Systems Thinking and the Future of Cities

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"We live in an interconnected world", the author argues.

In Brief

The idea that nothing exists in isolation–but only as part of a system–has long been embedded in folklore, religious scriptures, and common sense. Yet, systems dynamics as a science has yet to transform the way we conduct the public business. This article first briefly explores the question of why advances in systems theory have failed to transform public policy. The second part describes the ways in which our understanding of systems is growing–not so much from theorizing, but from practical applications in agriculture, building design, and medical science. The third part focuses on whether and how that knowledge and systems science can be deployed to improve urban governance in the face of rapid climate destabilization so that sustainability becomes the norm, not the occasional success story.

Key Concepts

- Reducing wholes to parts lies at the core of the scientific worldview we inherited from Galileo, Bacon, Descartes, and their modern acolytes in the sciences of economics, efficiency, and management.
- The decades between 1950 and 1980 were the grand era for systems theory. However despite a great deal of talk about systems, we continue to administer, organize, analyze, manage, and govern complex ecological systems as if they were a collection of isolated parts and not an indissoluble union of energy, water, soils, land, forests, biota, and air.
- Much of what we have learned about managing real systems began in agriculture. One of the most important lessons being that land is an evolving organism of interrelated parts soils, hydrology, biota, wildlife, plants, animals, and people.

- The challenge is to transition organized urban complexity built on an industrial model and designed for automobiles, sprawl, and economic growth into coherent, civil, and durable places.
- A systems perspective to urban governance is a lens by which we might see more clearly through the fog of change, and potentially better manage the complex cause and effect relationships between social and ecological phenomena. The application of systems offers at least six possibilities to improve urban governance.

A system is an interconnected set of elements that is coherently organized in a way that achieves something . . . . [it] must consist of three kinds of things: elements, interconnections, and a function or purpose.
—Donella Meadows, Thinking in Systems[1]

A system [is] (a) a set of units or elements interconnected so that changes in some elements or their relations produce changes in other parts of the system, and (b) the entire system exhibits properties and behaviors that are different from those of the parts.
—Robert Jervis, Systems Effects [2]

One of the most important ideas in modern science is the idea of a system; and it is almost impossible to define.
—Garrett Hardin, The Cybernetics of Competition[3]

History of Systems Theory

The postwar decades between 1950 and 1980 were the grand era for systems theory. Based on advances in communications, operations research, and cybernetics from World War II, Kenneth Boulding, James G. Miller, Ludwig von Bertalanffy, C. West Churchman, Herbert A. Simon, Erwin Laszlo, Jay Forester, Dennis and Donella Meadows, Peter Senge and others wrote persuasively about the power of systems analysis.[4],[5] The benefits were said to be many. Systems thinking would enable us to perceive the patterns that connected otherwise disparate things and to detect the counter-intuitive logic underlying an often deceptive reality, thereby creating more coherent diagnoses, policies, and plans.

The actual benefits of systems theory, however, remained mostly in the realm of computers and communications technology. Elsewhere, business as usual confidently marched on unperturbed. Despite the inherent logic of systems thinking, governments, corporations, foundations, universities, and non-profit organizations still work mostly by breaking issues and problems into their separate parts and dealing with each in isolation. Separate agencies, departments, and organizations specialize in energy, land, food, air, water, wildlife, economy, finance, building regulations, urban policy, technology, health, and transportation−as if each were unrelated to the others. So, one agency pushes hard to grow the economy while another is charged to clean up the resulting mess and so forth, which is to say that the right hand and left hand seldom knows−or cares−what the other is doing. The results are often counter-productive, overly expensive, risky, sometimes disastrous, and most always ironic. Systems modeling, for example, allowed us to anticipate and understand the looming catastrophe of rapid climate change, while systemic failures in government, policymaking, and economics have heretofore crippled our ability to do much about it. Systems theory, in short, has yet to have its Copernican moment and the reasons are ironically embedded in the scientific revolution itself.

