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Article

Eco-Polycentric Urban Systems: An Ecological Region Perspective for Network Cities

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Abstract: The research presented in this paper is a work in progress. It provides linkages between the author's earlier research under the sustainable land planning framework (SLP) and emergent ideas and planning and design strategies, centered on the (landscape) ecological dimension of cities' sustainability. It reviews several concepts, paradigms, and metaphors that have been emerging during the last decade, which can contribute to expand our vision on city planning and design. Among other issues, city form—monocentric, polycentric, and diffused—is discussed. The hypothesis set forth is that cities can improve the pathway to sustainability by adopting intermediate, network urban forms such as polycentric urban systems (PUS) under a broader vision (as compared to the current paradigm), to make way to urban ecological regions. It discusses how both the principles of SLP and those emergent ideas can contribute to integrate PUS with their functional hinterland, adopting an ecosystemic viewpoint of cities. It proposes to redirect the current dominant economic focus of PUS to include all of the other functions that are essential to urbanites, such as production (including the 3Rs), recreation, and ecology in a balanced way. Landscape ecology principles are combined with complexity science in order to deal with uncertainty to improve regional systems' resilience. Cooperation in its multiple forms is seen as a fundamental social, but also economic process contributing to the urban network functioning, including its evolving capabilities for self-organization and adaptation.

Keywords: sustainable city-region planning; polycentric urban systems; landscape ecological planning; holism and systems thinking; resilience; urban metabolism and self-reliance; cooperation

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"When we deal with cities we are dealing with life at its most complex and intense." [1]

1. Urbanization and Sustainability

Exponential growth of the world population has occurred only for the last 100 years, where it more than quadrupled: 1.6 billion in 1900, 2 billion in 1930, 3 billion in 1960, 4 billion in 1975, 5 billion in 1987, 6 billion in 1999, and presently approaching 7 billion [2]. Noteworthy is that the world urban population grew much faster. Population migration to live in cities and metropolises is a global trend. Presently about one in two people live in urban areas, which is estimated to increase to two out of three in 2050 [3]. Some estimates point to an even faster growth, where the urban population will reach about 61% in 2030 [2]. For example, in Europe approximately 75% of the population lives in urban areas and estimates point to approximately 80% in 2020 [4], representing the urbanization level of most industrialized nations today [5]. In the USA *circa* 80% of the population lives in urban areas [6]. One of the most urbanized nations in the world is Australia with more than 92% of its population concentrated in six State capital cities and other urban areas [7].

New megacities (>10 million) are growing in the developing world. The population in India (1.2 billion) has more than doubled during the last 50 years, but the urban population has grown nearly five times. These authors estimate that by 2021 the number of mega cities in India will increase from the current three (Mumbai, Delhi and Kolkatta) to six (including Bangalore, Chennai and Hyderabad), whereby India will have the largest concentration of mega cities in the world [8]. In China, since the "reform and openness policy" in 1978, urbanization has seen a tremendous boost, most prominent in the Pearl River Delta region during the past two decades, where urban areas have grown as much as 300% between 1988 and 1996 [9]. Economic growth and demographic changes will accompany growth in urban populations, especially in populous China and India, producing ever-greater demands on services that nearby and distant ecosystems provide [5]. Considering mid-sized cities (between one and five million inhabitants) urbanization rates have been steadily increasing globally, which will have profound impacts on natural and agricultural ecosystems, e.g., as reported by [10] to occur in China. "The merits of compact development were extensively debated in the 1970s. Critics questioned the claimed environmental, transport and costs benefits, and argued that was contrary to market forces towards sprawl, the decentralization of work and residents' desires. Debates focused largely on developed-country contexts and centrist approaches, but attention shifted to the merits of centrist versus decentrist compact development in the 1990s" [11].

Opposed to the concentration of urban population in large monocentric, high-density, and frequently compact cities is another important form of urban development—urban sprawl or the so-called "diffused city", which has increased during the last decades worldwide. It is broadly characterized by a dispersed spatial pattern of a mix of urban land uses, where four characteristics dominate: low-density, scattered development (*i.e.* decentralized sprawl), leapfrog development, and commercial strip development, and is associated with unplanned incremental urban

development [4,12,13]. Typical in the USA in the early part of the 20th century, it was promoted by the utopian city vision of Frank Lloyd Wright' Broadacre City of 1935 [14]. Later this phenomenon proliferated to other parts of the world. In Europe, where cities were traditionally much more compact, urban sprawl is now a common phenomenon and regarded as one of Europe's major challenges [4]. And it is the most significant and urgent issue in American land use [15].

An alternative, intermediate form of urban development is through a polycentric or multiple-nuclei structure, which some define as being compact [13]. Polycentric development is a form of decentralized concentration of numerous small- and medium-size urban centers, frequently (but not restricted to being) organized around a compact city center, forming large urban agglomerations. This concept was introduced in urban geography by Harris and Ullman in 1945, representing an evolution from multi-center city to multi-center city region or polycentric city region. The process of sub-urbanization associated to a large city originated numerous settlements located in its surroundings. From this original concept a more complex urban pattern evolved, especially in Europe—polycentric urban regions, which are made up of numerous polycentric city regions [16]. Polycentricity can emerge from two distinct set of relationships: (1) intra-urban patterns of population and economic activity clusters, e.g., Los Angeles, London or Paris; (2) interurban patterns such as the Randstad-Green Heart complex in the Netherlands, the area of Padua-Treviso-Venice in Northern Italy, the Southern California urban region, and the Kansai area in Japan [17]. Other distinctions of polycentric forms are made according to its evolution process: some emerged as a result of households fleeing from the city center to the suburbs, followed by the relocation of firms, and services—the centrifugal mode; others via a coalescence of existent cities and towns of similar dimension into contiguous functional urban regions. Examples of the latter are the Randstad, the Rhine-Ruhr metropolitan region, and the Flemish Diamond [18]. This urban form "seems to have become one of the defining characteristics of the urban landscape in advanced economies" [17]. Since the last decade or so the polycentric approach has been widely implemented in the European Union as a cornerstone of its spatial development policy [19]. There is a sufficient agreement "about the desirability of a polycentric urban structure organised on small and medium-sized, compact centres, well connected through an efficient network of public transport" [12].

