Interweaving Architecture and Ecology – A Theoretical Perspective
Or: What can architecture learn from ecological systems?

Batel Dinur

Abstract
This paper is part of an on-going research which attempts to reveal whether an analogy between ecology and architecture can benefit architectural design and if so, then in what ways. The analogy is done through an interpretation of three ecological principles which define the organization of living systems and then attempts to reveal how these three ecological principles may be implemented in architecture. The paper firstly describes the problem at hand and the need for a new model for architecture which may be better informed by the study of ecological systems. It then elaborates on the definition of the three ecological principles (fluctuations, stratification, and interdependence) which were chosen for investigation because they define the *organization* of living systems and therefore may be relevant as a basis for an analogy between ecology and architecture. The paper then presents brief examples of the current and possible further realization of these ecological principles in architecture.
Keywords: ecology, architecture, living systems' organization, process, fluctuations, stratification, interdependence.

Introduction
In this paper I will try to illuminate how an ecological understanding of systems may contribute to architectural design.
An 'ecological understanding of systems' means to understand how the components of a living system function together and make the system what it is. My question is whether a better understanding of these living processes may move architecture away from a perceived obsession with the static object, and into a more dynamic system? My argument is that a truly environmental architecture cannot be reached through the refinement of the static object alone, but must address complex interactions, and that these might be best informed through a study of ecology.
There are many principles which describe how living systems function and develop. Some of the principles include: emergence, fluctuations, symmetry breaking, dissipation, instability, criticality, interdependence, redundancy, adaptation, complexity, hierarchy, and more… The definitions vary but the principles remain the same. In this paper I will choose to focus on three principles which, in my opinion, provide a basis for understanding the *organization* of living systems and how this organization may inform the organization of non-living structures, such as buildings.
The three principles that I chose to focus on are: fluctuations, stratification and interdependence. Each one of them will be explained separately and through the links between them an understanding of a living system's organization will begin to emerge. As a result, we may begin to realize how an understanding of complex living systems can contribute not only to the way we analyze the world but also to the way we organize and construct it. Designers, architects and planners may then be able to truly integrate processes of nature with processes of social and cultural behaviour.
At the moment, cultural and social processes adopt mainly to economic needs (which are driven by technological inventions), and architectural design motives are no exception. While environmental concerns begin to influence decision makers within architecture,

the way in which architects and designers integrate environmental considerations into the planning of buildings is mostly expressed through the addition of environmental features into already existing social and economical structures upon which architecture depends. A truly environmental architecture will begin to happen only when architecture will emerge as a result of integration between natural living processes and cultural and social processes. The aim of this paper is to focus on the organization of living processes in order to be able to later on relate to these processes in architectural design.

Ecology and Architecture

'Ecology' is the study of living systems and their relations to one another. A living system is an integrated whole whose properties emerge from the relations between its individual parts. Each part reflects the whole but the whole is always different from the mere sum of its parts. Through this basic definition of a living system we can begin to identify the main difference between living and non-living systems. In a non-living system (in our case – buildings) the components together form the whole through a hierarchical structure of construction – each part of the system has its own function and is built specifically to perform this function. The interaction between the components serves the whole but we cannot say that the whole emerges from the interactions between the parts.

The study of living systems has influenced architectural design in various ways, although, the results suggest that architects and designers do not truly comprehend how living systems function, but rather try to borrow new ideas from science and ecology and express them in architecture in a rather superficial way.
Charles Jencks (1995) in his book 'The architecture of the jumping universe' and other articles, describes six different categories for compartmentalizing contemporary architecture, which, according to his view, manifest latest scientific thought. These categories are:

1. *Organi-Tech* – architects continuing an obsession with technology and structural expression while at the same time taking into account environmental aspects. (Ken Yeang, Renzo Piano, Richard Rogers, Nicholas Grimshaw)
2. *Fractals* – expressing self-similar, evolving forms, rather than self-same elements. (ARM, Morphosis, LAB, Bates smart)
3. *Computer blobs* - 'blob grammars' and abstruse theories based on computer analogies - cyberspace, hybrid space, digital hyper-surface. (Greg Lynn)
4. *Enigmatic signifier* – searching for inventive and emergent metaphors that will amaze and delight but are not specific to any ideology. (Frank Gehry - The Bilbao museum, Rem Koolhas, Coop Himmelblau)
5. *Datascape* - constructing datascapes based on different assumptions and then allowing the computer to model various results around each one. These are then turned into designs which create new forms of bottom-up organization not possible to realize before the advent of fast computation. (MVRDV)
6. *Landforms* – The basic metaphor of the earth as a constantly shifting ground rather than the terra firma we assume. Matter comes alive in this architecture at a gigantic scale. (Peter Eisenman, FOA's Yokohama Port Terminal)