Reducing wholes to parts, i.e. "reductionism," lies at the core of the scientific worldview we inherited from Galileo, Bacon, Descartes, and their modern acolytes in the sciences of economics, efficiency, and management. For a time, reductionism worked scientific, technological, and economic miracles. But, as we gained in power, wealth, speed, convenience, apparent control over nature, and self-confidence, we paid a considerable price that Faust (Marlowe's–not Goethe's) would have recognized. Like Faust, we were short-termers, discounting long-term costs and risks that could have been seen only from a systems perspective. The results are dumbfounding. In record time, we have shredded whole ecosystems, acidified the oceans, killed off entire species, squandered topsoil, leveled forests, and changed the chemistry of the atmosphere. "We are," in Edward Hoagland's words, "still part-chimpanzee with double degrees in trial and error." In the real world, things bite back, there are tipping points, surprises, emergent properties, step-level changes, time delays, and unpredictable and catastrophic "black swan" events with long-lasting global effects. To anticipate and avoid such things requires a mind-set capable of seeing connections, patterns, and systems structure, as well as a sightline far beyond the quarterly balance sheet or the next election. Wisdom begins with the awareness that we live amidst complexities that we can never fully comprehend let alone control. But caution was no part of the bullet proof exuberance written into our notions of progress, nor America's foundational documents.

White House Staff Photographers
Jimmy Carter, Gerald Ford and Richard Nixon at the White House, 1978. Gerald Ford played a major role in getting The National Environmental Policy Act signed into law by Richard Nixon in 1970.

Conceived by men much influenced by the Enlightenment–ignorant of ecology, and fearful of excessive authority–the U.S. Constitution, for example, gives no "clear, unambiguous textual foundation for federal environmental protection law," in the words of legal scholar Richard Lazarus. It privileges "decentralized, fragmented, and incremental lawmaking . . . which makes it difficult to address issues in a comprehensive, holistic fashion." , Congressional committee jurisdictions based on the Constitution further fragments responsibility and legislative results. The Constitution gives too much weight to private rights as opposed to public goods. It mentions neither the environment nor the need to protect soils, air, water, wildlife, and climate–and so offers no unambiguous basis for environmental protection. The commerce clause–the source for major environmental statutes–is a cumbersome and awkward legal basis for environmental protection. The result, Lazarus notes, is that "our lawmaking institutions are particularly inapt for the task of considering problems and crafting legal solutions of the spatial and temporal dimensions necessary for environmental law."[9] In other words, our manner of governing is often ecologically destructive.

The National Environmental Policy Act (1970) aimed to remedy such shortcomings. It required all federal agencies to "utilize a systematic, interdisciplinary approach which will insure the integrated use of the natural and social sciences and the environmental design arts in planning and in decision-making." The Act called for systems planning, but beyond the requirement for environmental impact statements for federally funded projects, it had no teeth. With few exceptions, things went on much as before.

The upshot is that, despite a great deal of talk about systems, we continue to administer, organize, analyze, manage, and govern complex ecological systems as if they were a collection of isolated parts and not an indissoluble union of energy, water, soils, land, forests, biota, and air. The idea of sustainability would seem to imply that the remedy is a systems approach to environmental management, but the reality is otherwise. Efforts toward sustainability are also fragmented into particular issues of energy, agriculture, air pollution, water pollution, forestry, green building, and so forth so that the parts support no larger whole. Yet, the biosphere and its constituent ecosystems are indifferent to mere human convenience and illusions, unforgiving of hubris, and remorseless in exacting their due. As someone once said, "God may forgive our sins, but nature won't."

How is Systems Thinking Applied Today?

Much of what we have learned about managing real systems began in agriculture, notably the work of horticulturist Liberty Hyde Bailey, agronomist Albert Howard in India, forester Aldo Leopold, agroecologists Miguel Altieri and Stephen Gliessman, plant geneticist Wes Jackson, range management expert Alan Savory, and ecologically savvy farmers like Joel Salatin. The most important lesson from their collective work is that the land is an evolving organism of interrelated parts soils, hydrology, biota, wildlife, plants, animals, and people. If sustainability is the goal, the land can neither be managed as a factory nor the profit it generates measured by its short-term yield. Managed as an organism, the land limits the scale and kind of farming and forestry practices and eventually disappoints all expectations that exceed its carrying capacity. Good land stewardship requires patience, dependable long-term memory, wide margins otherwise called precaution, and, as Wendell Berry reminds us, affection. It's true that profitability can be no greater than the rate at which sunshine can be turned into plant material and animal flesh without diminishing future productivity. In strict terms, a sustainable farm is one maintained in balance by natural inputs of sunlight, water, plant decay, animal manures, and an observant and competent ecological intelligence both of the farmer and the rural culture. Like the natural systems it mimics, a sustainable farm is always a polyculture and depends on the synergies between its various components from soil microbes to animals. Industrial agriculture, in contrast, is subsidized by fossil fuels, imported fertility, chemical pest management, and borrowed capital. It is a part of the extractive economy that mines soils, minerals, genes, and people alike. And it is always a monoculture aimed to make a profit in the short-term. The difference between the industrial and ecological farming puts them at opposite ends of a continuum that defines resilience.