Landscapes are being subjected globally to dramatically significant changes due to the continuous urbanization process and a strong use (and misuse) of earth resources [20]. Urbanization is the most dramatic form of irreversible land transformation, affecting both landscapes and the people who live in and around cities [21]. Although urban population growth over the past century has occurred on a very small portion of the global terrestrial surface (<3%), the impact of cities has been global, with 78% of carbon emissions, 60% of residential water use, and 76% of wood used for industrial purposes attributed to cities, affecting energy flows, biogeochemical cycles, climatic conditions, biodiversity and ecosystem functioning and services far beyond its limits [2,5,21]. As Eugene P. Odum describes it: "Great cities are planned and grow without any regard for the fact that they are parasites on the countryside which somehow supply food, water, air, and degrade huge quantities of wastes" [22].

Novel approaches are needed to address the complex issues arising from increasing world population, depletion of resources and decreasing quality of human habitat. A more holistic way of thinking must be adopted to reduce global environmental stresses [23]. The sustainability paradigm has emerged from these global issues. Sustainability is a powerful but hard-to-define concept that

confronts many disciplines, including planning. Sustainable planning is inherently multi-dimensional, aiming to assure the viability of ecological, social and economic systems presently and into the future [24]. Sustainability is the capacity of the earth to maintain and support life and to persist as a system [25]. This concept adopts a systems perspective being relevant to systems ranging from the global to the local scale. It strives for natural resource management consistent with the preservation of its reproductive capacity [22,26]. Recently sustainability science is emerging, focusing explicitly on nature-society interaction dynamics, and promoting inter- and transdisciplinarity perspectives, where landscape ecology should and would make significant contributions [27]. Many scientists believe that promoting sustainability is the over-arching goal of landscape (and regional) planning [28]. Cities must play a more central role when looking at global sustainability for several reasons [29], including the fact that they have increasingly sizeable ecological footprints [5,22,30,31], notwithstanding that "(…) cities epitomize the creativity, imagination, and mighty power of humanity. Cities are the centers of socio-cultural transformations, engines of economic growth, and cradles of innovation and knowledge production" [31], and that they represent arguably the most important habitats for humans [2]. "A sustainable city must achieve a balance among environmental protection, economic development, and social wellbeing. Urban sustainability requires minimizing the consumption of space and resources, optimizing urban form to facilitate urban flows, protecting both ecosystem and human health, ensuring equal access to resources and services, and maintaining cultural and social diversity and integrity" [31. It is not surprising that one of the key research priorities in landscape ecology is the integration of ecological research into urban policy, planning, design, and management strategies [32].

This paper is centered on the (landscape) ecological dimension of cities' sustainability, with a particular focus on horizontal or chorological processes from a regional perspective [33, 34]. The hypothesis set forth in this manuscript is that cities can improve their sustainability by adopting intermediate, network urban forms such as polycentric urban systems under a broader vision (as compared to the current paradigm), to make way to urban ecological regions. This regional vision considers three main components: a network of cities, towns, and rural villages linked by corridors —ecological, e.g., hydrological networks, cultural, *i.e.* transportation and information infrastructures, and multifunctional (ecological + cultural); a multifunctional hinterland of rural and natural resources aiming at increasing regional self-reliance, structured by a network of ecological systems that provides for key-ecological services (the region´s "ecological backbone"); and the interrelationships between cities and their functional hinterland. Landscape ecology principles such as holism and systems theory, and its basic tenet—the relationships between ecological and cultural patterns, processes and change, are combined with complexity science in order to cope with uncertainty to improve regional systems' resilience. Cooperation in its multiple forms is seen as a fundamental social, but also economic process to the urban network functioning, including its evolving capabilities for self-organization and adaptation.

2. Emergent Metaphors, Concepts, and Paradigms for Ecological City Planning and Design

In the last decade several concepts, metaphors, and paradigms have been emerging, which can contribute to expand our vision on city planning and design. Some of those described below have been approached in earlier publications of the author [24,33-35,38-40], further developed and or summarized for the purpose of this section: holism and systems thinking; autonomy or self-reliance;

urban metabolism; ecological footprint; uncertainty; adaptation; redundancy; the "form and function" principle; the "interdependence" principle, landscape context and chorological relationships; sustainability; sustainable landscape planning (SLP); landscape as an appropriate planning unit; strategic urban and landscape planning; connectivity; cities' networks and polycentric urban systems, and their hinterland; ecological infra-structure; dual perspective for landscape management; learning-by-doing and landscape monitoring; co-operation; and disciplinary convergence, and inter- and transdisciplinarity. Others had been proposed by several authors in the context of biological and ecological theory [23,41-43], complexity theory and theory of change [44,45], landscape ecology [46-49], urban ecology [26,30,32,46,50-55], landscape ecological planning ([25,56,57], green urbanism [29], regional, urban and open space planning [12,13,17,19,30,58-73], landscape urbanism [74-77], planning and design of green infrastructures [78,79], ecological urbanism [77,80], landscape ecological urbanism [80], and sustainability science [27,81]. Among these is auto- or self-organization and emergent properties; panarchies, resilience, regime shifts and critical transitions; variability; social ecological systems (SESs); ecosystem services, and landscape as a service matrix; sustainable regionalism; safe-to-fail; and translational research.

2.1. Holism

Holism states that the whole is more than the sum of their parts. It provides a new way to analyze landscapes, and argues that landscape elements receive their meaning or significance by their context, or their position within the whole [47]. An ecosystem's external "linkages" with the landscape are as important to proper functioning as the internal ecosystem environment [23]. Some even argue that context is more important that content [42]. This recognition of the importance of context emerges from systems thinking [42]. Besides landscape elements *per se* it is important to account for the (spatial) relationships between the elements that make up a landscape. All landscape elements, regardless of their specific land cover type, influence landscape functions through their spatial characteristics. This is a fundamental inter-relationship applicable to any landscape type, urban, rural, or natural. Thus, looking at landscapes holistically provides a common way of thinking about functions and processes, and how structure affects, and is affected by them [24].

The different systems that comprise our global habitat are highly interdependent. Indeed little is completely isolated from its surroundings, including people and cities. Urban landscapes are formed by a series of landscape elements such as houses and buildings, roads and highways, gardens and parks, *etc.* These elements are not isolated. They establish a number of relationships between each other. For example, housing is more expensive near urban parks because these generally provide for several urban functions, services, or amenities that are looked for by urbanites, e.g., urban climate is more amenable nearby parks which has a significant influence in bio-comfort, they provide for recreation opportunities, and a close contact between people and nature. Additionally cities are not isolated, and establish relationships with the surrounding rural landscapes and other cities.

