban biosphere, which require a systems approach to adequately represent feedbacks between public health and ecosystem services (Reis et al 2015).

Figure 1

Changing social urban environments on the other hand influence behavior “by shaping norms; enforcing patterns of social control (which can be health promoting or health damaging); providing or not providing environmental opportunities to engage in particular behaviors; and reducing or producing stress, for which engaging in specific behaviors might be an effective short-term coping strategy. Furthermore, environments place constraints on individual choice.” (Institute of Medicine 2001: 7, CSDH 2008). Health-behavior interactions point to the intersection of health and wellbeing and the need for jointly conceptualizing natural and social determinants of health, as for instance done in a framework (Fig 1) developed by the members of the “Urban Health and Wellbeing: a Systems Approach” global science program (Gatzweiler et al. 2016). This framework explains health outcomes as a complex function of improving people’s opportunity spaces – spaces constrained or opened up by societal rules and respective decision-making and governance, in which people can develop their capabilities and thrive to create healthy urban environments (Bowles 20016, von Braun and Gatzweiler 2015). Whether people are actually constrained or enabled depends on which degree urban systems governance takes the respective features of complex systems into account. Neglecting complexity by simple governance mechanisms such as the market or hierarchies only, leads to complexity reduction, which does not exclude a reduction of health promoting functions of complex urban systems (Box 1). As Scharpf (1994: 37) put it: “... *the advantages of hierarchical coordination are lost in a world that is characterized by increasingly dense, extended, and rapidly changing patterns of reciprocal interdependence, and by increasingly frequent, but ephemeral, interactions across all types of pre-established boundaries, intra- and interorganizational, intra- and intersectoral, intra- and international*”.

1.2 Approach

In order to make progress towards addressing the challenges of urban health and wellbeing it is therefore not sufficient to scientifically understand why and how they have been created. It is equally important to realise the respective requirements for the creation of healthy urban environments. This needs to translate into solutions and actionable processes, which change human behavior for the good of human, urban and planetary health.

Which actions need to be taken by whom in order to implement the requirements for healthy cities cannot solely be answered applying scientific methods; rather it requires a transdisciplinary and social process of awareness raising, engagement and decision-making. While many scientists are and continue to be very good at applying rigorous scientific methods, it remains a challenge to engage in transdisciplinarity (Lawrence and Gatzweiler 2017). The key requirements for healthy cities are well understood at the functional level. Healthy cities need functioning urban systems which provide a range of goods and services (Gatzweiler et al. 2016: 50-51) in particular clean water and working sanitation, clean air, healthy and uncontaminated soils, safe homes, secure neighborhoods, mobility, infrastructure of grey (e.g., transport) green (e.g., parks) and blue (e.g. lakes) spaces, and functioning health monitoring facilities as well as healthcare provision. How this functionality can be delivered, however, remains a challenge (Rydin and Chaytor 2012). Lessons from complexity theory of cities tell us that the challenges of urban health and wellbeing will persist unless both, scientific and

societal aspects, are perceived as inseparable and are addressed jointly (Batty and Marshall 2012, Batty 2009, Portugali 2006a).

Critical to the solution of an urban health problem is its perception, conception and contextualization. If urban health problems are not seen as emergent properties of complex urban system behavior then the solutions sought will tend to keep quantifiable costs low and not comprehensively address the interconnected variables which have co-produced the problem. Temporary, short-term and proximal remedial solutions (Morris et al 2017) may be found, for example by treating illness. Such approach, however, neglects sustainable and long-lasting (proactive) solutions, which typically require a change in system composition and behavior in order to address the root causal network of factors of adverse health outcomes more profoundly.

Urban systems which are perceived as producing unhealthy outcomes by the agents forming part of this system must, as a consequence of taking a complexity perspective, enable those agents to consider themselves as part of the problem and the solution. That does not only require a change in perspective, but also a cognitive leap (Portugali 2006a, b), to consciousness (Damasio 2009, 2010). In addition, this involves extending network interconnectivity, thereby improving systems functionality and systems intelligence to a higher cognitive level.

The implications of a change in perspective towards complexity are therefore far-reaching. They necessitate a paradigm shift in the importance attributed to disciplinary versus the transdisciplinary practice of science for urban health and wellbeing (Lawrence and Gatzweiler 2017). The systems approach requires not only science to produce knowledge, but to partake in a broader collective knowledge production process in society. This involves also, a change of how agency¹ and decision making are practiced in the city by all agents and stakeholders.

In the following sections, we will provide a short account of current urban health and wellbeing challenges (Section 2), interpret them from a complex systems perspective (Section 3), and formulate implications for science and society on how to achieve positive urban health outcomes in the face of complexity (Section 4).

2 Risks to urban health and wellbeing

Galea and Vlahov (2005: 1-2) define urban health as “...the health of urban populations, [...] and the determinants of population health in cities, with particular attention to how characteristics of cities themselves may affect the health of urban populations.” As such, urban health is very context specific. Urban health studies can have a focus on the urban environment as a major determinant of human health or peoples’ health is the focus and taken as an indicator for the health of the system. Both perspectives, the human-centered and the environmental, are included in the city as a system, which is a fuzzy construct.

Defining urban health as the health of the system’s agents (human-centered or agent based) and the health or functionality of the broader urban systems with all its intersectoral interdependencies (environmental), reflects a complex systems approach applied to urban health and wellbeing (Diez-Roux 2015).