He then maintains that architecture is the first field in human culture to consciously express the new scientific discoveries, or what he calls 'The new paradigm.' This assertion is misleading since there are several manifestations in various fields relating to ecology, systems and complexity theories[1], and Jencks chooses to ignore them. Salingaros (2004), a mathematician and architectural theorist, disagrees with Jencks' assumptions about architectural representations of the new sciences. Salingaros claims that the architectural manifestations that Jencks sees as representing new scientific ideas, are only sculptural representations of certain abstract ideas but do not actually represent the continuous, complex processes that are manifested in living systems. "It turns out that there is a basic confusion in contemporary architectural discourse between processes, and final appearances. Scientists study how complex forms arise from processes that are guided by fractal growth, emergence, adaptation, and self-organization. All of these act for a reason. Jencks and the deconstructivist architects, on the other hand, see only the end result of such processes and impose those images onto buildings" (Salingaros, 2004: 45).

The question that we can now ask is how can architecture reflect such complex living processes in a way which is not just based on formal considerations? As Salingaros notes, the key distinction is to see how ecology may inform architecture not as object but as process.

First of all, therefore, we must be able to understand the difference between *objects* and *processes*. According to Turchin (1991), a scientist and cybernetics philosopher, a process is "an action which we see as a sequence of continuing sub-actions. The states of the world resulting from sub-actions are referred to as *stages* of the process. Thus we see a process as a sequence of its stages." The main difference between a process and an object is, according to Turchin, that objects are constant with respect to certain cognitive actions, while processes represent an ongoing change.

This may lead us to distinguish the first principle which represents the difference between objects and processes – the principles of on-going change, flux, or *fluctuations* in living systems.

<u>Principle (1) Fluctuations</u>

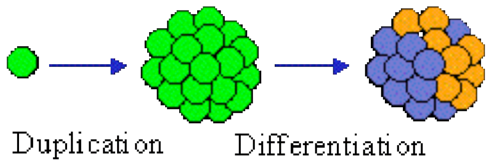
Living systems are not static. They constantly need to adapt themselves to changing internal and external conditions. Living systems thrive to maintain their *homeostasis*, their equilibrium, in order to sustain their internal organization and to be able to develop without giving in to external disruptions. This ability of living systems to produce and maintain their own organization is called 'Autopoiesis'. An Autopoietic machine is a machine organized (defined as a unity) as a network of processes of production (transformation and destruction) of components that produces the components which: (1) through their interactions and transformations continuously regenerate and realize the network of processes (relations) that produced them; and (2) constitute it (the machine) as a concrete unity in the space in which they (the components) exist by specifying the topological domain of its realization as such a network (Maturana and Varela, 1973: 78-9).

---

[1] The study of living systems - how they interact, function and develop, have influenced many fields outside the sciences. Researchers in: Philosophy and Ethics *(Naess: 1973, Ray Griffin: 1998),* Education *(Orr: 1992, O'Sullivan: 1999),* Economics *(Lovins: 1994, Khor: 2001),* Sociology *(Schumacher, 1973, Bookchin: 1994),* Engineering *(Sendzimir: 2002),* Feminism *(Diamond and Orenstein: 1990),* Psychology *(Shepard: 1998, Bateson: 2000),* Neurophysiology *(Maturana and Varela: 1973)* and others, are finding ways to apply the new scientific findings to their fields in various ways.