2.2. Systems Thinking

According to Capra "(…) to understand things systematically literally means to put them into a context, to establish the nature of their relationships (…); the root meaning of the word "system" derives from the Greek "synhistanai"—to place together" [42]. "Systems thinking is a method of

scientific enquiry that allows one to understand and investigate complex realities" such as landscapes [82], and can be characterized as an attempt to find common principles that apply at different levels of scale and across different types of phenomena [83]. The systems approach is hierarchical and views landscapes nested within larger systems (supersystems) and themselves composed of lower order systems (subsystems). A useful analogy can be made with the human body. Consider human cells as building blocks, which are organized as tissues, organs, organs systems (circulatory, respiratory, *etc.*) and ultimately as an organism. The human body is comprised of a group of systems. Similarly, individuals are part of communities that together form towns, states, and so on. Landscapes can be understood as groups of ecosystems, and regions as groups of landscapes [24]. The concept of networks introduced by early ecology enriched the systemic worldview where ecosystems are understood as networks of individual organisms [42]. Landscapes can also be viewed as networks of interacting ecosystems [46], cities as networks of urban elements (neighborhoods, buildings, infrastructures, *etc.*) [52], polycentric urban structures as networks of cities [19,60], and so forth. In the above context it is most important to acknowledge that when the notion of hierarchy (between levels) was introduced into ecological systems theory, it was not originally intended to portray a top-down, rigid structure involving a vertical authority and control, as tends to dominate in its everyday definition; the dynamic, adaptive nature of nested structures tended to be lost [45]. The latter introduced a new term to emphasize the latter interpretation: "Panarchy captures the adaptive and punctuated evolutionary nature of adaptive cycles that are nested one within the other across space and time scales" [45]. Here, the lesson to take home is that although living systems do present an organizational structure in hierarchies, it does not implies a top-down, vertical, and rigid but rather an adaptive, dynamic, network structure, whose elements work in complement with one another (see next section on autopoeisis).

In general, different systems levels have different levels of complexity, and each exhibits systemic properties that do not exist at lower levels—the so-called emergent properties, since they emerge at that particular level. Most important in contextual thinking is that the properties of the parts can only be understood within the context of the larger whole. This reverses the Cartesian paradigm where the dominant belief is that in systems the behavior of the whole can be understood entirely from the properties of its parts, leading to the Descartes's analytic method, an essential characteristic of modern scientific thought, in contrast with the ideas synthetized hereby on holism and system thinking. A crucial point in systems thinking is the ability to shift from one system level to another back and forth [42]. In some instances, is useful to perceive the larger context of a specific locale, or of a specific issue of concern (the forest; the "big picture") in order to recognize, understand and integrate the relationships between that place with its surroundings—the flows of energy and matter that crosses through and influence decisively its functioning. Complementarily we focus on the place in itself, in its parts (e.g., the trees of a forest) and most important in the intra-relationships between the parts (interaction between different trees); often we need to go even deeper and approach the specifics of each component (the functioning of a tree, its root system, the canopy, *etc.*), which in turn are systems by themselves.

Systems thinking is an emerging field. It was in the 50s and 60s that Ludwig von Bertalanffy, a biologist from Vienna, established his general systems theory or GST [84]. According to Steiner "(…) in GST control is maintained through the feedback received by what is dubbed the "control

mechanism." The control works like a homeostat (…), and the result is a regulatory action (…) that keeps the system in a dynamic equilibrium" [85]. Since then it has developed over the last 40 years in many different disciplines and through a range of applications [83]. According to these authors "(…) the report The Law of Sustainable Development, produced by the European Commission, states: ''Today, no serious study and application of the principles of sustainable development is possible without the help of systems science''. (…) Concepts emerging from systems thinking have had a profound influence (…) in helping to understand ''the complexity of ecological and organizational systems" [83]. Based on a comparative review of existing participatory and ecological planning methodologies the latter realized that "(…) the ecological planning methodologies have been developed in a whole within the last three decades reflect an increasing interest in the insights of systems thinking methodologies. Several of the key thinkers in these areas cite systems thinking and living systems biology as an inspiration in the development of the methodologies" [83].

System thinking appeals also to city planning theorists [85], and cities can be seen as systems. Inspired by Urban *et al*., Grove *et al*. adopt a hierarchical approach where households are a part of larger systems—neighborhoods, which in turn are part of a larger system—the city [86]. Cities can also be a part of larger systems, e.g., metropolitan areas [33] or other type of urban agglomerations worldwide, e.g., polycentric urban regions and network cities [19, 60]. Closely linked with holism and systems thinking are the concepts of self-organization and autopoeisis presented below.

2.3. Self-Organization and Autopoiesis

Self-organization is a most important and distinguishing characteristic of living systems that explicitly or implicitly incorporates in itself several important concepts to understand complex systems, such as socio-ecological systems (SESs) that constitute cities and metropolitan systems. "Self-organization is a process in which pattern at the global level of a system emerges solely from numerous interactions among the lower-level components of the system. Moreover, the rules specifying interactions among the system's components are executed using only local information, without reference to the global pattern. In short, the pattern is an emergent property of the system, rather than a property imposed on the system by an external ordering influence. (…) Critical to understanding our definition of self-organization is the meaning of the term pattern. As used here, pattern is a particular, organized arrangement of objects in space or time. (…) Emergent properties (…) are features of a system that arise unexpectedly from interactions among the system's components. An emergent property cannot be understood simply by examining in isolation the properties of the system's components, but requires a consideration of the interactions among the system's components. (…) Systems are complex not because they involve many behavioral rules and large numbers of different components but because of the nature of the system's global response. Complexity and complex systems, on the other hand, generally refer to a system of interacting units that displays global properties not present at the lower level. (…) Complexity in a system does not require complicated components or numerous complicated rules of interaction" [87].