The WHO definition of health from 1948 (WHO 1948) is “a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity.” Whereas the WHO definition primarily relates health to the human bio-physiological, mental and social state of

¹ Agency is a form of societal engagement and is about peoples’ ability to act on what they value and have reason to value. The concept of agency is in accordance to Amartya Sen’s capability approach and is about being free to act in pursuit of one’s values (Sen 1999, 1985).

wellbeing, or “being well”, the economic definition of wellbeing includes opportunities humans have to develop their capabilities (Sen 1999). To increase human capabilities and the opportunity spaces they have to develop their full potential is a characteristic of the definition of healthy cities proposed by Hancock (1988).

Major global changes are taking place which effect urban areas’ size, structure and functions and produce adverse urban health and wellbeing outcomes. Urban areas are estimated to contribute 70 percent to global greenhouse gas emissions (UN Habitat 2011). Climate change exacerbates heat island and extreme weather effects, like flooding (Ward et al 2016), increasing numbers and concentrations of people in cities affect their mental health, changes behaviors and life-styles, and creates the conditions for non-communicable but also infectious, incl. vector-borne diseases (Vlahov and Galea 2002). Furthermore, changing built and green urban environments change the living conditions and composition of urban and suburban fauna and flora, which does not only have recreational value but also impacts on human behavior (Hoisington et al. 2015; Logan, 2015).

Important challenges of urban health and wellbeing are mentioned, for example, in the WHO/UN Habitat global report on urban health (2016), the UN Habitat world cities report (2016) and report of many other governmental and non-governmental organizations² which look at some aspects of city life. Characteristic is that health risks in cities, although burdening the poor disproportionately higher, are also widespread among the higher income groups, due to unhealthy lifestyles and so-called non-communicable diseases.

Most prominent drivers of urban health risks include: 1. increasing population densities, 2. unequal access to resources and services and poverty, 3. unhealthy behavior and life-styles 4. environmental change and pollution, and 5. demographic change:

1. **Health risks associated to increasing populations.** By 2050, it is estimated that 70% of the world’s population will be urban dwellers. Rapid urbanization is presenting challenges to all countries but its pace and scale are greatest in low and middle-income countries, not only because of the rise of megacities (with populations over 10 million) but primarily due to the rapid development of mid-sized cities of 250-500k, the emergence of large interconnected city configurations and urban sprawl. 93% of the world’s population growth takes place in developing countries and all of the future growth is taking place in urban areas in Africa, Asia and Latin America – not as commonly perceived, as a result from rural-urban migration (UN HABTAT 2013).
2. **Inequality and health.** Health inequality is closely related to income inequality and there is a connection between income inequality and economic complexity. Countries which produce and export complex products have a lower level of inequality which could be due to the fact that a more diverse set of people benefit from producing them and that more complex products have a higher value than simpler products (Hartmann et al. 2016).

In all cities, health risks are considerably larger for lower than for higher income groups and even in a city like London, UK, or Baltimore, USA, the difference in life expectancy can be as high as 17 to 20 years (Baltimore City Health Department 2012, Cheshire 2012) for people living in different areas of the same city. An estimated 828 million people, roughly one third of the urban population, currently live in slum conditions around the world and suffer disproportionately from a wide range of diseases and health problems (WHO and UN HABITAT 2010). Those estimates have increased to “more that 880 million and projections say that 2 billion people will be expected to live in slum conditions by 2050 (UN HABITAT 2013).

² For example, UNICEF, UNFPA, UNAIDS, FAO, International Organization for Migration (IOM), Save the Children.

Health problems connected to poverty and poor housing, such as the lack of access to clean water and sanitation, to nutrition, education and employment. Poor housing conditions are also the cause for numerous risks to health and diseases such as schistosomiasis³ (Kloos et al. 2008, Baker et al. 2013).

3. **Health risks related to unhealthy life styles.** The epidemiologic shift towards non-communicable diseases (NCDs), primarily cardiovascular disease, diabetes, cancer, and pulmonary disease has made NCDs the number one cause of death globally, with a disproportionate impact in low and middle-income countries and their already fragile health care systems. Deaths from NCDs are projected to increase 77 percent between 1990 and 2020, growing from 28.1 million to 49.7 million deaths annually. The rise in NCDs is tied to globalization and urbanization as well as the aging of the population.
4. **Health risks from environmental change and pollution** (Lim et al. 2012). Pollutants in air (WHO 2016), water and soil (Shao et al. 2006). Changing microbial environment and the immune system (Rook 2013). Noise and light pollution (Regecova and Kelleroval 1995, Paunovic et al 2013, Hölker F. et al. 2010). Mental health risks like schizophrenia and loneliness in crowds (Kirkbride et al. 2007). Climate change and associated heat island effects (Peng et al 2012). The environmental impacts of urbanization -- increasing energy use and related greenhouse gas emissions, soil degradation, biodiversity loss, and severe water stress -- have also had tremendous health consequences: In 2012, approximately 7 million people died prematurely as a result of exposure to air pollution (WHO 2014) making air pollution the world's largest single environmental health risk.
5. **Ageing.** Populations have extended their life spans and as a result, the proportions of elderly are progressively increasing in almost all countries. Improved living conditions, health care, nutrition, living in safer environments have contributed to this to a large extent (Buffel et al. 2012). While the rapid rise in the world population aged 60 years or older is a public health achievement, it adds an additional challenge: In the next four decades, 21% of the population will be over 60, and the rate of age increase will be higher in developed countries. Creating urban environments that support active and healthy aging and health promoting conditions for all ages is critical in order to prevent pressures on the health and social service systems and to maintain a healthy workforce and active and engaged citizenship.

While urbanization has been associated to general improvements in urban health and wellbeing, at least 5 types of urban health risks have emerged. These risks need to be understood as emergent properties of complex socio-ecological-technological systems (SETS) in cities and responded to accordingly.

