UNDERSTANDING CITIES AS SOCIAL-ECOLOGICAL SYSTEMS

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Summary

This paper builds on earlier ecological approaches to urban development, as well as more recent thinking in the fields of sustainability science, resilience thinking and complexity theory, to propose a conceptual framework for understanding cities as social-ecological systems (SESs) as a point of departure for further dialogue in the study of urban sustainability. It proposes that cities should be understood as (1) complex, adaptive systems that are (2) integrated across spheres of matter, life and human social and cultural phenomena (or mind), (3) are structured as nested systems that allows interaction across scales and levels of organisation, and (4) that what differentiates cities (and SESs) from other types of ecosystems is the introduction of abstract thought and symbolic construction that allows for considered novelty, communication of ideas across time and space, and therefore learning, and reflexive thinking.

1. Introduction

As we are improving our understanding of the intricate relationship between human well-being and ecosystem integrity, it is becoming clear that the great global challenge of urban development in the 21st century lies in finding ways in which city planning and management address not only the needs of urban dwellers in large, rapidly growing and mainly poor cities, but address these needs in a way that acknowledge the interdependent relationship of cities and the ecosystems of which they are part. There is growing consensus that a reductionist command and control approach is perhaps not the most appropriate way of interacting with what is in essence a dynamic complex adaptive living system; and that resilience and adaptation are factors of urban sustainability as important as (if not more than) conservation, efficiency and equity. This necessitates a quite dramatic mind shift in how cities are viewed. The notion of cities as ecosystems can be traced back at least to the 1960's and the thinking of Howard Odum and Ian McHarg. More recent thinking attempts to describe the interface space between humans and nature (of which cities are one example) as social-ecological systems. However, while there is general consensus that social-ecological systems refers to the human-nature relationship, exactly how this relationship is to be comprehended and structured as an integrated system is not clear. This paper builds on earlier ecological approaches, as well as more recent thinking in the fields of sustainability science, resilience thinking and complexity theory, to propose a conceptual framework for understanding cities as social-ecological systems as a point of departure for further dialogue in the study of urban sustainability.

2. An Ecological Approach to Cities

Applying ecological thinking to cities is not a new idea and has led to several different approaches, some from the perspective of the science of ecology (such as urban ecology), some using ecological concepts as metaphors or guidelines for human activities (e.g. urban metabolism, ecological footprinting and carrying capacity), and some using nature itself as the metaphor to guide the physical development of cities (e.g. ecological design and engineering, biomimicry).

There are, however, major differences between what Tansey (2006) refers to as old ecological thinking and new ecological thinking. Within old ecological thinking, ecosystems are described as though they follow a linear evolutionary process towards a steady-state climax community; and as closed, localised systems with circular metabolisms that self-regulate into an equilibrium state which results in no waste and maximum resource efficiency (Alberti *et al..*, 2003; Tansey, 2006). New ecological thinking, in turn, shifts from an equilibrium to a non-equilibrium model that sees ecosystems as open, dynamic and highly unpredictable, driven by processes and often regulated by external forces, not necessarily internal mechanisms (Alberti *et al..*, 2003). Some of the foundational concepts of new ecological thinking include complexity, resilience, non-linear system dynamics, adaptive management, and emergence. This expands the ecological metaphor to acknowledge not just the flows of matter, energy and information within the system (the 'economy of nature'), but also the importance of context and relationship, as well as the fundamental role of change and adaptability in an essentially unknowable and unpredictable larger system. New ecological thinking also includes humans as components of ecosystems (McDonnel and Pickett, 1993; Alberti *et a.l*, 2003).

Urban ecology initially concerned itself with ecological studies in urban environments, seeing the city as a particular form of landscape (Weddle, 1986). Cicero (1989) identified four types of such studies: 1) comparing different land-use types within an urban setting; 2) comparing an urban area with a nearby 'natural' area; 3) gradient analysis that assess the ecological effect of urbanization along a gradient such as from inner city to periphery; and 4) urban succession or development dynamics of ecosystems where urbanization is seen as a 'disturbance' similar to fire or flood. However, recent thinkers (e.g. Rees, 1997; Grimm *et al.*, 2000; McIntyre *et al.*, 2000; Alberti *et al.*, 2003) have argued for a new theoretical framework that would include humans into ecosystem studies, and especially the study of human-dominated ecosystems such as cities, and have themselves proposed such frameworks.