Some diverse phenomena have been described as self-organizing in biology, such as homeostasis (property of a system that regulates its internal environment and tends to maintain a stable, constant condition of properties like temperature or pH, in a dynamic equilibrium), and flocking behavior (such as the formation of flocks by birds, schools of fish, *etc.*) [45,87]. "Prigogine and Stengers (1987)

showed that the evolution of settlement patterns and urban networks behave like complex systems out of equilibrium and that self-reorganisation of the spatial structure to adapt to the changing functional needs is characteristic." [47]

Poiesis is a Greek term that means making or production. Autopoiesis means self-making or self-production. Under this concept living beings are seen as systems that produce themselves in a ceaseless way through a network of interactions or production processes (the system's metabolism). The function of each component is to participate in the production or transformation of other components in the network through the relationships that specify the system. An autopoietic system is at the same time the producer and the product, in a circular organization (e.g., the nervous system) [26,41,42]. Notably the organization of a living system is always a network pattern [42].

Autopoeisis is a general organization pattern common to all living systems, whichever the nature of its components, *i.e.* the organization is independent of the properties of its components. The system´s structure is the physical embodiment of its organization, comprising both the system´s components and the functional relationships between components. Capra uses a bicycle to illustrate this concept: the systems' components are the frame, pedals, handlebars, wheels, chair, *etc.*, which have a set of functional relationships between them; the complete configuration of the functional relationships constitutes the bicycle's organization pattern (all of these relationships must be present to give the system the essential characteristics of a bicycle). Additionally to organization (pattern) and structure, this author argues for a third criterion when describing the nature of life. Process, as the link between organization and structure, regards to the activity involved in the continued embodiment of the system's organization pattern. Using a designer's metaphor, organization is the design sketches that are used to build the bicycle; the structure is a specific physical bicycle; and process, the mind of the designer [42].

Recently it was proposed to substantially expand long term ecological research (LTER) by including the human dimension focused on coupled socioecological systems (SESs). Long-term socioecological research (LTSER) regards society-nature interaction as a dynamic process in which two autopoietic systems, society, and nature interact, an approach particularly relevant to understand the relationships typical of complex urban environments [55].

Note that, from a self-sufficiency perspective, there is no such thing as sustainable cities [88]. Cities by themselves are not autopoietic since they are highly interdependent on the surrounding landscapes [38] continuously importing energy, food, materials, *etc.* and exporting the products of its metabolism, e.g., waste [22] (see section below on urban metabolism).

2.4. Resilience

The capacity of a system to maintain its self-organization is closely related to the concept of adaptation (see above), and of resilience. Resilience comes from the Latin resilire, which means to rebound or recoil. This concept was first introduced to ecology and the environment in 1973 by Crawford (Buzz) Holling, who promoted, among others, the use of systems theory [43]. Resilience is the ability to absorb disturbances and reorganize while undergoing change, while retaining the same function, structure, identity, and feedbacks, the capacity for self-organization, and the capacity to adapt to stress and change [89]. Adaptive capacity resides in aspects of memory, creativity, innovation, flexibility, and diversity of ecological components and human capabilities [90]. It is important to

distinguish two paradigms where resilience emerges that may be labeled equilibrium and non-equilibrium [51]. The first is focused on stable equilibrium conditions and is presently applied only to very particular situations; the second is more inclusive and deemed useful for urban planning and design, focusing on systems' dynamic and evolutionary capacity to adapt and adjust to internal or external change. Hereafter this second meaning is adopted.

The concept and theory of resilience have a growing appeal in the disciplines of ecology and planning [80], and one can identify an increasing dialog between these two disciplines in addressing urban environments. In this context an urban planner and an ecologist proposed a new metaphor, "cities of resilience", that both disciplines can share [91]. Ahern argues for an adaptive approach to planning and design, including monitoring and "learning-by-doing" [56,57,78,79], much attuned to the proposals of "designed experiments" [54]. Resilience capacity together with innovation can play an important role via "responsible experimentation, developing a culture of monitoring, and learning from modest failures" [79]. According to this author "resilience capacity can be strengthened by biodiversity, modularity, tight feedbacks, social capital, acknowledging slow variables and thresholds, and innovation "[79]. Resilience is at the core questions to be approached by the emerging science of sustainability [81], including also self-organizing complexity, inertia, thresholds, complex responses to multiple interacting stresses, adaptive management, and social learning [27]. There is common agreement in the literature that systems, organizations and people who are able and willing to adapt tend to be more resilient [43].

2.5. Redundancy

""Redundancy" is defined by the Oxford English Dictionary (OED) as "the state or quality of being redundant; superfluity, superabundance;" (…) "redundant" is further defined as "excessive, abounding too much." [92]. The word, paradoxically, has substantially different meanings in the fields we survey, yet most, like the definition from the OED, carry a negative connotation. In their work these authors refer to redundancy of multiple units (building blocks) within some larger system and provide a thorough discussion of different kinds of redundancy, ranging from genetic to engineering systems. This review includes ecological systems where "redundancy is typically of the "multiple non identical copies" sort within ecosystems, or across ecosystems" and is associated with biodiversity, ecosystem function, and resilience [92].

Functional ecological redundancy is basically the degree to which organisms have evolved to do similar things [93]. Several species fill similar ecological roles increasing the number of potential community organizations that can uphold similar ecosystem functions. By maintaining the distribution of redundant species across multiple time and space scales it is possible to maintain key-functions of the ecosystem in the face of change, which makes the system resilient [53,88]. On a different note Rosenfeld argues that in terms of practica1 conservation issues, the concept of functional redundancy is a double-edged sword. For example, it is important to prioritize species protection, but at the same time it postulates that certain species perform similar roles in ecosystems and thus redundant species can be expendable [92]. He recognizes, however, that this interpretation was not intended by its original proponent, where redundant species were seen as necessary to ensure ecosystem resilience in face of perturbation [94].

In the context of landscape ecological urban planning and design, Ahern argues for the advantages of redundancy (and modularization), and distributed or decentralized systems as opposed to concentrated. Here redundant elements or components provide for the same or similar urban functions, which help spreading risks, and thus constitute "strategies to avoid putting all your eggs in one basket," and for preparing and pre-planning for when (not if) a system fails [79]. It represents a "humble" design tactic where one acknowledges that it is not possible (and desirable) to exert total control over socio-ecological processes, and just try to mediate indeterminacy: "(…) since we can never be completely certain of how water flows and other ecologies work, one needs to build in redundant systems to make sure it works (…)"[95].