3 Response to urban health risks: A complex systems perspective

Jayasinghe (2015) defines urban health outcomes as emergent properties of complex urban systems⁴. Such emergent properties are defined by patterns of interactions in multiple sectors or domains of the urban system. These patterns are dissipative structures which emerge (and dissipate) with flows of energy and matter (Prigogine 1989). Not only urban health outcomes are emergent structures, the city as an urban structure is also an artificial emergent property and a dissipative structure. Dissipative structures, although maintaining a stable form, are only stable as long as matter and energy flow through them. A living dissipative system is, e.g., a cell or an organism, requires a steady flow of nutrition, water or air to maintain its order and stay alive. A dissipative system lives within one (or more) larger systems from which it draws energy and creates structural complexity (Prigogine 1967).

³ Also known as bilharzia, is a parasitic disease caused by blood flukes (trematodes) of the genus *Schistosoma*. It is transmitted by contact with contaminated fresh water.

⁴ Adverse urban health outcomes are however not outcomes of intentional and intelligent design, rather of failures thereof. Consequently, the patterns of interconnectivity from which they emerge, are not interconnected sufficiently or in ways to avoid them.

Defining urban health depends to a large extent on what a city is, which remains controversial (Portugali 2006a: 11) because a city is a fuzzy artefact. It constitutes an artificial-natural, self-organizing system of systems. The human agent and its social interactions makes cities complex. Cities are defined by what they are composed of and how those components interact with another and their environment. Those components or parts can be urban agents, like “individuals, households, firms, public and private planning agencies and the like.” (Portugali 2006a: 14). Urban systems are typically a mixture of social, ecological, technological systems. System boundaries are open, abstract and fuzzy and they are created in the process of understanding system interactions.

How can urban health be improved by better understanding cities as complex systems? Complex systems science has extended our horizons and deepened knowledge of cities and health. On the one side we know more about general underlying rules of systems which are complex, on the other side complex systems science has called for the diversification of methods and knowledge domains and transdisciplinary methods applied to the study of urban health.

Complex systems approaches are likely to yield new insights at the interface of human and environmental health (Peters 2014) and health problems which are connected to positive and negative feedback loops. Diez-Roux (2011: 1633) argues, for example, that the use of analytical methods in health disparities research that primarily focus on identifying independent effects are hampering progress and that systems approaches can stimulate innovation and help identify novel intervention points.

The transdisciplinary knowledge domain required (Lawrence and Gatzweiler 2017) for making cities healthier places is not only about which kind of science is carried out, but also how science itself is organized and governed. Loorbach (2010) recommends constructing a looped, co-operative connective knowledge governance tissue giving attention to learning, interaction, feedback, integration and experimentation so that all of the knowledge contained in society can be made better use of. According to Chapmann and Fullan (2010) such networked instead of hierarchical learning structure achieves a more equitable distribution of merit goods such as knowledge and education.

The systems approach to urban health and wellbeing (Bai et al. 2017, Gatzweiler et al. 2016) presents the implementation of the lessons from complexity science, applied to our knowledge of complex urban systems. It contains elements of self-reference, interconnectivity, self-organization, cognition and system intelligence. It is an approach for science and society to cope with system complexity and advance health and wellbeing of people and the functionality of complex urban systems themselves.

The approach merges natural and social science approaches to knowledge generation into one by adopting a transdisciplinary approach. It does so by recognizing the need to understand the patterns of interconnectedness and change by means of quantitative modeling on the basis of available data and by recognizing the need to include stakeholders in the modeling and urban planning process and thereby co-creating knowledge for urban health and wellbeing.

4. Key concepts and features applied to urban health and wellbeing

Table 1 summarizes the key concepts and features of complex systems applicable to urban health and wellbeing, which we will assess in the following sections with regard to the insights they can provide for development and implementation.

4.1 Self-organisation and dissipativeness of urban systems

The concept of self-organization was described by Ashby (1947), a British mathematician and a pioneer of cybernetics and modern complexity theory, Foerster and Zopf in “principles of self-organization (1962) in the domain of system theory, by Ilya Prigogine’s description of dissipative structures (Prigogine 1984) and by Herman Haken’s (1996) theory of synergetics. Self-organization occurs due to dissipation and cooperation between the many parts of the system. It can be observed in situations when external influences on a system do not cause its behavior, but instead trigger internal processes by which a system spontaneously (re)organizes (see also Kauffman 1993). Niklas Luhmann (1990, 1987) describes social systems as self-organizing when they produce their own components and internal structures.

According to Portugali (2010: 335) seeing cities as self-organized systems gives reason for two practical approaches to actions in the city. First, self-organization teaches us about the control parameters of cities and how they can be managed, controlled and planned, so as to produce intended outcomes. Second, seeing cities as self-organizing systems leads us to perceive also the control parameters themselves as self-organizing systems and therefore the city as a whole system, as uncontrollable. From that second view, cities are profoundly “unstable, chaotic, far-from-equilibrium, unpredictable, and (...) therefore we have to find ways to live with their complexity. From this perspective follows, for example, a new type of action in the city, a new type of city planning, the aim of which is not to control, but to participate” (Portugali 2000: 336).

4.2 Self-referentiality

Adverse urban health outcomes for human beings, e.g., diseases and pollution, can be seen as emergent properties of complex systems which have not been integrated into the interconnected, organized and functional social network structure of complex systems. Luhmann (1990, 1987) referred to this process as societal internalization. A process, which integrates a risk into social structure and enables the actors to make conscious decisions and act. It responds to the need of people to make sense, interpret, explain and foresee potential disasters resulting from risks. Such a process is described by Luhmann (ibid) as a tendency of social systems to create closed self-referential systems.

