Urban Metabolism of Low Carbon Cities

Introduction

As Jacobs (1969) observed, "*An essential quality marked by all living cities is high degree of organized complexity*". Contemporary rules for urban form, however, reduce both complexity and connectivity in today's cities and, most of the time, these rules fail to deliver urban coherence and livable cities. Jacobs believed that planning was one of the principal obstacles to achieving organized complexity. She viewed urban dynamics as a product of a small urban grain and a high diversity of activities (Zhang, 2010). Her description, consciously or not, anticipated a framework for conceptualizing cities as metabolic systems, as do the writing of McLoughlin (1969) who wrote of 'man in ecological settings'. More recently, we have seen the approach adopted more broadly in the growing body of work in urban metabolism (Gandy 2004; Girardet 1992; Kennedy et al 2007; Wolman, 1965) in gaining an understanding of sustainable cities.

This paper reviews our understanding of urban metabolism as a concept and suggests directions in which this concept can be extended in its application in urban design, in search to develop models for Low Carbon Cities. To do this, however, we must examine its underpinnings. The metabolic understanding of the city has been enabled by an engagement with systems theory. Although planning was already adopting systems theory in many areas by the 1960s, the primary application focused on inter-relations in-between land-use and transport (Buchanan, 1963). In late 1960s, McLoughlin (1969) applied systems theory not only to promote location theory, but also to question the role of 'end-state' master plans, envisaging town plans as trajectories and not propositions of resolved ideal futures (Taylor 1998).

> *"The form of the plan is that of trajectory of states at suitable time-intervals"* (McLoughlin, 1969).

The emergence of the systems view of planning can be seen as a logical response to the perceived shortcomings of physical master plans. But in the same time, between 1950s and 1960, town planning was also changing from being primarily an art to being primarily a science. It happened at a time when the scientific approach was gaining ground in many fields, grounding decisions on scientific evidence (Taylor, 1998). This movement was not dissimilar to the ideas of the European Enlightenment in the eighteenth century, which postulated that man is capable of improving quality of life based on scientific understanding of the world (Taylor, 1998).

The perspective taken is that of Descartes, which breaks up problems into small known elements and solves them incrementally without context:

> *"…all science is certain, evident knowledge"* (Descartes, 1994).

Such evidence therefore does not admit the unknown and can only address the known. Cartesian philosophy has underpinned our scientific thinking from Newton through the industrial revolution to the twentieth century and can be seen as the direct to the Corbusian house as a machine (Le Corbusier 1923) and the Cartesian city (Le Corbusier 1922). The world was still visualized as series of fragmentary objects without relationships between these elements, perhaps one of the fundamental failings of twenty century planning. As we now know, this approach pushed us increasingly away from sustainable solutions.

Systems theory was often criticized as not adequate for reaching decisions and therefore to satisfy planning criteria (Webber, 1963). Instead of approaching the city as a set of interrelated processes, the city was conceptualized as discrete systems: zoning, infrastructure, transport and services were all dealt with in isolation. In this framework, each system is maximized individually, flaunting an essential rule of systems theory which states that maximization of each sub-system will result in a larger system which cannot perform to its full potential.

> *"If one tries to maximize any single variable, instead of optimizing it, this invariable lead to destruction of the system as whole"* (Capra, 1995*).*

Metabolism and the city

Today, once again academics and professionals are returning to concepts of system thinking, using this to understand cities as complex adaptive systems where a complex system is defined as a functional whole consisting of interdependent and variable parts. Complex systems are very unlike conventional systems such as machines. The elements of a complex system do not have fixed relationships, fixed behaviors or fixed quantities and therefore their individual functions are impossible to define in Cartesian ways. As Jacobs noted in 1969, *living cities* are characterized by complexity (Jacob, 1969). A high degree of organized complexity within urban form contributes to quality of life, but essential to this complexity, the difference between whether something is alive or dead, is an active metabolism.