2.6. Urban Metabolism

Urban metabolism is a metaphor that looks at the city as a system, which requires inputs and outputs; if we look at it as an organism, it requires food and other resources, e.g., water, energy, materials, *etc.* and releases the byproducts of its metabolism to the environment, *i.e.* waste. This metaphor was developed earlier in the 20s and 30s by the human ecological approach of the so-called "Chicago School" where the city was conceived as a closed and functional system that could be treated as an organism or "superorganism" [96]. Later, in the 60s, a few academics also adopted this perspective but rarely if ever used it in policy development in city planning: "by looking at the city as a whole and by analyzing the pathways along which energy and materials including pollutants move, it is possible to begin to conceive of management systems and technologies which allow for the reintegration of natural processes, increasing the efficiency of resource use, the recycling of wastes as valuable materials and the conservation (and even production) of energy" [63]. Since this metaphor was essentially biological in nature, the latter extended the original idea to "include the dynamics of settlements (transportation, economic and cultural priorities) and livability in these settlements (health, employment, income, leisure, *etc.*), which he called the "Extended Metabolism Model of the City".

This emergent notion has been very useful in quantifying the horizontal (chorological) relationships and trends in consumption and waste generation of expanding cities. Over two decades several studies have shown large increases in the output of materials of cities, e.g., food and building materials, and outputs such as food wastes, paper and plastics. As an example, in Beijing "total carbon emitted from solid-waste treatment increased by a factor of 2.8 from 1990 to 2003." [5]. Additionally the metabolism approach provides a way to integrate biophysical and socioeconomic processes [55]. Analyses of urban metabolism include the analysis of the pathways along which material and energy [22,63], and more recently information flow [55]. Urban metabolism is consistent with the holistic and systemic approaches to cities, and new city planning approaches that consider the relationships established between the built environment and its wider landscape (spatial) ecological context, as in the ecological footprint approach [33].

2.7. Cooperation and Competition

Capra argues for a change in the XXI century that brings new thinking and values, shifting from self-assertion to integration [42]. The author points out that neither tendency is good or bad and both are essential aspects of all living systems. However the Western industrial culture overemphasized the former and neglected the latter. For example, the competition paradigm, a self-assertive value, needs to

be replaced, or better, complemented by cooperation in order to enable sustainable human ecological systems. In order to provide support for the above stated argument we can look at living systems and its organization once more to provide insight and analogies that arguably could be useful for the core theme of this paper—sustainable city planning and design.

An important concept in the context of autopoeisis is structural coupling [98], which is closely related with the notion of interdependence. It occurs whenever there is a history of recurrent interactions leading to the structural congruence or compatibility between two (or more) systems (e.g., between two organisms) or between a system and its containing environment. Note that in this context the structure of the organism will not change as specified or instructed by the environment's structure, and *vice versa*—these interactions only "triggers" structural changes in one another. As long as a set of nondestructive, compatible or congruent interactions exist between a system (e.g., a city) and its environment (e.g., the surrounding landscapes, and or the hinterland) these two act as mutual sources of perturbation, triggering changes of state [98]. These authors provide an example in the context of cities: "Thus for example, in the history of structural coupling between the lineages of automobiles and cities there are dramatic changes on both sides, which have taken place in each one as an expression of its own structural dynamics under selective interactions with the other" [99]. In sum, structural coupling is always mutual; both organism and environment undergo transformations, and for example changes in cities trigger influences in its "region of influence" (see below) in multiple ways, and *vice versa*. Expanding on the example above mentioned on structural coupling and the influence of cars in cities, the urban form of the "diffuse city" (or sprawl) was facilitated by an increased urban mobility provided by individual transportation. A similar effect can be seen in the star-shaped urban form of post-industrial cities that expanded along the main axis of transportation infrastructure —railways, roads and highways, or both. Reciprocally cities congestion, partially due also to urban form, induced also the appearance of smaller cars—city cars. Both phenomena are intrinsically connected, reflecting a strong interdependence. The corollary is that sectorial approaches (in this case the city, for one side, and the car industry for the other) are bound to influence each other, significantly. Thus the need to look at the several dimensions of cities as a whole, where systems interact with other systems, at different levels, rather than from a reductionist perspective, focusing on one single dimension or on particular places as isolated features.

Maturana and Varela explained above how organisms interact to each other and with the surrounding environment [41]. The notion of structured coupling is useful to provide for insights on how organisms adapt to the environment. Below the authors continue this explanation by shedding light to "competition" and "natural selection" as the mechanisms that are traditionally related to "survival" of some species over others, and thus to species evolution. "The maintenance of the organisms as dynamic systems in their environment is centered on a compatibility of the organism with their environment which we call adaptation. The adaptation of a unity to an environment (…) is a necessary consequence of that system's structural coupling with that environment. (…) Conservation of autopoeisis and conservation of adaptation are necessary conditions of the existence of living beings". Important to the concept of cooperation (*versus* competition) is the above mentioned authors' observations on how Darwin supposedly proposed the process of "natural selection": "We often hear that what Darwin proposed has to do with the law of the jungle where each one looks out for himself, at the expense of others in unmitigated competition. (…) This view of animal life as selfish is doubly

wrong: (a) instances of behavior which can be described as altruistic are almost universal in natural history; (b) living organisms existence is not geared to competition but to conservation of adaptation, in an individual encounter with the environment that result in the survival of the fittest" [100]. At this point it is important to clarify the distinctions between the three basic types of interactions between species: competition "leads to negative outcomes for both groups involved", whereas symbiosis "benefits both participants", and predation, or parasitism "benefits one and is detrimental to the other" [101]. Complementarily it is important to note that "(…) in nature there is no competition. What exists is competence". As noted by Maturana, when two animals meet before the same piece of food and only one eats, this happens because in that specific moment one of them was the most competent to do so. But this does not mean that the animal that was unable to eat is doomed to be, from that moment on, forever forbidden to eat until death arrives. This does not happen in nature. However, when circumstances involve competition in human culture, the individual who succeeds to eat does not satisfy himself with this fact: he or she needs to make sure that the one who was not able to eat must cease forever to be a threat. In other words, competitive men usually do not feel sure of their competence, so they have the need to get rid of whoever could jeopardize them. In other words, when men cannot trust in themselves as living beings, their peers must be eliminated as soon as possible. But even so—let us insist on this point—this cannot be ascribed to the cultural dimension in itself: it plays such a role in a culture like ours, which does not know how to deal with aleatority and ceaseless change. And these conditions, as we know, constitute the very essence of life. In other words, we do not know how to deal with autopoiesis—that is why we feel ourselves in need to aggress it and to deny its reality" [102]. As part of the paradigm shift in sciences presented in earlier sections the "neo-Darwinian conception of evolution" is challenged by the notion of co-evolution, "(…) that emphasizes cooperation as the creative play of an entire evolving universe" [103].