A living system, then, changes constantly according to its own changing internal conditions and the need to maintain its own homeostasis. But beyond that, a living system must also react to external conditions that may threaten its structure.
Rosney (1997) explains that "for a complex system, to endure is not enough; it must adapt itself to modifications of the environment and it must evolve. Otherwise outside forces will soon disorganize and destroy it. This is true for ecological systems as well as sociological systems. The paradoxical situation that confronts all those responsible for the maintenance and evolution of a complex system, whether the system be a state, a large organization, or an industry, can be expressed in the simple question, How can a stable organization whose goal is to maintain itself and endure be able to change and evolve?" (Rosney, 1997: 2)
Looking at biological systems we can notice that complex multi-cellular organisms have physiological systems that enable them to adapt to changes in their internal and external environment. These systems adapt the organism to changes that would otherwise disrupt its efficient functioning. The physiological and other adaptive systems also enable the organism to adapt to internal and external changes that occur as it develops from an egg into a fully-grown organism. Again, in the absence of these adaptive systems, the changes could damage the organism, and disrupt its proper development (Stewart, 2000: 75).
If we look at the human body, for example, we can see that our heart rate, blood pressure, breathing, metabolic rate, and many other features of our bodies are being adapted continually to small-scale environmental changes. And the pay-off from this continual adaptation is apparently sufficient to justify the considerable investments made by our bodies in the systems that produce this adaptation (Stewart, 2000: 76).
In other words, we can look at the continual adaptation of a living system as a means for survival. The more dynamic the system is; the better it is able to adapt itself to changing conditions in the environment.
Beyond a means for survival, adaptation occurs in living systems to a larger extent in situations where a system transforms itself to become a more evolved system. In these situations, a system may fluctuate quite drastically and as a result – achieve a higher complexity of order. This process is called 'metasystem transition.'
According to Turchin (cited by sharov, 2000), a metasystem transition requires the following 2 steps:

1. Duplication of the original system, and
2. Establishment of control over multiple copies.



In this figure, the initial element duplicates, then differentiation follows. Differentiation is a typical (but not necessary) result of control of elements by the entire system. However, control always changes system components in order to increase the performance of the entire system (Sharov, 2000:1).
Why does a living system need to transform and become more complex? Since the systems are in constant interactions with their environments, they need to be able to adapt to changes that occur in the environment in order to continue to survive. Since the environment itself consists of evolutionary systems which continually grow and become more complex, the living systems which interact with this changing environment will

need to grow and change accordingly. The net result is that many evolutionary systems that are in direct interaction with each other will tend to grow more complex, and this with an ever-increasing speed (Heylighen, 1994).
We have observed so far that living systems display two complementary dynamic phenomena that are both essential aspects of a living system's self-organization. One of them, which may be described loosely as self-maintenance, includes the processes of self-renewal, healing, homeostasis, and adaptation. The other, which seems to represent an opposing but complementary tendency, is that of self-transformation and self-transcendence, a phenomenon that expresses itself in the process of learning, development and evolution. Living organisms have an inherent potential for reaching out beyond themselves to create new structures and new patterns of behaviour (Capra, 1982).
The principle of fluctuations is manifested in both phenomena: a living system fluctuates in order to maintain its internal structure, and it also fluctuates (rather more drastically) in order to evolve and transform itself into a more complex structure.
Fluctuations can thus be seen as a basic principle constantly manifested in living systems.

In terms of the first principle of fluctuations, this means that architecture needs to learn from living systems: how can a system maintain its stability while still allow change and adaptation to occur? It might be useful now to inquire into the actual structure of living systems: what kind of structure allows a system to remain stable while at the same time enables it to constantly change and transform itself?

Principle (2) Stratification

Living systems are structured hierarchically. They consist of different levels which interact with one another. The hierarchical order is usually constructed in a 'bottom-up' manner. This means that the smallest parts of a system produce their own emergent properties [emergent properties are properties that occur as a result of the interactions between the components in the system]. These are now the 'lowest' system features and form the next level of structure in the system. Those system components then in turn form the building blocks for the next 'higher' level of organization, with different emergent properties, and this process can proceed to higher levels in turn. The various levels of the system can all exhibit their own self-organization (Lucas, 1996).
Self-organization means that the system can organize itself without the help of any external agent. It is as if the system knows how to arrange itself into an ordered pattern. One of the most common examples of self-organization is crystallization, the appearance of a beautifully symmetric pattern of dense matter in a solution of randomly moving molecules.
So, the system self-organizes itself in a structure of stratified order – multiple levels, so that each level can have its own organization. It is important to distinguish that the stratified order is necessary for the organization of complexity. Since the various systems levels posses differing complexities, the stratified order makes it possible to use different descriptions for each level.
A 'higher' level, emergent property will typically constrain the behaviour of the 'lower' level components. This is called *downward causation*. It is as if the higher level exerts its influence downward to the lower level, causing the molecules to act in a particular way. Downward causation is to be contrasted with the more traditional 'upward' causation underlying Newtonian reductionism, where the behaviour of the whole is fully determined by the behaviour of the parts (Heylighen, 1997: 12).