Definition of Metabolism

Metabolism, as defined by Oxford Dictionary is:

> *"…the chemical processes in living things that change food, etc. into energy and materials for growth"*

Everything that is alive is made up from building blocks that contain only six elements: carbon (C), hydrogen (H), oxygen (O), nitrogen (N), sulphur (S), and phosphate (P). Also most of the structures that make up microbes, plants, animals are made of just three basic elements, or classes of molecule: amino acids, carbohydrates and lipids (fats). Any living organism depends on these molecules and metabolic processes make sure that these molecules are produced, or broken down and used as energy source, in digestion and use of food. Furthermore any living organism must obey the laws of thermodynamics. Oxford Dictionary defines thermodynamics as:

> *"…the science that deals with the relations between heat and other forms of energy"*

The second law of thermodynamics states that the amount of entropy (disorder) will tend to increase if system is closed. However all living organism are open systems, which allows for exchange matter and energy with its surroundings. This also means that all living systems are not in equilibrium; instead they perform as dissipative systems that maintain their state of high complexity by increase of entropy in their environments.

In nature the environment, in which most of the organism live, is changing all the time and therefore metabolism processes tend to be finely regulated, to ensure a constant set of conditions within the cells, known as homeostasis. Regulated heavily by enzymes, metabolism self-regulates in response to changes in the levels of substrates or products.

Metabolism as an urban metaphor

> *"…cities are continuous converters of materials into artificial objects."*

It is clear that Marx had a clear understanding of ecological disruption caused by industrialization and capitalism (Marx, 1844). In *Economic & Philosophical Manuscripts* defined urban metabolism (Marx, 1883). He was probably the first person to do it. In his critique of industrialization, he described metabolism as process of exchange of material and energy between nature and society. He also defined the concept of natural capital, and warned us that natural capitalism will have power to control society unless we change the way we use our resources and learn how to control this process.

> *"Just as the savage must wrestle with nature to satisfy his needs, to maintain and reproduce his life, so must civilized man, and he must do so in all forms of society and under all possible modes of production. This realm of natural necessity expands with his development, because his needs do too; but the productive forces to satisfy these expand at the same time. Freedom, in this sphere, can only consist in this, that socialized man, the associated producers, govern the human metabolism with nature in a rational way, bringing it under their collective control instead of being dominated by it as a blind power; accomplishing it with the least expenditure of energy and in conditions most worthy and appropriate to their human nature. But this always remains a realm of necessity. The true realm of freedom, the development of human powers as an end in itself, begins beyond it, though it can only flourish with this realm of necessity as its basis"* (Marx, 1981).

Today we are very much aware that natural capital, on which our civilization depends to create economic prosperity, is rapidly declining, and furthermore the rate of this decline is increasing proportionally to the levels of material gain. Natural capital theory recognizes the essential interdependence between the production and use of monetary capital and the depletion of natural capital.

Based on Marx's writing, Foster (2000) came with the concept of *Metabolic Rift,* which offers a critique of environmentalism and portrays capitalism, and not modernism, as an essential problem associated with our environmental crisis. Whether we blame modernism or capitalism for our current environmental crises, cities are systems of production and consumption where human behaviors directly influence the use of land and the demand for supply of resources (Turner, 1989). Unfortunately these processes are not metabolic processes as we can observe in nature for they are linear and incomplete and therefore cannot deliver on our needs for sustainability and Low Carbon Cities.

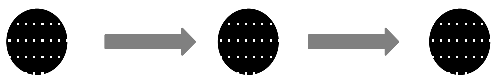

Fig. 1 Linear Metabolism

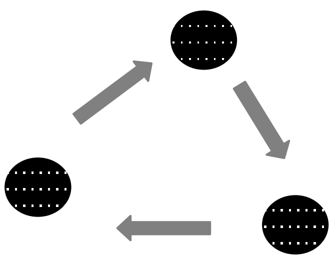

Fig. 2 Circular Metabolism

The failure in understanding of metabolism in recent literature can be illustrated in the distinction between linear and circular metabolic processes. Linear metabolism is defined by input, which is unrelated to output, such as where nutrients are removed from land never to be returned. Circular metabolism is evident where every output can be used as an input for another process. Although circular metabolism, essential for natural systems to survive, comes as obvious answer to model our cities, most cities depend on a linear metabolism. We are all aware that cities require significant inputs; including substantial energy, to survive and that they generate significant outputs, such as CO2. Unfortunately we are doing little to change this system.