Autopoesis, self-organization, adaptation, complex systems and the above discussed concepts have been increasingly integrated in the last decade in social sciences research. "In the literature on complexity theory applied to social systems, 'self-organization' has a more specific meaning, for example, 'a process in which the components of a system in effect spontaneously communicate with each other and abruptly cooperate in co-ordinated and concerted common behaviour" [104].

As an example in spatial planning, cooperation between urban areas is at the very core of the polycentric regions paradigm adopted in the European Union. Here cooperation is viewed as a competiveness factor for the intervening cities: "Promoting complementarity between cities and regions means simultaneously building on the advantages and overcoming the disadvantages of economic competition between them" [19]. In the spatial planning policy framework for the European Union the polycentric paradigm plays a pivotal role. Complementarity is approached from a broad perspective and should focus not merely on economic issues but together with other urban functions such as environmental quality and social well-being. As an example, when one considers the emergence of polycentric communities foreseen to result from the implementation of this spatial planning approach, if we are to assure those to be socially viable, then co-operation should be fostered and built on common interests of all participants, as to re-integrate the n cities of the urban ensemble into one single community [65].

Another dimension of cooperation is the most needed collaboration between ecologists and social scientists, and planners and designers in inter- and transdisciplinarity studies focusing on urban

environments, which are found critical to the emerging sustainability science [32]. Arguing for a stronger emphasis in the human dimension of sustainability and for both inter- and transdisciplinarity studies in planning Botequilha-Leitão emphasized the need for a symbiosis, within the SLP framework, between natural sciences (e.g., landscape ecology), social sciences (e.g., collaborative methods), and humanities (e.g., landscape history) as they all hold much value to an integrated, transdisciplinary planning approach [38]. It also argued for bridging the gap across a (too often) fragmented and divorced science (and knowledge as a whole). This holds true also between science and planning. In a world still dominated by reductionist thinking different areas of knowledge are reluctant to knowledge sharing and cooperation. It does not facilitate a proper, efficient, and true multidisciplinary integration much needed when planning for sustainability. In similar terms Musacchio argues to link sustainable design to sustainability science and calls for an expanded definition of translational research "[The process medical researchers use to bring scientific discoveries from research into clinical practice] (…) directed toward environmental professionals: a collaborative learning process between scientists, designers, planners, and engineers who seek to solve complex environmental problems by connecting scientific theory, concepts, and principles to the design and planning of the built environment. This definition of translational research assumes that such approaches and methods are transdisciplinary—not only are interactions among scientists, designers, and planners important, but public participation is a vital part of the process that should include practitioners, elected officials, local residents, and others" [105].

In the above context it is most important to develop collaborative ecological planning. As argued before public participation in the planning process is essential to successful planning [38,39]. Failure of former planning approaches led to the increasing recognition that collaborative methods are crucial in order to promote more and better citizen participation. Research has shown that people are more likely to accept an issue resolved when they have had a voice in the decision-making process [106]. Landscape planning and design professions have acknowledged this fact and incorporated participation in most methodologies. Meaningful and informed stakeholder and public participation is viewed as a most important dimension in a sustainable land planning process. Bottom-up approaches are needed and citizen participation is a key issue for successful planning, design and implementation of sustainable landscapes. Collaborative methods, e.g., collaborative design, are most useful to understand the cultural dimension and its interface with natural processes [38,107]. Public participation increases acceptance and the implementation success of plans, by increasing plan's legitimacy. It empowers citizens, decreases the participation deficit, and thus contributes for a better democracy, and promotes social connectivity. It also increases citizens' self-esteem and confidence. Finally it helps in accounting for uncertainty in planning by sharing responsibility and involving citizens that will be affected by decisions in the decision-making process, which contributes also for sharing power and thus increases decentralization and shortens the distance between decision fora and the receivers of policies [38].

I finish this section by stating "Axelrod's (1984) principles of cooperation (…)—co-operation can get started by even a small cluster of players who are prepared to reciprocate, can thrive even in a world where no one else will cooperate and can protect itself once established—so long as the co-operation is based on reciprocity and the shadow of the future is important enough to make this reciprocity stable" [108].

3. Envisioning the Cities of the Future

3.1. A Paradigm Shift

More than half of the world's population is urban and this phenomenon will continue to grow, with an emphasis on coastal areas where natural resources, e.g., biodiversity, are particularly concentrated; it is in cities that most of the environmental problems concentrate; moreover cities constitute highly vulnerable situations to the effects of global climate change [5]. Cities are highly vulnerable also due to the almost total reliance on external inputs: some commodities and manufactured goods travel thousands of kilometers between the point of production and the point of consumption [22], which is arguably made possible by an oil-based economy. Industrial societies in general and cities in particular, are the product of petroleum and may implode without it [109]. Not surprisingly "(…) most, if not all, our cities are unsustainable" [31]. However urban spatial planning is primary concerned with the degree of segregation or aggregation of different economic and social functions, efficiency of transportation and delivery of utilities, and efficient filling of undeveloped space [110]. The environmental dimension is usually a secondary consideration (if considered at all). Urban regions' planning targets are traditionally focused on the several dimensions of socio-economical systems such as economics, transportation, housing, industry and so forth and not so much on climate, water, biodiversity, and other ecological systems dimensions [46]. Therefore we need a novel approach in city planning and design to lead us into the path of sustainability.