City systems are self-referential or self-creating (autopoietic) as they are able to (re)produce themselves by themselves, a general form of system-building using self-referential closure: The operations which produce the system (processes and structures) are inside the system and therefore they are operationally closed, despite being open systems and connected to their environment. In the absence of self-referentiality and self-organization, city systems become vulnerable to entry of predator systems that seek to dominate them and try to erase memory, imposing external order (Aquilué et al 2014).

4.3 Unplanability and uncontrollability

Given the characteristics of self-organization, cities are on one side, chaotic, unplanable and unpredictable and they self-organize. Urban planning thus faces a dilemma by aiming at planning the unplannable. Portugali (2000) defines four planning dilemmas, which argue for the minimization of public intervention by planning but basically have nothing to say about the practice of planning. The first is based on the insight that planning is a political, non-scientific process which cannot be entirely objective in the positivist tradition. The second dilemma is based on the (Marxist-structuralist) insight that urban change would need to come from (revolutionary) societal transformations, leaving no role for the planner to play in planning and designing the city. The third dilemma emerged out of post-modernism and its rejection of

“control and order” approaches. The dilemma was that when the postmodern-deconstructivist approach becomes the rule, it is no longer postmodern. The fourth dilemma of self-organization questions plannability of cities because of their unplannable and unpredictable features as self-organizing complex systems (Portugali *ibid*: 230).

4.4 Spontaneous order and the ‘Freedom vs Organization’ dilemma

Bertaud (2014) addresses dilemmas of “rules vs. chaos” or “planning vs. spontaneous order”. He recognizes, however, that engineered planning and spontaneous development both have a place in urban development. Too much planning can produce unwanted outcomes for health and wellbeing, when for example, because of regulations, consumption is imposed on consumers who cannot afford living and building according to the imposed regulations (e.g. minimum house size) and thus causing social exclusion and slums. Positive examples of spontaneous housing, are for example, when informal settlements are not forbidden and people are allowed to live according to their affordability, while connected to public service infrastructure (see also Rydin et al 2012). A fundamental dilemma of all dilemmas is the conflict between freedom and organization. The dilemma is that organization is necessary for freedom and, at the same time, constitutes a fundamental threat to freedom (Ostrom 1983). This dilemma cannot be solved, but it can be continuously dealt with, as we will show by examples. Ostrom (*ibid*: 12) argues that the tension must remain a necessary part of the human condition in “striving for something better”.

4.5 Interconnectivity and structure

Humans in cities interact with another and with their natural and built environments in networks. Helsley and Zenou (2013: 2) argue that “Cities exist because proximity facilitates interactions between economic agents.” Within those networks, people hold positions and interact in physical, social, institutional, political and other types of spaces and interact with other agents or non-human components of the systems and form a diversity of interaction patterns.

Systems are created when those interactions are repeated and structure emerges. Systems have a structure which is defined by the links and interactions. Examples of structures are city walls, roads, buildings or an institutional structure, defined by sets of rules which emerges from repeated interactions (Law and Bany-Ariffin 2008). Increasing interconnectivity in systems can improve their functionality, agent’s access to goods and services, data and resource metabolism, and mobility.

4.6 Cognition

The mechanism of structural adaptation or adjustment between systems has been defined as cognition. It is a process of constant matching of external environments with internal representations or mental maps of them (Wexler 2008), also referred to as structural coupling. Cognition is essential in achieving systems intelligence; or, it is the process which takes place when building systems intelligence. It is the process which takes place when reconfiguring system network connectivity to enable the system to behave (intelligently) in response to environmental change in order to survive. Cognitive processes are responses to disturbances from the environment in the form of changes of the system’s internal structure (Maturana and Varela 1928). A cognitive city improves its information processing capabilities in all sectors for building collective intelligence by means of, among others, cognitive and soft computing techniques which enable to capture human values and imprecise information when there is not only a lack of information for solving a problem but also for identifying the problem (Mostashari et al. 2011, Zadeh 1994).

4.7 Systems intelligence

Systems intelligence is used in two different contexts. One focuses on the individual, the other on the intelligence of a system (Hämäläinen and Saarinen 2010). Those two approaches to cope with and react to systems complexity result from the need to survive in complex environments. With the evolution of more complex forms of biological organization intelligent forms of life emerged. David Krakauer from the Santa Fe Institute of Complex Systems (2015), characterizes intelligent systems by three main elements:

1. Representation. The ability to represent the environment by the nervous system.
2. Inference. The ability to adapt, learn, memorize and use what has been learnt to predict.
3. Strategy. The use of inference and representation to anticipate and outcompete others.

With those defining elements, intelligence is present everywhere in living systems. The advantage of being intelligent as a more complex organism as compared to a singular cell organism, is that more complex organisms, like humans, can extract, store and process information about their environment and they can change strategies, properties or ideas in response to environmental change, whereas simpler living systems simply die if their traits do not fit to the environment they live in.

4.8 Emergence

From a complex systems perspective, health and wellbeing is an emergent property of a complex adaptive system – system features or patterns which appear from chains of interactions between many system components. The outcomes or patterns of health that emerge from city systems are dependent largely on the extent of intelligence of the city system and its inhabitants. Emergent health risks are the outcome of complexity, as well as of a failure in science and urban governance to adequately address the requisite variety by transdisciplinarity and collective, adaptive and resilient urban systems governance. Intelligence harnesses complexity by making emergent health outcomes more preventable and plannable. The concept of smart cities is a related aspect of intelligence and emphasizes predominantly information and communications technology (ICT), but does not exclude people.