Concept of metabolism: infrastructure and waste

We have been using the concept of metabolism to predict and assess the demands of cities for food, water, raw materials, fuel, etc. We can make now very accurate predictions and the basic needs of the city; we can model the goods and traffic movement from and into the city, as well as the demands for electricity, gas and water. Based on that information, the infrastructure of the city is constantly modified in order to accommodate ever-increasing demand. More roads, more cables, more pipes are put in place; the more infrastructure we put in place, the more the demand for services and goods growth. Without any doubt our infrastructure tends to increase our consumption and waste. There is adequate evidence to prove the hypothesis that building more roads leads to more traffic, instead of getting rid of congestion (Duranto, 2009)

> *"Here's one more study showing that more roads are not the answer to our rush hour traffic problems: they only attract more cars"* (Cernansky, 2011)

The same evidence comes from Nadis and MacKenzie who believe that increasing transportation capacity has been totally ineffective in eliminating congestions in the cities and surrounding areas:

> "*Building more roads, or widening existing roadways, has been the traditional response to traffic problems. History shows, however, that this approach leads only to increase in traffic and lower air quality"* (Nadis and MacKenzie, 1993).

Ever since the nineteenth century, the metabolism of the city has been closely related to the infrastructure that was installed in an uncoordinated manner in response to civic needs. In the past two centuries, urban infrastructure has been added to cities in order to promote efficiencies, health and safety, facilitating the exchange of goods and, therefore, improving city economies. Unfortunately most of the systems installed operated, and still operate, entirely independently of one another (often in competition) and share little physical space and replacement is usually carried out by adding to the inventory of systems, not through replacement or enhancement. The infrastructure placed in our cities ever since industrial revolution, has been supporting the growth and expansion of urban fringe. We can now move faster, and further, we can rely on electricity, gas, and water, in order to perform the simplest tasks. Infrastructure has become an essential part of our lives. We cannot exist without it; we have become dependent on it. But, as Nadis and MacKenzie (1993) point out, urban infrastructure (especially some urban transport) is increasingly seen as a threat to urban health, safety, economic efficiency and quality of life.

Before the Industrial Revolution, city metabolism was more circular than linear. Although cities were centers of trade, goods production and exchange, the human waste coming out of the cities was used as fertilizer on nearby fields and other trash was broken down over time by microorganisms since most of the materials used at that time were biodegradable. Today we use far too many materials, which are non-biodegradable, including plastics, glass and ceramics, which were promoted at the beginning of twenty century as part of health and safety campaigns. Manufacturers benefit from this since anything that is thrown away needs to be replaced and this in turn creates more profit potential. We have also put infrastructure in place to deal with waste, to make the waste invisible. And what we cannot see we don't have to worry about.

In nature there is no waste. All the organism covert resources into useful products and waste, through metabolic processes, and waste in nature become food and source of energy again. Cities do not operate this way. They produce artificial products, which have very little, if anything to do with the system in which they operate. Being artificial, means that they will never become a source of food, and rarely the source of energy. As the result our cities are center of production of huge amount of waste. Generation of waste as the result of linear metabolism is one of the problem associated with forever increasing ecological footprint of our cities and our inability to create Lower Carbon Cities.

Americans waste or cause to be wasted nearly 1 million pounds of materials per person per year (Hawken, 2008). Each household in Australia spends approximately AU$ 1,250 per year on goods that are never used (Hamilton, 2005). For the Australian nation, this is an expenditure of AU$10.8 billion, larger than government expenditure on universities and roads. What we buy and do not use is waste; even if we don't throw away it away, we need to store it which, in turn, leads to ever larger houses or rented storage. As the result, unnecessary consumption of products leads to consumption of more land, more resources and create more demands on infrastructure.