I argue that one of the key-challenges to Man today is to envision human habitat from a broader perspective (both thematically and spatially) than just the built-up space, *i.e.* urban areas, particularly when considering large urban agglomerations. Planners should mesh both socio-economic and ecological dimensions, and acknowledge the horizontal relationships of both processes with its context, into a unified approach. When planning and designing the cities of the future one should include all of the other landscape functions and processes that sustain them. These include those landscapes that provide for the necessary inputs needed for urbanites not only to survive but to live fully, namely the landscapes of production (and recycling) and recreation, and those that provide for the essential services that forms the ecological backbone that sustain all of the other functions [38] together in regional, cohesive, multifunctional, and resilient landscapes [22,61,73]. It is a shift from the parts to the whole, *i.e.* from the city, the economic-financial dimension, and mostly sectorial-based policies, to considering the city and its "region of influence" (see Section 3.3), and the three dimensions of sustainability—economic, social and ecological—supported by truly integrated policies, and governance institutions.

In a recent past the dominant conservation paradigm was focused on *ex situ* solutions such as zoos to preserve endangered species, and segregation-based, museum-like approaches for preserving the last natural ecosystems from Man's negative influence. Today a paradigm shift in conservation biology is undergoing from single-species management to ecosystem management and from isolated reserves to managing the entire landscape [15,111]. The implementation of wide range ecological networks can be seen in Europe, *i.e.* the ecological network "NATURA 2000" at continental level [19,29,38], at the national level in some European countries such as in the Netherlands [29], among others, at the regional level, e.g., the Regional Ecological network for the Algarve, Portugal [34], or at the metropolitan level, e.g., in the Metropolitan Area of Lisbon [38]. As conservation is broadening its

objectives to encompass the entire landscape as a whole so should humans consider the entire globe as their habitat. The former, narrow perspective of human habitat is rooted in the 17th Century Western culture that viewed Nature, not as its home (habitat) as the ancient Greek did, but solely as a reservoir of natural resources for Man's own benefit, as implicit in Bacon (1624) and Descartes (1636) writings [112]. A legacy of the Enlightenment, this "Cartesian dualism" that maintains the psychoseparation of humans from their natural roots where human enterprise is somehow seen as separate from and above the world. In this period of "transition to sustainability" [81] it must be counteracted and overcome.

To cope with such complex, multidimensional issues that cities are facing entering the XXI century, the cities of the future need novel planning perspectives informed by holistic and systemic thinking. "The major problems of our time cannot be understood in isolation, since they are systemic, meaning they are interconnected and interdependent and must be seen as different aspect of one single crisis—a crisis of perception. This results from an outdated worldview—a perception of reality inadequate to deal with these problems" [42]. The new logic introduced by the information society with its high rates of change and the emergence of new, complex environmental issues calls also for a long-term planning vision that ought to frame everyday decisions. These broad visions would contribute to counteract those small, piece-meals, non-concerted actions decisions that have a particularly high impact in urban and suburban landscapes [111]. Part of the problem is that science has become so reductionist that society is victimized by a "tyranny of small technologies" (deriving from small decisions). "Piece-meal" or "quick-fix" approaches often work well in the short term of economic and political worlds, and when done independently as they often are, the central problem is not properly addressed [47]. According to T. Kuhn we have been experiencing in the turn of the XX century a paradigm shift, both scientific and social [49,113]. "Such a scientific revolution has occurred in the last 20±30 years with the emergence of the new field of what could be called `complexity science'. It has been enabled by the major paradigm shift from parts to wholes, leading from entirely reductionistic and mechanistic toward more holistic and organismic approaches, (…) and systemic thinking" [49].

In the former section I have explored several useful metaphors, concepts, and paradigms for sustainable city planning and design. These are emerging as a response to the challenges for urban planning of the new century, in the context of the abovementioned paradigm shift. Below I will elaborate on the role of the science of landscape ecology for a regional approach to city planning, focusing on some key-concepts and how those new emergent ideas described above can together contribute for better planning the cities of the future.

3.2 The Role of Landscape Ecology for Regional Planning of Cities. The SLP Framework

Landscape ecology, the scientific pillar of the sustainable land planning framework (SLP) [24,38,39], is increasingly relevant to sustainability in general and urban development in particular [31,46]. In order to promote more sustainable approaches to planning in the last decades of the 20th century we observed a transformation of the landscape planning paradigm to incorporate an explicit ecological approach, namely in Europe and in the USA [38,39]. More recently landscape planning begun to adopt landscape ecological principles and tools [24,25,38-40,56,114,115] and extending its principles more or less explicitly to urban planning and design [24,31-40,46,51,53,54, 57,74-78,80,85] *inter alia*.

In earlier works I proposed and explored a framework for sustainable land planning (SLP) [24,38,39]. The SLP framework is a strategic landscape planning approach, based on the science of landscape ecology and several associated key-principles derived from holism, systems theory, and complexity theory described in earlier sections. SLP is proposed as both an art and a science by promoting the integration of the ecological, social, and cultural dimensions into design, planning and management of sustainable landscapes; it thrives for ecological and social equity and for the involvement of citizens and stakeholders at large across the entire planning (circular, iterative, continuous, learning) process (see PROBIO case-study below); and it adopts an adaptive planning approach under a "learning-by-doing" attitude which includes a continuous cycle of implementation-monitoring-evaluation [44] "(…) by treating the adopted planning solution as a working hypothesis rather than a 100% full proof solution (as done traditionally), that should be tested and closely monitored for its consequences" [38]. "Sustainability is a goal that no one as yet knows how to achieve. The act of sustainable planning and design is a heuristic process; that is, one in which we learn by doing, observing, and recording the changing conditions and consequences of our actions" [117]. Together with scenario techniques, and public participation this adaptive approach also contributes to deal with uncertainty both in science and planning [48,57], and thus to increase system's resilience [44,83]. It integrates ecological with social and cultural processes, e.g., by promoting a participated process and by incorporating landscape history, which both contribute to formulate landscape visions. Finally SLP encourages intuitive and creative thinking by incorporating the development of shared planning visions, and the design of spatial planning concepts. The latter are useful to explore possible future directions, and to support the discussion of a broader range of ideas, the development of scenarios and the engagement of both decision-makers and the public at large into the planning process. SLP is arguably appropriate to all planning realms, e.g., water resources [24,40], conservation planning [24,38,39], and urban planning [24,33,38,39].

The research project "Decision Support System for Planning and Management of Biodiversity in Protected Areas (acronym PROBIO, Ref. no. POCTI/MGS/36580/99)" (1999-2003) is an example of the application of the SLP framework [38]. The following description of PROBIO will focus on the integration of the social component via the process of collaborative planning and design implemented.