Based on inputs provided by the International Council for Science's (ICSU) Urban Health and Wellbeing programme, the UN report (2014) states that "Smart health-care management converts health-related data into clinical and business insights, which include digital health records, home health services and remote diagnoses, treatment and patient monitoring systems. It also facilitates the provision of health care using intelligent and networked technologies that help monitor the health conditions of citizens. It is enabling a shift in focus to prevention instead of cures, with a broader view of overall care, healthy living and wellness management."

Although technology plays an essential role in creating an enabling inclusive environment for cities to be smart, technology in itself is usually only a means to achieve a higher end, such as the health and wellbeing of urban populations. Smart people and other smart domains of cities (including, for instance, Internet of Things, IoT applications) can therefore be seen as elements of creating overall urban systems intelligence. Intelligent cities are more than just smart. They are cities in which interconnectivity increases in smart ways; where monitoring and feedback mechanisms of technology and society enable early warning and, as a consequence, constant structural adjustments between the city people have and the city people want and need. This includes adaptations to climate change and demographic and epidemiological changes.

5 Key features needed to develop intelligent cities for urban health and wellbeing

The lessons we can draw from complexity science for improving urban health and wellbeing are derived from key features of complex systems which are themselves interrelated and complex (Box 1). Learning from that understanding for the purpose of urban systems health and wellbeing requires a complex adaptive, collaborative system for knowledge and action itself (Munoz-Erickson 2012).

Box 1

According to Ashby's (1960) law of requisite variety, such a system for governing knowledge and action would need to have as much variety in the actions it can take as exists in the system it is regulating. Other features of complex systems, especially self-organisation and self-referentiality would require systems governance for urban health and wellbeing to emerge from the city itself and not from outside, which is only possible if citizens are involved.

There are also lessons to be learnt by science itself. The science required for learning from complexity needs to be able to transcend, connect and communicate between knowledge domains and lead to informed action for urban health and wellbeing. The concepts and features of complex systems apply to the science of urban health and wellbeing themselves. This has consequences on how the scientific process is organized and which methodologies and conceptual frameworks are applied. The subsequent learning process needs to be governed accordingly and feed back into science itself. Understanding from a scientific neutral or objective stance is insufficient and post-normal science approaches need to be considered.

Despite overall improvements in the health status of people in the world, urban and planetary health is increasingly at risk. That risk can be perceived as emerging from a discrepancy between the increasing complexity of the urban systems and that of the systems designed to govern urban complexity. Urban governance needs to respond to urban complexity based on the principle of requisite variety.

Urban areas which are not enabling to improve people's quality of life need to change their network structures of interconnectivity to not only connect but also provide access and build up people's capacities. From a systems perspective interconnectivity of urban areas needs to increase the opportunity spaces in which health and wellbeing can be improved. This is however conditional on infrastructure development in all sectors.

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Table 1: Concepts and features of complex systems applicable to urban health and wellbeing.

Concepts and features	References
Self-organization and dissipative systems	Portugali 2000, 2010, Cornell et al. 2013, Liu 2008, Anderson e al. 2013, Popa et al. 2015 Lawrence and Gatzweiler 2017
Self-referentiality	Luhmann 1990, 1987, Gregory 1981, Morin 1992
Unplanability and uncontrolability	Portugai 2000
Spontaneous order and the “Freedom vs. organization” dilemma	Bertaud 2014, Rydin et al. 2012, Ostrom 1983
Interconnectivity and structure	Helsley and Zenou 2013, Law and Bany-Ariffin 2008
Emergence	Holland 1998, Jayasinghe 2015, Diez Roux 2015, 2011
Law of requisite variety	Ashby 1960, Gershenson 2007
Cognition	Rizzello 1999, Wexler 2008, Maturana and Varela 1928, Haapala 1998, Damasio 2010, Gatzweiler 2002, UN Habitat 2015, Violich 1995, Zadeh 1994, Mostashari 2011
Systems intelligence	Hämäläinen and Saarinen 2010, Saarinen and Hämäläinen 2004, Malone 2008

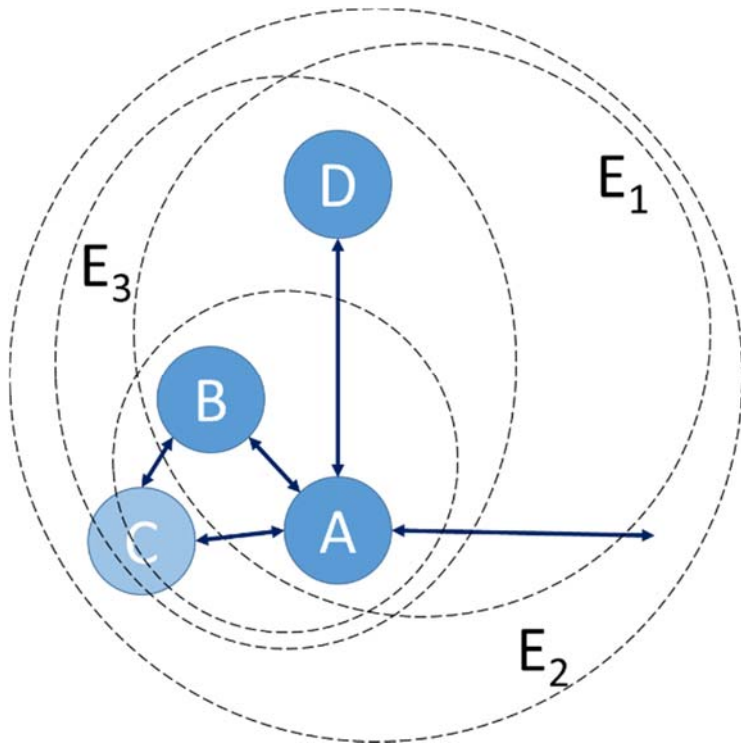


Figure 1

Agents interact with another in the urban system, where they can have different positions (A, B, C) in multiple urban environments or subsystems (E_1 , E_2 , E_3). Those environments can be enabling or constraining. Being better connected and positioned enhances capabilities.