> *"There is something sad about all this stuff we work so hard to buy, can't live with, but inevitably can't bear to part with"* (Botsman, 2010).

Our cities are full of storage areas. Parking, storage, unused gardens, roads services, water in leaking pipes, the list is endless and our consumerist approach to life is making situation worst by a minute. Our cities are full with things which most of the time will never be used again. Billions of assets remain unused, stored and eventually thrown away as waste, and we know only too well about all the problems associated with waste. We are all familiar with the Great Pacific Garbage Patch, also known as the Pacific Trash Vortex. Videos and images abound of this floating collation of waste, estimated to be twice the size of Texas and in some places more than 30 meters deep, containing a high concentration of plastics, chemical sludge, and other debris that have been trapped by the North Pacific Gyre (Day 2011). A similar patch exists in the Atlantic Ocean, The North Atlantic Garbage Patch (Lovett, 2010). Researchers have shown that plastic marine debris affect at least 267 species worldwide, and majority of them do not reside in the North Pacific Gyre. These patches are direct consequences of the way in which linear metabolism effects our environment.

In nature all the organism work very hard in order to keep our metabolic processes going and support life. We have been doing our best to get rid of many workers from our eco system. Unemployment, also create huge problem within our cities. According to the International Labor Organization in Geneva, nearly one third of the population either is unemployed or have jobs, which cannot support their families. It looks like we wasting huge amount energy that could potentially be used. Stahel and Reday presented to the European Commission in Brussels, in 1976 the report *The Potential for Substituting Manpower for Energy*,which illustrated an impact on economic competitiveness, waste prevention and resource savings that could be achieved by circular economy or economy loops. The report was published later as *Jobs for Tomorrow: The Potential for Substituting Manpower for Energy* (Stahel, 1981).

The goal of a sustainable city is ever receding. With a focus of processing raw materials into consumer goods and thus to waste, the linear model defeats sustainability goals.

> *"In scientific terms, there is no phenomenon called production, only transformation. No matter how energy or resources are used, scattered, or dispersed, their sum remains essentially the same, as dictated by the Law of Conservation of Matter and Energy. This law is of more than passing interest because it means that the term 'consumption' is the abstract figment of economists' imagination — that it is physically impossible in all processes or transformations. What is consumed from the environment is not matter or energy but order or quality — the structure, concentration, or purity of matter. This is a critically important concept because it is "quality" that business draws upon to create economic value"* (Hawken, 2008).

It is here that a consideration of metabolism can help as we consider the various functions of a city; the metabolic processes ought to keep the city alive. Is it adequate to simply "keep it alive"?

Loop Economies

In searching for examples where waste is close to zero, we can turn to slums. In Indian slums there is no unemployment, and recycling is close to 90 percent. While we are suggesting we should live in slums, there is a useful indicator, for in slums, there are few *consumers* and lots of *transformers*. If we where to remove consumers from our cities and replace them with *transformers* will we be able to change our linear metabolism into circular one?

Analyst and architect by training, Walter Stahel, and chemist Michael Braungart independently promoted the idea of "cradle to cradle", back in 1980s. Walter Stahel believes that you could actually turn the economy from a linear industrial economy into a loop and by doing that avoid the problems associated with resource extraction and waste management (Stahel, 2010). Braungart visualizes:

> *"…the world as a series of metabolisms in which the creations of human beings, like creation of nature, become "food" for interdependent systems, returning to either an industrial or biological cycle after their useful life is completed." (*as quoted in Hawken, 2008:17)

What they were trying to develop was economy very different to one where goods and products are made in order to be sold and latter on thrown away into the rubbish bin. Instead they proposed what they called *service economy,* where consumers were no longer buying goods and turning them to rubbish, but obtaining *services* by renting or leasing goods directly from manufacture. Manufactures were made responsible for maintaining the goods and therefore making sure that the products, which they produced, were well made, long lasting and require minimum maintenance. In this kind of economy the product is a means not the end. And the product remains as an asset as long as it is well maintained.