A number of these frameworks are based on the concept of resource flows, as explained by Grimm *et al.* (2000:574): "The concept of ecology of cities has to do with how their aggregated parts sum, that is, how cities process energy or matter relative to their surroundings." Amongst the routes proposed that could be used to understand the ecology of cities are: material and energy flow accounting (e.g. Odum, 1967 & 2002; Odum, 1997; Haberl *et al.*, 2004), whole-system metabolism (Girardet, 1996) and the estimation of the ecological footprint of the city (Rees and Wackernagel, 1994; Rees, 1997). These routes take existing ecological methodologies and apply them to the dynamics of resource use in cities.

A second approach to applying ecological thinking to cities is through ecological design and engineering. The argument is that if cities are seen as another of nature's biological systems then they should follow the 'rules of nature'. These rules have been defined as the four laws of ecology by Barry Commoner: "Everything is connected to everything else; everything has to go somewhere; there is no such thing as a free lunch; and Nature knows best" (cited in Ross, 1991:194). Karl-Henrik Robèrt's *Natural Step* (Robert, 1995) describes these rules as four system conditions: we should not take more from the Earth's crust than is slowly redeposited; nature cannot sustain a systematic increase of chemical compounds - we cannot emit more waste products than nature can process; the physical basis for the earth's productive natural cycles and biological diversity must not be systematically deteriorated; and there must be fair use of resources in order to meet human needs on Earth. Frijtof Capra (1996) and Janine Benyus (2002) also identified additional rule sets that make similar statements.

The logical progression from this was that the infrastructure of cities (as ecosystems) should be designed to follow these laws. This approach was introduced into modern 'sustainability' thinking by theorists such as Howard Odum (1967), Ian McHarg(1969), who built on the thinking of Frederick Law Olmsted, Ebenezer Howard and Patrick Geddes to suggest city planning, management and design that learn from and co-operate with nature. From this starting point a number of contemporary scholars and practitioners (e.g. Todd and Todd, 1993; Lyle, 1994; Girardet, 1996; Van Der Ryn and Cowan, 1996; McDonough and Braungart, 2002; Eisenberg and Reed, 2003) developed the basis of what is now referred to as ecological design. Kibert (2006) describes three versions of ecological design: strong ecological design based on principles of biomimicry and cradle-to-cradle design; weak ecological design based on minimizing lifecycle impacts; and intermediate ecological design based on the synergistic integration of built environment systems with ecosystems.

However, the metaphors of ecology cannot be applied to the city without taking into account the human component. Arida, (2002:xix) recounts that Saint Isidore of Seville (c. AD 560-636) traced in his Etymologies the origins of the word city to different sources: "the *urbs* (or stones) of the city, laid for practical reasons, and *civitas*, the emotions, rituals and convictions that take form in a city". Saint Isidore would point out that the approaches described above focus on the *urbs* – on the physical aspect of human activities within an "ecosystem created by humans specifically for dwelling" (as cities are described by Stearns and Montag, 1974). Yet, apart from regulatory suggestions, the *civitas* is not addressed. While attempts have been made by ecologists and sociologists to understand how the social aspect of humans can be included in the study of city as ecosystem, Alberti *et al.* (2003) pointed out that neither of these sciences can explain how integrated human and ecological systems emerge and evolve, because human and ecological factors work simultaneously at different levels. Calls for a "new integrative ecology that explicitly incorporates human decisions, culture, institutions and economic systems" (Grimm *et al.*, 2000:575) has led to a new field of research that focus specifically on coupled human-nature systems, now referred to as social-ecological systems, which will be explored in the next section.