This influence of the higher levels on the lower levels helps to maintain the order within the system as a whole and to make sure that the system will achieve its goal of self-maintenance and evolution. Unlike a disordered or random process which can tend in any direction, the processes that occur in a living system have a purpose. The process of interactions in living systems is subjected to the influence of the whole of which it is part. Its range of choices is limited as it becomes a differentiated part of the larger process committed to the achievement of a single overriding goal (Goldsmith, 1998).
The nature of the interactions between the different levels or subsystems can be visualized by imagining a few relatively autonomous organizationally closed subsystems that continually interact with one another. Those interactions will then determine subsystems at a higher hierarchical level, which contain the original subsystems as components. These higher level systems may continue to interact until they define a system of yet a higher order. In this way, we can imagine a hierarchical order where at each level we can distinguish a number of relatively autonomous, closed organizations. For example, a cell is an organizationally closed system, encompassing a complex network of interacting chemical cycles within a membrane that protects them from external disturbances. However, cells are themselves organized in circuits and tissues that together form a multi-cellular organism. These organisms themselves are connected by a multitude of cyclical food webs, collectively forming an ecosystem (Heylighen, 1997: 11).
One of the major differences between a 'top-down' hierarchical structure and a 'bottom-up' hierarchy, is that in the latter one the process of formation of the hierarchical structure emerges out of minute adaptive processes of each level to the one that preceded it. In the 'top-down' hierarchy the higher levels exert their power over the lower levels and emergent properties (those that occur as a result of interactions and adaptation of the components to one another) are less likely to occur. In a 'top-down' hierarchy, a replacement of one of the lower components will not have the same effect on the system as a replacement of one of the higher components, while in a 'bottom-up' hierarchy; a replacement of any one of the components will have the same effect on the rest of the system.

In terms of the second principles of stratification, we can begin to ask: how can a building's design emerge out of the interaction between its properties and different layers? How can the design shift from an *imposition* of order into an *emergence* of order? This may lead us to distinguish the third principle in the formation of living systems – the nature of the interactions between the parts; the principle of *interdependence*.

Principle (3) Interdependence

The principles of fluctuations and stratification explain that the structure of a living system is in constant change: components in a system constantly interact in order to create higher and higher levels of organization, and even when the system reaches homeostasis it keeps fluctuating in order to adapt to outside influences. The changes that keep occurring in the system keep the system unified thanks to the connections between the parts.
Salingaros explains that "when components are joined together to form a complex system, properties emerge that cannot be explained except by reference to the functioning whole. Actually the connectivity drives the system: in order to create the whole, the connections grow and proliferate, using the components as anchoring nodes for a coherent network" (Salingaros, 2004: 48).

It now becomes apparent that the connections between the parts play a major role in the maintenance and evolution of the system. But how do these connections work? What is so special about them that gives them the power to regulate the whole system?
The connections between the components and between the different levels can be described as intricate and non-linear pathways, along which materials, nutrients, energy and information alternatively flow. These flows affect the components on the different levels in a circular manner. Change in one component is fed back to the system through its effect on the other components to the first component itself. This feedback loop can be either positive or negative feedback. Heylighen explains that "feedback is said to be positive if the recurrent influence reinforces or amplifies the initial change. In other words, if a change takes place in a particular direction, the reaction being fed back takes place in that same direction. Feedback is negative if the reaction is opposite to the initial action, that is, if change is suppressed or counteracted, rather than reinforced. Negative feedback stabilizes the system, by bringing deviations back to their original state. Positive feedback, on the other hand, makes deviations grow in a runaway, explosive manner. It leads to accelerated development, resulting in a radically different configuration" (Heylighen, 1997:10).
The notion of the feedback loop was examined by the cybernetics scientists. Cybernetics, a science developed in the late 1940's, had focused on understanding the principles of organization in complex systems (both living and artificial systems): how systems use information and control actions to steer towards and maintain their goals, while counteracting various disturbances. Cybernetics is concerned with those properties of systems that are independent of their concrete material or components. This allows it to describe physically very different systems with the same concepts, and to look for similarities in form and relations between them. The only way to abstract a system's physical aspects or components while still preserving its essential structure and functions is to consider relations: how do the components differ from or connect to each other? How does the one transform into the other? (Heylighen & Joslyn, 2001).
One of the problems that cybernetics encountered at some point was that there is a big difference between the properties of the systems themselves from those of their representing models, which depend on us as their creators. The system's descriptions will always be subjective, and therefore, it may be more accurate to include the observer in the description of the system. This notion was groundbreaking in scientific terms, since science was no longer considered entirely objective. To stress the matter further, Davis (1989:77) mentions Rosen's approach to complexity. Rosen explicitly recognizes the subjective quality that is involved in complex systems. He stresses that a key characteristic of complex systems is that we can interact with them in a large variety of ways. It is not so much what a systems *is* that makes it complex, but what it *does*.
Foerster (1984) makes a deeper leap forward when he claims that information is not contained within the system itself but that the system is only a vehicle for information. The information is perceived only through the observer. "We only have to perceive lectures, books, slides and films, etc., not as *information* but as *vehicles* for potential information. Then we shall see that in giving lectures, writing books, showing slides and films, etc., we have not solved a problem, we just created one, namely, to find out in which context can these things be seen so that they create in their perceivers new insights, thoughts, and actions" (Foerster, 1984: 194). Complex systems, then, because of their open nature, allow an endless variety of interactions to occur with the system, and the interactions are those that give the system its meaning, each according to its context. In other words, if we bring the discussion back to architecture, we can suggest that once a building is constructed as a complex system, it will be perceived and conceived differently according to its context and to the people that interact with it. A building