Car Share as service economy

As an illustration of a different economy we can look at the evolution of models for car rentals. At first glance car rental may just look as the right step forward, especially if we realize that majority of car rental companies are closely related to car manufactures. Until 1995 General Motors owned National Car Rental Company; Ford and Volkswagen recently bought up the car-rental companies Hertz and Europcar respectively (Economist, 1996). But car rental companies define criteria for car usage by entering into arrangement with car manufacturers and rental companies can benefit from cars designed for limited life spans, thus cheaper to buy and frequently replaced with new models. As a linear metabolism, however, it generates significant waste.

Approaching car ownership in the *service economy,* as described above, the product can become not the end but the means. In 1995, Peugeot introduced the TULIP Concept (Transport Urbain Libre Individuel and Public), an electric car as alternative transportation within the city. The idea was similar to rent a bike system, which became so popular in recent years in cities like Melbourne, London or Copenhagen. Users will be able to take the cars and leave them in different points in town. In this way Tulip cars may become part of public transport, allowing users to interchange from public transport to personal vehicle, depending on requirement of their journeys. The founder of Zipcar, a membership-based car sharing company, founded in 2000, advertises his cars, as cars *"…your mother said you could never have. When you are not using it, it is someone else's problem, and who cares."* Zipcar is using the same psychological and sociological strategies to encourage people to share cars, as strategies that have been used for years to encourage people to buy cars. Their advertising ask consumers: "*Today's a BMW day. Or is it Volvo day?* The Service Economy, or product service system can:

> *"… cater to desire for 'just one more' but without creation of waste. The "what we feel like today' mentality makes the option of picking and swapping between a Prius, a Mini Cooper, a Toyota Station Wagon, and an eight-person People Mover appealing."*

The most important aspect of *service economy* is its ability to satisfy consumer needs to own something, for a short period of time, and being able to replace, or change it without creating any waste. The next step will be to make people desire not objects by services. Steffen suggests that:

> *"… we need to create services that enable people to tell each other who they are through the use services instead of through ownership of things"* (Steffen, 2006)

A Service Economy system addresses all the same consumer needs as the model of mass consumption but it also helps to address some of our most worrying economic and environmental problems (Botsman, 2010). Changing our attitudes and turning away from mass consumption to collaborative consumption will have a huge impact on creation of waste and storage.

What's mine is yours

So maybe one way to deal with changing our metabolism from linear to circular could be by changing the way we understand own relationship to physical products and individual ownership. Do we need to own something, or can we own it partially. What benefits do we get from total ownership if any? Are we more concern with access or ownership? Botsman and Rogers (2010) argue that:

> *"…we don't want the CD; we want the music it plays. We don't want the answering machine; we want the messages it saves. In other words, we want not the stuff but the needs or experiences in fulfills"* (Botsman, 2010).

This concept of not owning is as old as our civilization. In the past people relied much more on borrowing and sharing. In the ancient city of Ur, dated from around 2010 BC, we can find documents suggesting equipment being lease by priests to the farmers. Aristotle's declared that:

> *"on the whole, you find wealth much more in use than ownership"* (Choucroun, 2011*).*

Many companies around the world are starting to apply Aristotle's idea, believing that access is now the privilege, while ownership is just a burden (Choucroun, 2011). This is a revolutionary change in relationship between producer and consumer, a fundamental shift from an economy of goods and products and hyper-consumption to new economy of service and flow. To put it in another words, an economy based on flow of economic services that can protect the natural capital, on which it is built.