Ecologically designed buildings are another source of practical instruction about systems. Until the advent of the green building movement, the process occurred serially: architects did the basic design and passed the blueprints to the engineers to heat, cool, light, and plumb. They, in turn, handed it off to the landscapers to make it look like it belonged where the happenstance of real estate prices and often bad planning had dropped it. The incentives−financial, legal, and reputational− demanded that the structure be over-heated, over-cooled, and overbuilt−hence overly expensive. Much profit was made in excessive redundancy, rather like making chairs with eight legs where the carpenter is paid for each extra leg.

Stuck in Customs / Flickr
‘Scarlet Ribbon’ cultivar in Tasmania. The term “cultivar” was first coined by Liberty Hyde Bailey, which is defined as a plant whose origin or selection is primarily due to intentional human activity.

Early ecological designers such as Sim van der Ryn, Bob Berkebile, Bill McDonough, Pliny Fisk, and the U.S. Green Building Council pioneered a different approach to design that optimized the whole building as a system, not its separate components. A tighter, better insulated building shell, for example, meant downsizing the HVAC systems and reducing long-term operating costs while improving human comfort. Similarly, creative daylighting improved aesthetics and occupant productivity, while reducing lighting bills and, again, long-term costs. But the largest benefit of “biophilic design” was in the very human fact that we are happier, healthier, and more productive in places carefully calibrated to our five senses.[10]

There are other areas of applied systems knowledge, but in comparison to architecture, none are so easy to grasp or as cogently instructive about the ways we might improve management of other systems. Yet, they offer different insights. Farms and natural systems operate by a slower clock speed from that of buildings. Farming requires patience appropriate to the growing season and the cycles that govern fertility and fecundity. We can manipulate some of the variables inherent to farming, but the larger patterns of soils, hydrology, biota, wildlife, weather and so forth have seasons and cycles to which we are strangers and interlopers. To the extent that we can manage at all, prudence would have us leave wide margins to accommodate our ignorance and other shortcomings. Buildings, or what are awkwardly called “the built environment,” on the other hand, are human creations. The designers are privy to their mysteries and inner workings in ways we cannot be to natural systems of farms. Even so, builders are often surprised by unanticipated behavior of mechanical systems, design flaws, and human behavior in what were supposed to be well-designed structures.

There is a third source of systems knowledge available in the study of the body. Walter Cannon in The Wisdom of the Body (1932), for example, introduced the notion of “homeostasis” as a way to explain how the “extraordinarily unstable material” of our bodies in “free exchange with the outer world” miraculously persists through many decades.[11] Yale professor and physician Sherwin Nuland, in a book of the same title, later (1977) described the process in these words:
“Always on the alert for the omnipresent dangers without or within, ceaselessly sending mutually recognizable signals throughout its immensity of tissues, fluids, and cells, the animal body is a dynamism of responsible consistency. By untold trillions of energy-driven agencies of correctives,

inappropriate alterations are balanced and changes are either accommodated or set right—all in the interest of that equilibrating steadiness that is the necessary condition of the order and harmony of complex living systems . . . . Its capacity to communicate within itself and with its external environment is the basis of an animal's viability in the face of the many unremitting forces that never cease to threaten its existence."[12]

The idea of the body as a complex system might have led to a systems view of medicine and healing, bridging the gap between Western and Eastern medicine. But the practice of Western medicine by that time was thoroughly reductionist and immune to instruction from other cultures.[13],[14] Immersed in the Western manner of science, physicians still tend to diagnose illness with no deeper causes, heal diseases in isolation as if the body were a broken machine, and prescribe as if effects of medication did not ripple throughout the body. The result is that solutions often become the source of new problems and the start of vicious cycles.

The same, however, could be said of most, if not all, fields of business, economy, public policy, and technology. Whether applied to farms, buildings, or bodies, systems thinking isn't easy, but the essence is wholeness−that is to say the harmonious integration of the various components. It is evident in various indicators of health: ecological, social, and human. So, what can systems thinking teach us about how to better manage urban regions?