which will be able to change constantly in relation to natural and cultural processes that interact with it will be a building that is constantly created and re-created not by a single designer but by endless amount of forces and users that come into contact with it.

We can now begin to ask how does the understanding of the three ecological principles may change the way in which we perceive and design buildings?

The principle of **fluctuations** suggests that buildings may be designed and perceived as places where different cultural and natural processes interact. The building should reflect the processes that occur on site, and the more it allows the processes to be experienced as *processes* rather than *representation of processes*, the more it will succeed in connecting people to the reality of the site.

The principle of **stratification** suggests that the building's organization should emerge out of the interactions between its different properties and levels. This kind of organization allows complexity to be managed in a coherent manner.

The principle of **interdependence** suggests that the relations between the building's properties are reciprocal. The 'observer' (designer and user) as well as the site are inherent properties in the building. The interdependence between the properties is ongoing throughout the life of the building.

Bibliography

1. Capra, F. (1982). *The turning point*. London, Flamingo.

2. Davis, P. (1989). *The cosmic blueprint*. London, Unwin Hyman Ltd.

3. Foerster, V.H. (1984). *Observing systems*. California, Intersystems Publications.

4. Goldsmith, E. (1998). *The way: an ecological world view*. USA, The University of Georgia Press.

5. Goodwin, B. (2002). In the shadow of culture. *The next fifty years: Science in the first half of the twenty-first century*. Brockman, J. (Ed.), New York, Vintage books.

6. Heylighen, F. (1994). The growth of complexity. *Principia cybernetica web*. http://pcp.vub.ac.be. 2004

7. Heylighen, F. (1997). *The science of self-organization and adaptivity*. http://pespmc1.vub.ac.be/Papers/EOLSS-Self-Organiz.pdf. 2004

8. Heylighen, F. (1998). Basic concepts of the systems approach. *Principia Cybernetica web*. http://pcp.vub.ac.be. 2004

9. Heylighen, F. and Joslyn, C. (2001). Cybernetics and second order cybernetics. *Encyclopedia of Physical Science & Technology*. R. A. Meyers. New York, Academic Press. Vol. 4**:** 155-170.

10. Jencks, C. (1995). *The architecture of the jumping universe*. London, Academy editions.

11. Lucas, C. (1996). Self-organizing systems FAQ. http://www.calresco.org/sos/sosfaq.htm. 2004

12. Maturana, H. and Varela, F. (1973). The organization of the living. *Autopoiesis and cognition*. London, D. Reidel publishing company.

13. Rosnay, D. (1997). Homeostasis: resistance to change. *Principia Cybernetica web*. http://pcp.vub.ac.be. 2004

14. Salingaros, N. (2004). *Anti-architecture and Deconstruction*. Germany, Umbau-Verlag.

15. Sharov, A. (2000). Metasystem transitions in biology. *Principia Cybernetica web*. http://pcp.vub.ac.be. 2004.

16. Spirn, A. (1998). *The language of landscape*. New-Haven, Yale University Press.

17. Stewart, J. (2000). *Evolution's arrow*. Australia, The chapman's press.

16. Turchin, V. (1991). Process. *Principia Cybernetica web*. http://pcp.vub.ac.be. 2004.

17. Willis, A. (2000). The limits of sustainable architecture. www.teamdes.com.au/pdf_files/limits%20. 2003.