Urban Metabolism Today

We have been transforming our natural environment into human-dominated system, with very different set of processes, creating a new set of ecological conditions. The idea of city being a part of ecosystem is not new. From 5th century BC Hippocrates, through 1st century AD Vitruvius to Leon Battista Alberti in 1485, all understood the complex model of interdependence between cities and nature (Spirn, 1985). Geddes (1915) engaged with evolution of the city a part of nature; he was probably the first person to apply biological and evolutionary concepts together with theories on development and evolution of city forms. However, the first concept of urban ecology came from Chicago School in 1920s. Burgess and Park (1925) came with theory of concentric rings. Working in the sociology department at the University of Chicago, they developed theory of urban ecology that proposed cities as environments like those in nature, governed by similar forces that effected natural ecosystems. Based on Darwinian concepts, competition was one of the most dominant forces the governed the growth. This competition was clearly visible when observing competition for land or resources, which in turn led to the special differentiation of urban space into zones. Burgess and Park further described how businesses and people move out of the city center when they become more prosperous and how more desirable areas command higher rents (Burgesss, 1925; Park 1921, 1925). Their model was based on succession theory borrowed from plant ecology and postulated that most cities would have five concentric rings. Areas of social and physical deterioration would be concentrated near the city center and the more prosperous the area the further it will be from the center. This theory was one of the earliest to explain the spatial organization of urban areas and was long lasting; Davis (1992) was still using concentric ring theory to describe the structure of Los Angeles. In other disciplines, especially in planning or urban design, concentric theory was quickly criticized as over simplistic and abandoned. The conceptual framework based on ecology and nature was considered as superficial and over simplistic, since it ignored social and cultural dimensions as well as political, economic, and industrialization aspects of urban geography.

Recently the succession model has been replaced by a new model of dynamic change, regulated by three properties of ecosystems:

- the potential for change
- the degree of connectedness
- the system resilience.

The resilience of a system is one of the most important factors, which decides whether system is able to survive. It determines how vulnerable the system is to unexpected change and surprises (Gunderson, 2002, 2009). In ecology, resilience is described as the capacity of system to respond to disturbance and ability to fast recovery. First introduced by Hollings (1973), resilience is defined as*: "the capacity of a system to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure, identity, and feedbacks"* (Walker, 2004).

In *Panarchy: Understanding Transformations in Human and Natural Systems,* Gunderson and Hollings ask a fundamental question whether it is possible understand human environment interactions as their own unique system and to stop seeing environment as component of social systems, and society as sub-component of ecological system (Gunderson& Hollings 2001). Gunderson and Hollings have been working on establishing the theoretical framework for linking local interactions between human dynamics and ecological processes to the overall structure of urban landscape (Hollings, 2002). Hollings and Gunderson's work combined with *hierarchy theory,* has led to development of models of nested hierarchies with vertical and horizontal structures interacting with each other (O'Neill et al. 1986; Wu 1995; Wu and David, 2002). *Hierarchy theory* can be described as a dialect of general systems theory. It probably developed as part of movement towards a general science of complexity, based on work of chemist Ilya Prigogine, and economist Herbert Simon, which focuses on levels of organization and scales observed within system. Hierarchy theory could be applied to social, economic, or biological system. It could also play important role when studying urban landscapes.

In 1960s, 1970s and 1980s more models of urban development were based on ecology. Some described cities as a heterotopic ecosystem, which depends on large inputs of energy and materials from the outside and has ability to absorb emissions and waste (Odum 1963, Duvigneaud 1974, Boyden et al.1981). Odum based on his work on general systems theory, developed ecosystem ecology theory, by proposing additional laws of thermodynamics. He was first to publish papers in areas of ecological modeling (Odum, 1960), ecological engineering (Odum, 1963), ecological economics (Odum, 1971), and even on ecosystems for life support function in space travel. Duvigneaud in *La synthese ecologique: populations, communautes, ecosystemes, biosphere, noosphere,* analyzed ecosystems in terms of energy transfers with neighboring ecosystems.

More recently Boyden et al (1981) made a connection between ecology and social processes, by focusing on understanding the complex, multi-scaled interactions that characterize human-ecological situations and their associated problems. *The Metabolism of Cities* (Wolman 1965) describes the resource consumption and waste generation of the cities. Following Wolman's theory, metabolism studies have been conducted all over the world. The comparison that is now available to us can tell us how urban form, ground water withdrawals, heat island, nutrient cycles and material supplies impact not only urban metabolism but also urban footprint. Most of the analyses seek to quantify the overall fluxes of energy, water and waste within bigger environment. We can now assume that urban metabolism can provide us with valuable information about heath of the city, which could be measured by energy efficiency, material cycling, waste management and efficiency of infrastructure.