3. Understanding Social-Ecological Systems

Cities are arguably the most closely coupled human-nature system and therefore presents a particular challenge to research on social-ecological systems. The exact nature of social-ecological systems (SESs), or what it is that differentiate SESs from other types of ecological systems, is still open to debate. The Resilience Alliance (2006) describes SESs as "complex, integrated systems in which humans are part of nature." However, while there are numerous methodologies and conceptual frameworks for studying aspects of social-ecological systems, the understanding of how the social and ecological components are to be integrated into one system is still evolving. Grimm *et al.* (2000) suggested a modelling framework that would include variables in social patterns and processes and human perceptions as drivers of change together with ecological drivers. Alberti *et al.* (2003) proposed a similar conceptual model that links human and biophysical drivers, patterns, processes and effects. However, both these models are limited to a view of humans as another species of mammal with no attempt to address those aspects that differentiate social-ecological systems from other types of ecological systems. Haberl *et al.* (2004) moves some way towards addressing this gap by suggesting that social-ecological systems should be seen as a 'biophysical' sphere of causation governed by natural laws, and a 'cultural' or 'symbolic' sphere of causation reproduced by symbolic communication.

An analysis of papers published over the past ten years in the main journal of social-ecological system research, Ecology and Society, suggested the following four propositions as a point of departure for formulating a conceptual framework for understanding the nature of SESs:

- *Proposition 1*: A social-ecological system is one integrated system that spans across matter, life and human social and cultural phenomena (or mind).
- *Proposition 2*: A social-ecological system consists of relationships between elements at a number of scales and within nested systems.
- *Proposition 3*: SESs are systems that are complex and adaptive, with properties of self-organization and emergence.
- *Proposition 4*: What differentiates SESs from other systems is the introduction of abstract thought and symbolic construction.

3.1 SESs as integrated systems of matter, life and mind

Four frameworks that aim to unite matter, life and mind through an evolutionary hierarchy were explored: the 'Spheres of evolution' of Vladimir Vernadsky, Pierre Teilhard de Chardin and others that describes what Barrett (1985) describes as a 'noosystem', Kenneth Boulding's 'Hierarchy of Systems Complexity', Herman Dooyeweerd's 'Cosmonomic Idea of Reality', and Ken Wilber's 'All-Quadrants All Levels (AQAL)' framework. A synthesis of these frameworks suggests that SESs are made up of three distinct, but nested and interpenetrating, spheres or domains of existence: the geosphere (matter), the biosphere (life), and the noosphere (mind). These spheres represent a continuum of increasing complexity and consciousness, with matter as the first (lowest) level, life as the next level emerging from (and thus including) matter, and mind as the last (highest) level emerging from life. Thus, life requires matter in order to exist, and mind requires life and, therefore, matter for its own existence.

Within these spheres there are certain modalities, or irreducible areas of functioning, each with its own set of 'laws' that governs existence within that particular level of functioning, and supports the emergence of the next level. These 'laws' are deterministic at the lowest levels and become increasingly normative in the higher levels. SESs span across all three spheres and the modalities within each of the spheres, although elements within SESs can exist at different levels. As elements of the system become more complex and conscious they inhabit higher levels of development, but at the same time contain all the properties of the lower levels.

Apart from the ‘vertical’ dimension provided by the holarchy of development, each level of development also spans horizontally across four quadrants of interior, exterior, collective and individual. SESs thus represent the combination of the ‘exterior’, as created by biogeochemical processes (in which humans have come to play a disproportionate part), and the ‘interior’, as created by, and experienced through, the human psyche and processes of thought, including the “shared cultural worldspace” (Wilber, 2000). It is proposed that SESs are not seen as made up of humans, their social structures, and the technological and cultural artefacts that support these structures (the social system) on the one hand, and everything else that constitutes life and the universe (the ecological system) on the other. Instead, humans are placed within nature as an integral part of the processes of change and co-evolution. Thus at the exterior level, humans and their artefacts are an indivisible part of the biosphere and they, like any other organism, participate in and co-create the metabolic and change processes that shape the biosphere. Humans are bound by the same laws that apply to other organisms when operating at the lower modalities, but their interior processes allow humans to apply these laws to create and adopt technologies that introduce novel components to the system at scales both above and below that of the individual human. However, this is only one part of the picture. SESs consist of many types of hierarchies with elements interacting across the various levels and types of hierarchy. The next step is to understand the holarchic and cross-scale nature of this structure, and the interrelationships between elements operating at the various levels.

3.2 Nested Across Multiple Scales

Hierarchies of scale are just one aspect of the multilayered structure of SESs to understand. Also important are hierchies of level, and in particular the concept of holarchy, which can be seen as the nested hierarchy of whole/parts or holons. Another multi-level conceptual framework that is prominent in the literature on the study of SESs is that of panarchy.