Box 1 Features of complex systems and lessons for urban health and wellbeing

Box 1 Features of complex systems and lessons for urban health and wellbeing

1. Recognizing self-organization, the challenges of urban health and wellbeing should be approached by 1) addressing the control parameters of systems from which the problem emerges. This can be delivered by improved, integrated planning, and 2) as the control parameters themselves are complex systems, they are inherently uncontrollable and therefore require participatory and transdisciplinary governance approaches.
2. As a consequence of self-referentiality, urban systems and urban identity is created by people for people within the urban system. As part of urban systems, people (re)create the environments and identities of cities in which they live and work. Urban social systems produce themselves and their urban environments. Lack of self-referentiality in urban systems, by external domination can lead to high public costs for maintenance, loss of identity and alienation.
3. Urban planning for health and wellbeing needs to be a process integrating scientific, political and socio-cultural aspects. Cities are on the one hand, chaotic, unplannable and unpredictable and they self-organize themselves independently of scientific predictions and planning rules. Urban planning, on the other hand, faces a dilemma by aiming at planning the unplannable.
4. Spontaneous order and engineered planning are both essential building blocks to address the plannable and unplannable aspects of complex systems from which urban health challenges emerge. Positive examples of spontaneous housing, are for example, when informal settlements are not prohibited and people are allowed to live according to their financial means, while connected to public service infrastructure for water, sanitation, security, energy and waste management.
5. Agents inside a system can improve their health and wellbeing if the network structure of interconnectivity enables access to data and resource flows, as well as mobility which can be used for the benefit of the system's agents.
6. As urban health challenges are emergent properties of multiple cause-effect chains in coupled systems across urban sectors, the variety of problem-solving structures needs to resemble the variety of the problem.
7. Cognition is a structural adjustment process taking place when people perceive and create the city in response to information, signals or stimuli in their environment. In that process adaptability and identity is created. A cognitive city builds itself based on the knowledge and experiences of its citizens. As data which capture human values are essential for building cognitive cities, among others, soft computing can be applied.
8. Urban systems can become more intelligent by being adaptive to their environments. Integrated monitoring and feedback mechanisms, technology and societal interactions enable constant structural adjustments between the city people have and the city people want and need. This includes, for instance, adaptations to climate change, demographic and epidemiological pressures.

Table 1: Concepts and features of complex systems applicable to urban health and wellbeing.

Concepts and features	Insights for urban health and wellbeing (UHWB)	References
Self-organization and dissipative systems ¹	UHWB problems are approached by 1) addressing the control parameters of systems from which the problem emerges. This can be done by planning. 2) as the control parameters themselves are complex systems, they are uncontrollable. Consequently city planning needs to be participatory and transdisciplinary.	Portugali 2000 Portugali 2010 Cornell et al. 2013 Liu 2008 Anderson e al. 2013 Popa et al. 2015 Lawrence and Gatzweiler 2017
Self-referentiality ²	Urban identity is created in a recursive self-referential process: people create the identities of cities with which they can identify themselves. Society shapes individuals who create society in a continuous dialectic.	Luhmann 1990, 1987 Gregory 1981, Morin 1992
Unplanability and uncontrollability ³	Urban planning for health and wellbeing is a scientific as well as political and socio-cultural process. Cities are on one side, chaotic, unplanable and unpredictable and they self-organize themselves independently of scientific predictions and planning rules. Urban planning thus faces a dilemma by aiming at planning the unplanable.	Portugali 2000
Spontaneous order ⁴ and the “Freedom vs. organization” dilemma	Spontaneous development (freedom) and engineered planning (organization) are both needed to address the plannable and unplannable aspects of complex systems from which UHWB problems emerge. Positive examples of spontaneous housing, are for example, when informal settlements are not forbidden and people are allowed to live according to their affordability, while connected to public service infrastructure for water, sanitation, security, energy and waste management.	Bertaud 2014, Rydin et al. 2012 Ostrom 1983
Interconnectivity and structure ⁵	Agents inside a system can improve their health and wellbeing if the network structure of interconnectivity enables access, data and resource flows and mobility which can be made use of for the benefit of the systems agents.	Helsley and Zenou 2013, Law and Bany-Ariffin 2008
Emergence ⁶	UHWB problems are emergent properties of multiple cause-effect chains in coupled systems across urban sectors.	Holland 1998, Jayasinghe 2015, Diez Roux 2015, 2011
Law of requisite variety ⁷	The problem-solving structure needs to resemble the structure of the problem regarding its participants and the variety of actions which need to be taken.	Ashby 1960 Gershenson 2007
Cognition ⁸	Cognition is a structural adjustment process taking place when people perceive and create the city in response to information, signals or stimuli. In that process identity is created. The identity of the city is linked to the identity of those who have created it. A lessons for what to avoid in creating cities is the loss of urban identity by destruction of cultural heritage, public space and biological and cultural diversity.	Rizzello 1999, Wexler 2008, Maturana and Varela 1928, Haapala 1998, Damasio 2010, Gatzweiler 2002, UN Habitat 2015, Violich 1995
Systems intelligence ⁹	Urban systems can become more intelligent by collectively applying the systems approach. Interconnectivity increases, monitoring and feedback mechanisms by technology and society enable constant structural adjustments between the city people have and the city people want and need. This includes adaptations	Hämäläinen and Saarinen 2010, Saarinen and Hämäläinen 2004, Malone 2008

	to climate change, demographic and epidemiological changes.	
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Notes:

¹ One of the first to describe the concept of self-organization was Ashby, a British neuroscientist, psychiatrist and mathematician and a pioneer of cybernetics and modern complexity theory, as well as Foerster and Zopf in "principles of self-organization (1962) in the domain of system theory. In the domain of urban studies Ilya Prigogine's dissipative structures need to be mentioned (Prigogine 1984). Complexity theories of cities and theories of self-organization can therefore hardly be separated. Self-organization can be observed in certain situations when external influences on a system did not cause its behavior, but instead triggered internal processes by which a system spontaneously organized itself. Complex, self-organizing systems have three characteristic features (Portugali 2000):

1. They are open systems, i.e. they are part of their environment and derive and exchange energy, matter and information from and to their environment.
2. The flow of energy, matter and information through their boundaries creates new structures and new modes of behavior.
3. Their parts are so numerous that "there is no technical way to establish causal relations among them [and they are] interconnected in a nonlinear fashion by a complex network of feedback loops.

Self-organization can be regarded as a theory about chaos and order - of the way chaotic systems organize themselves and attain order. The theory of dissipative structures suggests that this self-organization is due to dissipation and the theory of synergetics (Haken 1996) suggests that this is due to cooperation between the many parts of the system. Both processes are at play. A central idea of self-organization is that external forces do not determine or cause a system's behavior, but instead trigger an internal, independent process by which the system spontaneously organizes itself.

From a social science perspective, Niklas Luhmann (1990, 1987) describes social systems as complex organic systems capable of self-production (producing their own basic components), self-organization (creating their own boundaries and internal structures) and self-referencing.

Cities perceived as complex, self-organized systems are images, cognitive maps or models which we use to understand, investigate and change cities for, e.g. improving health and wellbeing. According to Portugali (2010: 335) seeing cities as complex, self-organized systems gives reason for two practical approaches to actions in the city. First, as a conceptual and mathematical theory, self-organization teaches us about the control parameters of cities, how they can be managed, controlled and planned, so as to produce intended outcomes. This can be referred to this as the natural science approach to knowledge generation.

Second, seeing cities as self-organizing systems leads us to perceive also the control parameters themselves as self-organizing systems and therefore the city as a whole system, as uncontrollable. From that second view, cities are profoundly "unstable, chaotic, far-from-equilibrium, unpredictable, and (...) therefore we have to find ways to live with their complexity. From this perspective follows, for example, a new type of action in the city, a new type of city planning, the aim of which is not to control, but to participate" (Portugali 2000: 336). In the following we will refer to this as the social science approach to knowledge generation.

² Adverse urban health outcomes for human beings, e.g., diseases pollution, can be seen as emergent properties of complex systems which have not been integrated into the interconnected, organized and functional social network structure of complex systems. Luhmann (1990, 1987) referred to this process as societal internalization or integration of risks. A process which integrates a risk into social action situations and enables the actors to make conscious decisions. It responds to the need of people to make sense, interpret, explain and foresee potential disasters resulting from risks. Such a process is described by Luhmann (ibid) as a tendency of social systems to create closed self-referential systems. Systems are self-referential in the sense that their elements, do not primarily deal directly with their environments, but rather with representations of their environment. The type of interactions in complex systems are recursive and self-referential in feedback loops.

³ Given the characteristics of self-organization, cities are on one side, chaotic, unplanable and unpredictable and they self-organize themselves independently of scientific predictions and planning rules. Urban planning thus faces a dilemma by aiming at planning the unplanable. Portugali (2000) defines four planning dilemmas, which argue for the minimization of public intervention by planning but basically have nothing to say about the practice of planning. The first was the insight that planning is a political, non-scientific process which can not be entirely objective in the positivist tradition. The second dilemma was based on the (Marxist-structuralist) insight that urban change would need to come from (revolutionary) societal transformations, leaving no role for the planner to play in planning and designing the city. The third dilemma emerged out of post-modernism and its rejection

of “control and order” approaches. The dilemma was that when the postmodern-deconstructivist approach becomes the rule, it is no longer postmodern. The fourth dilemma of self-organization questions planability of cities because of their unplannable and unpredictable features as self-organizing complex systems (Portugali *ibid*: 230).

⁴ Bertaud (2014) addresses similar dilemmas of “rules vs. chaos” or “planning vs. spontaneous order”. He recognizes, however, that engineered planning and spontaneous development both have a place in urban development. He shows that too much planning can produce unwanted outcomes for health and wellbeing, when for example, because of regulations, consumption is imposed on consumers who cannot afford living and building according to the imposed regulations (e.g. minimum house size) and thus causing social exclusion and slums or wasteful use of urban space for housing. Positive examples of spontaneous housing, are for example, when informal settlements are not forbidden and people are allowed to live according to their affordability, while connected to public service infrastructure for water, sanitation, security, energy and waste management. The health and wellbeing of people living in informal urban settlements is then defined by their capabilities, which are not restricted by rules such as minimum consumption standards in housing markets and enhanced by providing access to public infrastructure such as electricity grids, water supply and garbage collection (see also Rydin et al 2012). An underlining fundamental dilemma of all those dilemmas is the conflict between freedom and organization. The dilemma is that organization is necessary for freedom and, at the same time, constitutes a fundamental threat to freedom (Ostrom 1983). This dilemma cannot be solved but it can be continuously dealt with as we will show by examples. Ostrom (*ibid*: 12) argues that the tension must remain a necessary part of the human condition in “striving for something better”.