Cities and Systems Thinking

In addressing the question of "what kind of problem a city is," Jane Jacobs once wrote:
"Cities happen to be problems in organized complexity . . . present(ing) 'situations in which a half-dozen or even several dozen quantities are all varying simultaneously and in subtly interconnected ways.' Cities, again like the life sciences, do not exhibit one problem in organized complexity, which if understood explains all. They can be analyzed into many such problems or segments which as in the case of the life sciences, are also related with one another. The variables are many, but they are not helter-skelter; they are 'interrelated into an organic whole."[15]

cjuneau from Ottawa, CANADA / CC BY 2.0
What appears to be a wheatfield in downtown Ottawa is actually the green roof on top of the Canadian War Museum in Ottawa, Canada.

The challenge, then, is to transition organized urban complexity built on an industrial model and designed for automobiles, sprawl, and economic growth into coherent, civil, and durable places.

Urban governments are being stressed in a world with more people, more "stuff," and higher expectations–all moving at an increasing velocity. In Peter Senge's words, "humankind has the capacity to create far more information than anyone can absorb, to foster far greater interdependency than anyone can manage, and to accelerate change far faster than anyone's ability to keep pace."[16] The managers of urban systems require the capacity to shift "from seeing parts to seeing wholes, from seeing people as helpless reactors to seeing them as active participants in shaping their reality, from reacting to the present to creating the future." All of this is easier said than done. It will come as no surprise to city officials that city regions, as Donella Meadows wrote, are "self-organizing, nonlinear, feedback systems [and] are inherently unpredictable [so] . . . we can never fully understand our world, not in the way our reductionist science has led us to expect."[1]

Resilient governance requires the calibration of two kinds of non-linear systems: social and economic, e.g., laws, regulations, taxation, policies, elections, and markets with ecological systems, e.g., biology, hydrology, geology, wildlife, climatology, and land-use. These systems work on different time scales and by different processes as parts of a whole that we call the biosphere. But they are not equal. Human contrivances–economies, technologies, politics, and social behavior–ultimately must conform to biophysical realities or eventually face disintegration. Systems perspectives and management tools can help us better deal with the complexities of interacting non-linear systems. We designed the systems by which we are governed and provisioned, and we can redesign them. But only, in Meadows' words, if the people who manage them "pay close attention, participate flat out, and respond to feedback."

A systems perspective to urban governance is a lens through which we might see more clearly through the fog of change, and potentially better manage the complex cause and effect relationships between social and ecological phenomena. It would help make up for our chronic inability to foresee the consequences of our behavior. Knowledge of system structure and operating rules may help improve resilience in a rapidly warming world punctuated by black swan events, and perhaps anticipate counter-intuitive outcomes that would otherwise come as surprises. The application of systems analysis is no panacea, but it does offer at least six possibilities to improve urban governance.

First, in confronting an overwhelming cacophony of raw data, systems analysis can help governments organize information in order to distinguish the ecological signals from the noise. A city is a complex and confusing array of inputs and outputs: fuels, food, materials, water, and so forth enter, and carbon dioxide, wastewater, waste heat, pollutants, refuse, and all manner of other things exit. Were a city placed under an imaginary glass dome with the inputs and outputs entering and leaving through clearly marked pipes, we would understand these entropic flows and their interactions more directly. It is possible, however, to better understand the city through models that show ecological transactions as diligently as any accountant tracks the flows of money. Models of the city as a system of ecological inputs and outputs are a useful tool to place seemingly disparate and confusing data into its larger ecological context in order to improve decision-making across sectors, departments, and agencies.

Second, the data necessary to understand resource flows and the larger ecological context of a city can be deployed to educate a citizenry to understand the relationships between its behavior and its environmental and economic prospects. The use of internet and publicly deployed flat screen displays (dashboards) placed in buildings, city kiosks, sports arenas, libraries, hotels, and schools to track and display data on resource flows, carbon emissions, investment, land-use patterns, ownership, and public attitudes–and their interactions–can be a powerful tool to educate citizens about feedbacks, leads and lags between action and results, and to raise understanding of complex issues.[17] The result could be a widely accessible and cost-effective education in the basic dynamics of biophysical, social, and economic interactions.