Hierarchies of scale have to do with the quantifiable and measurable aspects of a system (Gibson *et al.*., 2000). The most commonly used hierarchies of scale fall into three categories: temporal, numerical and spatial. In hierarchies of scale the next hierarchical level is the sum of the previous levels (e.g. one kilometre equals the sum of a thousand metres or of a million millimetres) and the difference between levels is merely a quantitative one. Hierarchies of level, on the other hand, are concerned with organization and structure and, as described by Simon, this category of hierarchy is the ordering structure of complex systems (Simon, 1962). In essence, hierarchies of level refer to a structural organization whereby a system (mechanical or natural) is constructed by first constructing simple sub-assemblies, which in turn are connected into a subsystem of a higher order. These sub-systems are in turn connected to create the final system. The system is therefore constructed from the bottom up in increasing levels of internal complexity.

The difference between hierarchies of level and those of scale is that the difference between the hierarchical levels in the system is also qualitative and functional. The entities at level three have properties and functions substantially different from those at levels two or one. This is also where the major difference between mechanical systems and natural systems enters. With mechanical systems, the properties of levels two and three can be predicted with a certain amount of certainty from the properties and interactions of the elements at the levels below. However, in natural systems the properties of each level that emerges from the interactions at lower levels cannot be “strictly and totally deduced from their components” (Wilber, 2000:54) and are qualitatively different. The most important aspect of this category of hierarchy is that each element is simultaneously a whole (as an individual entity) and, as an element in the system at that level, a part of a larger whole. The whole can thus be seen as an emergent property of the structural relationships and interactions of the parts. This type of hierarchy is referred to as a holarchy (Koestler, 1975:103).

Furthermore, each holarchic level operates according to its own set of rules or patterns that determine behaviour at that level. However, lower levels can influence higher levels through upward causation and higher levels can control or influence what happens at lower levels through downward causation (Roger Sperry cited in Wilber, 2000:28). This notion of interaction and influence across different hierarchical levels is the central tenet of the next major concept to be discussed, namely panarchy.

As part of their quest to develop an integrative theory for understanding processes of change happening globally, Holling, *et al.*. (2002) coined the term ‘panarchy’ to provide an organizing framework for theory dealing with cross-scale dynamics in natural and social systems. The term is a complex wordplay on the idea of hierarchy (of level and scale) combined with the prefix ‘Pan’ to indicate change across the whole. The panarchy framework is based on two premises. The first is the idea of the adaptive cycle and that the levels of the panarchy can be drawn as a set of nested adaptive cycles arranged as a dynamic hierarchy in space and time (Holling, *et al.*., 2002:101). The second is that the adaptive cycle phases at different levels interact or connect with one another. The panarchy is constructed gradually as potential accumulates at one level, until a threshold is passed that allows the establishment of a slower and larger level. Conversely, the panarchy collapses or enters state breakdown when there are simultaneous crises at different levels (e.g. all levels of the system enters the breakdown phase of their individual adaptive cycles at more or less the same time) or a crisis cascades across all levels. From this point of view, the objective of sustainability initiatives is not to resist or reverse change, but to accept that change is inevitable and manage the phase changes within systems in such a way that the system does not lose its fundamental identity and tip into another stability domain, or that such collapses do not cascade upwards into the larger system. This means managing the capacity of the system to experience shocks while retaining essentially the same function and structure, and therefore identity, a concept known as resilience. A resilient social-ecological system has a greater capacity to avoid unwelcome surprises (regime shifts) in the face of external disturbances and so has a greater capacity to continue to provide us with the goods and services that support our quality of life (Walker and Salt, 2006:37). In order to understand how resilience can be managed, it is necessary to understand the characteristics of SESs as complex, adaptive systems.