> *"…what is new today is the acknowledgment that the sciences of ecology and of the cities have pretty much ignored each other until very recently. The theoretical perspectives developed to explain or predict urban development and ecosystem dynamics have been created in isolation; neither perspective fully recognizes their interdependence"* (Alberti, 2008)

Alberti describes how different disciplines have been studying the same issues from their own perspective only. Ecologists concentrated on ecosystems from points of view of dynamics of species populations in the environment; economists completely ignored the dynamic interactions between land development and environmental change, when studying patterns of urban development; and social scientists have crude representations ecological processes. It is not uncommon to have all the different disciplines working on the same site but using different techniques, methodologies, and systems, with data that is always represented in isolation, without being able to show it in interdependent model. As the result we have ecological models of urban ecosystems with vastly simplified human processes.

Urban Metabolism Tomorrow

If our cities are central to the problems of ecological crisis, it is easy to predict that they maybe be very soon central to ecological solutions. One way to go forward could be to understand the metabolic processes within our cities. At the moment cities operate in dramatically different way to natural systems. But like any organisms they concentrate the energy flows from surrounding areas to support huge amount of diverse activities. The main concept that defines life, as defined in this paper, is the continuous flow of energy and matter, which leads to the production of waste. In cities, the waste is constantly produced; in nature there is no waste. In nature a network of chemical reactions form the basis of all the functions and behaviors of organisms. In cities, the form of the city depends on the network of infrastructure, and the form of the city dictate the way we behave, use our resources, and interact with each other. The networks are basic factors of organization of life. Networks within our urban settings are also the basic factor of organization of our cities. Through network of chemical reactions, the organisms in nature, maintain themselves, adapt themselves and regenerate without centralized control. In cities, the network, which support our lives rely mostly on central control and typically are organized as a hierarchy diagram (a tree structure). In nature ecological models are always supported by a large numbers of producer flows; cities have inverted pyramids, where producers are lower in total flow than consumers.

Ecological communities and human communities exhibit very similar basic principles of organization, but ecological communities through the past three billions years have managed to successfully optimize their sustainability, something that human communities have been particularly bad at this. Perhaps if we want to become more sustainable we should start learning some key principles from ecology and see if we could apply them to our future cities. According to Capra (1984), there are four crucial principle of ecology, which we should consider:

1. interdependence
2. cyclical flow of resources
3. cooperation
4. partnership

All four of them dictate how ecosystem organizes itself and optimize sustainability. And all of them are critical in the process of metabolism. As Capra (1997) says we do not want to sustain economic growth, but we need to sustain *the web of life*. Nature sustains life through metabolism and if we were to sustain *the web of life* within the city, we probably should start with infrastructure. The web of life is a network and our infrastructure is a network too. But while living networks constantly correct themselves, our infrastructure has not such ability. Would it be possible to start developing infrastructure that corrects itself, repeats these corrections through self-regulation, which will lead to regulation and then to self-organization? And if we discover that we are already doing it, at least in some places, the next thing we need to consider how we can make sure that the system, which we are producing are resilient enough. Network structures in biology are closely connected to diversity. The more diverse the system the more resilient it becomes. To put it in other words: biodiversity is a consequence of the complexity of networks, and the more complex the networks, the more complex pattern of interactions, and so on.

The different models for future cities, Low Carbon, sustainable and with circular metabolism are already here. As Gibson says:

> *"The future is already here; it is just unevenly distributed"* (Gibson, 1999)

However Gibson also suggests that we are probably still not well equipped to see and take advantages of the processes that are happening around us. We already have technologies and models to implement more circular and less linear metabolism. And these models coupled with available technologies have great potential for change. The change is probably around the corner but it is always so much easier to see the potential and possible trends where things may go, but it is much more difficult, if not impossible to predict when these changes will start taking place.

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