⁵ Humans in cities interact with another and with their natural and built/technological environments in networks – interconnected webs of interaction. Helsley and Zenou (2013: 2) argue that “Cities exist because proximity facilitates interactions between economic agents.” Within those networks, people hold positions and interact in physical, social, institutional, political and other types of spaces and interact with other agents or non-human components of the systems and form a diversity of interaction patterns. As this is also valid for rural environments, the distance between human agents within those networks, as well as the frequency of interaction, is shorter and higher as compared to systems which are not or less urban.

Systems are created when those interactions are repeated and structure emerges. Structure emerges from interconnections. Systems have a structure which is defined by the links and interactions of its human and non-human components. A physical structure, e.g. a city wall, roads, buildings or an institutional structure, defined by sets of interrelated rules, are examples of structures. Social structure emerges from repeated interactions and is reflected, for example, in the institutional infrastructure of societies (Law and Bany-Ariffin 2008). Increasing interconnectivity in systems can improve their functionality, agent’s access to goods and services, data and resource metabolism, and mobility.

⁶ Formation or appearance of structure or a characteristic feature of a system resulting from system interactions which are unplanned, unintended or spontaneous.

⁷ Ashby’s law (1960) states that any regulative system needs as much variety in the actions that it can take as exists in the system it is regulating. An implication for action, in particular for social organization, and participation resulting from Ashby’s law is that “a complex (variable) brain is required to cope with a complex (variable) environment” (Gershenson 2007: 20).

⁸ The mechanism of structural adaptation or adjustment between systems has been defined as cognition. It is a process of constant matching of external environments with internal representations or mental maps of them (Wexler 2008), also referred to as structural coupling. Cognition is essential in achieving systems intelligence; or, it is the process which takes place when building systems intelligence. It is the process which takes place when reconfiguring system network connectivity to enable the system to behave (intelligently) in response to environmental change in order to survive.

Maturana and Varela (1928) defined cognition as the activity involved in the self-generation of systems. Just like intelligence, cognition does not necessarily require a brain or a nervous system. Cognitive processes are responses to disturbances from the environment in the form of changes of the system’s internal structure (network pattern of connectivity and interaction). Not every process of physical change in an organism infers an act of cognition. An injury to an organ by external force, for example, is not an act of cognition, whereas the process of healing (structural change) in response to the injury is. Consciousness, in contrast to cognition, is manifest only in higher (more complex) organisms and humans and enables them to be aware of themselves being aware instead of merely being aware of themselves (Damasio 2010, Gatzweiler 2002: 34).

⁹ Systems intelligence is used in two different contexts. One focuses on the individual, the other on the intelligence of a system (Hämäläinen and Saarinen 2010). Those two approaches to cope with and react to systems complexity result from the need to survive in complex environments. With the evolution of more

complex forms of biological organization intelligent forms of life emerged. David Krakauer from the Santa Fe Institute of Complex Systems (2015), characterizes intelligent systems by three main elements:

- 1) Representation. The ability to represent the environment by the nervous system.
- 2) Inference. The ability to adapt, learn, memorize and use what has been learnt to predict.
- 3) Strategy. The use of inference and representation to anticipate and outcompete others.

With those three defining elements, intelligence is present everywhere in living systems, just at different scales and different degrees of complexity and functionality. The advantage of being intelligent as a more complex organism as compared to a singular cell organism, is that more complex organisms, like humans, can extract, store and process information about their environment and they can change strategies, properties or ideas in response to environmental change, whereas simpler living systems simply die if their traits do not fit to the environment they live in.

Systems intelligence eventually, is characterized not only by the elements which define intelligence for survival, but also by the capacity of understanding and creatively engaging with complexity. The definition of systems intelligence we refer to here is from Saarinen and Hämäläinen (2004: 3): "intelligent behaviour in the context of complex systems involving interaction and feedback. A subject acting with Systems Intelligence engages successfully and productively with the holistic feedback mechanisms of her environment. She perceives herself as part of the whole, the influence of the whole upon herself as well as her own influence upon the whole. By observing her own interdependence in the feedback intensive environment, she is able to act intelligently."

To achieve systems intelligence requires education and awareness building about the systems people are connected to and interact with, and also about the behavior of those systems. An additional challenge for society for avoiding adverse urban health outcomes is to upscale systems intelligence to collective intelligence. Collective intelligence is successful group effort to respond (e.g.) to environmental change and survive. Thomas Malone (2008: 1) defines collective intelligence as "groups of individuals doing things collectively that seem intelligent." The information processing and rule building for collective intelligence does not only happen in an individual brain. It is a coordinated effort of many to achieve better (health) outcomes together than alone. Building collective intelligence is therefore also a process of institution building. Individual knowledge (about urban systems) and behavior (about urban health) are transformed into sets of rules, routines and socio-cultural values (Brondizio and Gatzweiler 2010) which define the behavior of a group or society. Although Gowdy and Krall (2013) argue that the evolution of an ultrasociety since the advent of agriculture and the beginnings of the Anthropocene is threatening the stability of the earth's life support systems, there is not much evidence of intelligence having shifted from individual to societal levels. The possibility remains that in the course of evolution collective intelligence will further improve and lead to sustainable development of mankind.