3.3 Complex and Adaptive

SESs are complex, in that they are diverse and made up of multiple interconnected elements, and adaptive, in that they have the capacity to change and learn from experience. Lucas (2004) explains that the essence of complex adaptive systems is that they self-organize to optimize the function of the system, creating new niches as necessary, and changing their composition to fit the changing patterns they encounter. Unlike mechanical systems, where systems and parts have fixed functions that either work or do not, adaptive systems have flexible functions that adjust to the context of their environment. A key aspect of these types of systems is that their constituent agents are constantly making predictions based on its various internal models of the world (its implicit or explicit assumptions about the way things are out there), and adapting to each other and to the external environment. These adaptive responses and interactions allow the system as a whole to undergo spontaneous self-organization into collective structures with properties that cannot be predicted from the properties of the parts, and which the agents may not have possessed individually (Waldrop, 1992) - a concept referred to as emergence. Furthermore, the connections or interactions between the elements of the system are non-linear and contain feedback loops, which implies that small causes can have large results. Understanding SESs as complex, adaptive systems therefore means that the important properties to consider are those related to change and the system's ability to deal with change – for example, resilience, adaptability, transformability, connectivity and diversity.

One of the hallmarks of complex systems is the aggregation of local actions into well-defined global patterns such as cities and neighbourhoods (self-organized criticality) (Miller and Page, 2007). Within these systems, microlevel agents interact to create the global properties of the system. These global properties then feed back into the microlevel interactions. This happens in both physical and social systems. What differentiates physical systems from social systems is that the agents in social systems often alter their behaviour in response to anticipated outcomes. This brings us to what it is that differentiates SESs from other ecological systems – their capacity for abstract thought and symbolic construction.

3.4 A Capacity for Abstract Thought and Symbolic Construction

As Westley, *et al..* (2002:108) describes, the ability of humans to make sense of their world through abstract thought and symbolic construction allows "the formation of social systems and a 'virtual reality' through which options and scenarios can be explored and new possibilities can be imagined". They suggest four elements of the dimension of symbolic construction: the creation of a hierarchy of abstraction (which allows the agent to separate him/herself mentally from the realm of time and space); the capacity for reflexivity; the ability to remember the past and learn from it (hindsight) and imagine the future and plan for it (foresight); and the ability to externalize symbolic constructions in technology. Furthermore, the ability to use symbols and with symbols, language, allowed humans to develop sophisticated means of communication that allow abstract ideas to be communicated not just across vast distances, but also across time. This ability to communicate across space and time allowed for the creation of the three dimensions of social systems identified by Giddens (1979), that is the structures of signification (the social rules that govern meaning), domination, and legitimisation (the rules that actors draw upon to sanction their own behaviour as well as that of others, according to Abou Zeid, 2007).

It is this sophisticated interior aspect and the opportunity it creates for novelty, foresight, reflection and learning, as well as the beliefs, norms and values that are formed at this intangible level, that differentiate SESs from other ecological systems. It not only allows the development of novel social and technological systems that determine the nature of interactions between humans and other aspects of the biosphere, but also allows humans to engage in reflection regarding the meaning and consequences of these interactions.