Systems analysis can help, third, to improve planning and forecasting. Elected leaders in many rust-belt cities like Detroit assumed that the good times would last forever and were caught flat-footed when they did end. The use of models that clarify assumptions, identify feedback loops, and monitor system behavior and ecological conditions can help decision-makers better anticipate change and to plan, tax, budget, and make smarter policies. Looking ahead, cities in a rapidly warming world must prepare for larger storms, longer droughts, supply disruptions, and economic turmoil. These, in turn, ought to affect decisions about zoning, land-use, location and type of infrastructure, building codes, food supply, economic development, taxation, and emergency preparedness.

Fourth, the tools of systems analysis can help to improve the quality of urban decision-making. To get a driver's license, for example, one must take a course and pass a test. But for officials charged to manage the public business we require virtually no evidence of any basic understanding of how the world works as a physical system or the dynamics that govern the interactions of social and natural systems. We would be justifiably intolerant of public officials who were unable to read or count, but ecological illiteracy—an equally serious problem—causes no consternation whatsoever. As part of their routine orientation to city government, officials−elected and appointed−ought to be required to pass a basic test in ecology and systems dynamics. However that would be carried out, the goals would be to (1) raise the effectiveness of decision-making by increasing the awareness of how urban regions function as social and economic systems interacting with natural systems, and (2) to equip leaders with better tools of analysis and foresight by which to manage public business.

Fifth, systems analysis can improve organizational behavior. The capacity to respond to feedback is inhibited by many factors. It can be blocked when fear, group-think, or complacency paralyze decision-making. Rather than suppressing dissent, systems analysis can help to clarify the unexamined differences in beliefs embedded in competing paradigms and mental models. David Cooperrider and Peter Senge have developed techniques to facilitate systems thinking to build organizational community around common visions. Their goal is to enable members of organizations to see themselves as players in an enterprise making decisions that involve feedbacks, step level changes, emergent properties, stocks, and flows that advance the awareness of agency in causing one outcome or another.

Finally, systems thinking can lead to greater realism and precautionary public policies for the simple reason that most systems are nonlinear and therefore inherently unpredictable. From a systems perspective, we should design policies of all kinds with wide margins, hedged bets, and redundancy. Every intended solution should solve more than one problem while causing no new ones. The goal, in short, is to build smarter and more adaptable institutions and organizations that are capable of learning, foresight, intelligent agency, and "robust to error," at the intersection of human action and biophysical realities.

From a systems perspective, there are no such things as "side-effects," only the logical outcomes derived from the rules and behavior of the system. Climate change, ozone holes, cancer clusters, and Texas-sized, mile deep gyres of trash floating in the middle of the Pacific Ocean are not side-effects of economic growth, but the predictable outcomes of a system designed to grow at all costs. Likewise, from a systems perspective, there are few accidents−only the institutionalized lack of foresight which is a flaw in the way a particular system is organized. The point, in Senge's words, is that "everyone shares responsibility for problems generated by a system."

Looking into the Future

The goal of systems analysis and organizational learning is not just to find a more clever way for cities and other organizations to do what they have been doing all along. It is rather a tool to help reexamine purposes and performance relative to complex and rapidly changing circumstances. Like any tool, its effectiveness depends on the skill and wisdom of the user. Systems analysis is not magic: it cannot tell us what to model or what's worth doing and what's not. It can help sell more caffeinated sugar water throughout the world causing obesity, diabetes, and tooth decay, or it can help us understand why that is a bad thing to do. It will not make the stupid and hardhearted wise or caring. It won't tell us anything that lies outside our paradigms, worldviews, or the light of our particular campfire. It is, after all, only a tool and will do no more than what it is asked to do, and no more than any culturally constrained and time-bound technique can ever do. We have to supply the compassion and good judgment, and care enough to want to know the consequences of our actions. Furthermore, there is nothing new in systems thinking beyond the higher level precision and analytical power inherent in sophisticated computer modeling. Earlier societies created complex ways to foresee and to restrain certain behaviors that could damage their collective prospects.[18] The Amish achieve many of the same results by maintaining a coherent and sober, if restrictive culture.

In the end, systems analysis applied at the level of organizations, cities, and regional governance buys us time until national governments catch up. At any level, however, it is only a tool to clarify the consequences of our actions, identify our options, and extend our foresight a bit. And those are not small gains.