4. Discussion

The easiest way to illustrate how the above framework applies to cities is to use a narrative example of how a system perturbation such as crime at the level of the individual agent cascades through the different levels and spheres of the city system. In the imaginary city of Ezulweni a burglar breaks into the house of a middle-class couple, stealing their electronic goods and second car. According to his value system (a noosphere concept) he is perfectly justified in doing this as a form of wealth redistribution after his ancestors have endured years of oppression under the wealthy elite. Outraged and fearful, the couple install burglar bars in front of their windows and security gates at the doors (a noosphere response to a biophysical threat resulting in a change of their biophysical environment). A couple of weeks later, the burglar breaks into another house down the road, and then another. He is bold because the social structures that are supposed to protect the community from crime are hampered by a lack of biophysical resources (e.g. patrol vehicles) and normative dysfunction (a demotivated police force) and he no longer has any fear of being caught. Fearful of becoming the next victims, all the houses in the neighbourhood install bars (adaptive behaviour). However, this does not stop the burglar as he merely uses a crowbar to break through the security bars (adaptive behaviour). His success further emboldens his friends, who also try their hand at a little burglary, which escalates the perceived threat and with it fear. The neighbourhood install alarm systems and start building walls around their properties. At this point, while each agent is still acting in response to an external driver (the burglar) and the response of his neighbours, their combined efforts are already having an effect on the function and identity of the neighbourhood (a scale up), and on the local economy as businesses opened up to exploit the new niche presented by a need for security (abstract thinking allowing them to predict a market opportunity). The walls mean that neighbours no longer have social contact (which has implications for social cohesion) and people no longer walk down to the corner store (which adds to local traffic and carbon emissions). The criminals, finding that all these new security measures cannot be overcome by a mere crowbar, up their game and introduce firearms, turning the crime of burglary into robbery and vehicle hijacking (thus upping their effects on the hierarchy of significance). This increases the levels of fear within the neighbourhood, where people respond by either moving (leading to a drop in property values), or increasing their security by purchasing firearms themselves (thus escalating the levels of violence and altering value systems). However, firearms costs money and the thieves find they need higher levels of sophistication to achieve their aims. This leads to criminal specialization and organised crime syndicates with accompanying changes in the value systems of the communities from which the criminals hail. Powerless to stop the criminals on an individual level, the householders now organise themselves and close off their neighbourhood with fences, gates across formerly public streets, and armed security guards. With this action they cause a number of changes to the larger urban system. Firstly, the structure of the city is changed, disrupting traffic patterns and increasing the burden on roads outside the enclosed neighbourhood, which increases congestion and with it, air pollution. Increased levels of air pollution have a detrimental effect on human health within the city and add to global carbon emissions and therefore climate change. In addition, the property values of those houses outside the walls plummet and some houses are simply abandoned, leading to a deteriorating urban environment. Frustrated, the criminals also move their efforts to other, more vulnerable neighbourhoods where householders go through the same cycle until eventually the city becomes fragmented into security enclaves and a new phenomenon – the gated community – emerges in new development, forever altering the character of the city. To this, the city authorities finally respond by introducing legislation that bans enclosed neighbourhoods, but this cannot be enforced as the situation has already escalated out of hand and the city does not have the funds to take all these communities to court to enforce the legislation. In the meanwhile a large economic sector has developed around crime and security and this sector contributes significantly to both the national GDP and the tax base, while providing many low-skilled jobs.

One can continue to unpack this story in many different directions, but the point is that small individual actions have come together to influence the system at much larger scales. These actions were driven by a combination of social and individual value systems across a range of ethical norms, and were enabled by social structures to effect a lasting change on the biophysical system of the city, as well as the national economy and aspects of the global biophysical system. As the story unfolded there were key points at which there was an opportunity to change the trajectory of the story. However, as the changes cascaded up levels, the interventions that would have been required increased in scale and cost. Unfortunately, because many of the changes were initiated at an individual level, they were not picked up by the social structures that should have responded before these changes have already cascaded up a level. If city authorities had understood cities as social-ecological systems where individual actions, driven by value systems shaped by a changing environment, can have far-reaching effects on the identity of the city, they would perhaps have tried to intervene earlier, rather than when it was too late to do anything but adapt to the changes.

5. Conclusion

Understanding cities as social-ecological systems with complex, adaptive behaviour requires the urban sustainability debate to shift from a quest for the ultimate rules for city planning and design, to finding ways that accept and embrace change and novelty while building the capacity for resilience in the interaction between noosphere and biosphere. This would require a rethink of indicator systems to monitor changes not only in the biosphere, but also in the noosphere, (e.g. changes in norms and values) and track the systemic influences and the complex, adaptive processes found in cities. It would further require that planning and regulatory processes are guided by an understanding of systemic interactions; take into account issues of behaviour, relationship, resource flows and resilience across the social-ecological system; and acknowledge that uncertainty and unpredictability is a characteristic of cities that requires adaptive management and flexibility in implementation. Lastly, it requires that the conceptual and other models used to inform systemic planning processes account for the flows between interior aspects (e.g. value systems or structures of legitimisation such as regulations) and both interior changes (e.g. a shift towards a specific value system such as environmentalism) and exterior change (e.g. changing value systems driving the development of new technologies). It must further be able to close the loop by accounting for changes in the exterior related to manifestation of interior events (e.g. the use of a new technology increasing pollution levels).

The ideas outlined in this paper only begin to scratch the surface of a very complex, yet compelling, way of looking at cities. It is hoped that the pebbles it has dropped in the pond will spread beyond this conference to further enrich and stimulate the debate and contribute to a better understanding of how best to achieve sustainability in cities.

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