The major goal of PROBIO was to develop a Decision Support System (DSS) for Planning and Management of Biodiversity in Protected Areas. The DSS integrated landscape metrics, scenarios, and a Multi-Agent System (MAS) in a GIS environment, supported by collaborative planning and design. The study area was the Natural Park of Sintra-Cascais (PNSC), located in the Lisbon Metropolitan Area, in Portugal. The PROBIO project used alternative future planning scenarios in order to anticipate and prevent or minimize environmental impacts on protected areas, and to attract stakeholders' participation, and the public in general to the planning process. Biodiversity indicators based on landscape metrics were useful to evaluate the different planning scenarios or management alternatives. The MAS was developed to model the socio-economic component and to help multi-purpose negotiations between the several (social and economic) agents in the Park, forming the central core for scenario generation. The assumption was that agents modeling could help the PNSC staff enhance its relationships with the social-economic agents involved in the park area. A series of workshops were promoted as to involve public and stakeholders participation. Before the workshops individual meetings were conducted with more than 40 stakeholders (individuals and groups) who supplied

important information about the activity and vision of each participant. This information allowed identifying the main strategic vectors for the development of the region, which were translated into the scenario themes. The first workshop aimed at a pre-diagnosis using a SWOT procedure. At the end a questionnaire was distributed that allowed us to evaluate stakeholders' opinion about the workshop. They thought it to have been relevant, stimulating, informative, and efficient. They mentioned they learned about the issues that were debated and about the other stakeholder' opinions. The goal of the second workshop was to translate the planning issues identified by the stakeholders into a more spatial and detailed form, *i.e.* to reference geographically (present and potential) land use conflicts. This method is referred to as collaborative design. We produced a set of maps in transparencies that allowed to overlap them as in the McHarg method, e.g., natural resources, cultural heritage, zoning plans, *etc.* In the last workshop we presented the results to the stakeholders, in a nontechnical language. Previously we sent to the stakeholders a list of criteria (social, economic and ecological) asking them to rank these according to a dual goal: allow urban development, and protect wildlife. We discussed these criteria with them and produced a new ranking, as a product of a group decision. For this session we divided the stakeholders in groups as done in the other workshops. Then we aggregated the individual rankings (surveys were anonymous) and debated a final ranking with them. These criteria served as input for the MAS, to define rules for the simulation of urban growth in the PNSC. According to both the PNSC director at the time (O. Knoblich, pers. com), and the one that followed a few years later (C. Albuquerque, pers. com.), the experience was highly useful to the ongoing process of the PNSC new zoning plan, and to establish a strong linkage with the stakeholders and the public in general in this protected area. The integration of social sciences with landscape ecology, history, and planning, and computer modeling was crucial to approach the management of protected areas more sustainably by integrating the social-economic with the ecological dimension.

3.3. The Ecological Urban Region

3.3.1. A Chorological Perspective for City Planning

In the last decade studies on urban landscapes adopted a broader perspective by looking at cities as ecosystems, including the relationships established with the surrounding landscapes [5,22,31,33,34,46,70,73]. I argue this a fundamental issue to be taken in consideration when aiming at increasing resilience and thus sustainability in cities, metropolitan areas, polycentric urban regions, and urban agglomerations at large. A key-principle of the SLP framework is the "interdependence principle" [118], which stems from holistic and systemic thinking. It implies the recognition of important interdependencies between ecosystems and human culture. Additionally, the spatial dimension of sustainability is strongly related to the interdependence of land uses, and spatial processes. Implicit in this principle is another system's key-concept embedded in SLP—"context". From a spatial perspective both concepts are strongly related with an important dimension of landscape ecology—the horizontal or chorological approach.

"Traditionally, resource planners and managers do not consider horizontal relationships, for example by ignoring the (ecological and environmental) context in which exploited resources are often, if not always, embedded (De Leo and Levin 1997, p. 9)". (…) Prior to the advent of landscape ecology, even ecologists would not consider context to be a major factor for studying ecological

systems. An ecosystem, or a site based approach, was followed. However ecosystems, and sites, are not isolated. Horizontal (chorological) natural processes or ecological flows are a fundamental component of ecological systems. It is therefore crucial to approach a site from a chorological perspective, considering horizontal processes. Such processes are flows and movements that cross local ecosystems or land uses" (Forman 1999). (…) We have to enlarge our lens of planning to encompass these processes occurring in the (ecological) context where the activity we are planning for takes place. (…) From a systems, hierarchical perspective, the site in itself is a system integrated within a higher system. It is therefore important to explicitly consider the horizontal relationships between a site and the system(s) within which it is integrated" [38].

3.3.2. A Spatial Conflict

Because cities are not planned and managed considering the chorological dimension spatial conflicts arise that need urgently to be addressed. Most cities are located in strategic areas from the natural resources perspectives, e.g., water, seashores, fertile soils, minerals, or combinations thereof. Across its history human populations tend to aggregate in places where there is a high concentration of resources—ancient civilizations appeared in the fertile valleys of most important rivers, e.g., Nile, Tigris, Euphrates and Indo. Presently if one looks at Europe, the United States, and the world at large we can see large cities and or continuous urban agglomerations located nearby the coasts or in rivers' valleys, deltas, and estuaries e.g., Hamburg, Amsterdam (and practically the entire Netherlands), Paris, London, Barcelona, Seville, Lisbon, New York City, Boston, Chicago, San Francisco, *etc.* Regardless, cities are continuously growing. They expand frequently into the productive landscapes that surround and frequently sustain or can sustain them in the future. This causes a spatial conflict, where urbanization usually prevails. For example, the city of Lisbon alone depends for its biological metabolism on an area almost three times the Lisbon Metropolitan Area (LMA) *per se*, *i.e.* 8000 sq.km [62]. Its main water supply comes from a dam (Castelo de Bode) located *circa* 120 kilometers northeast of Lisbon. This is similar to Boston and its Quabbin Reservoir, New York City, San Francisco, and many other cities. A noteworthy aspect is that the LMA has a wide reserve of underground water underexplored, namely in the Setúbal Peninsula located nearby the city of Lisbon. This is the expansion area for the southern part of the LMA, causing among other urbanization effects soil sealing which reduces infiltration into the aquifer systems. In fact the most important aquifers in Portugal are located along the coastline, where the two Portuguese metropolitan areas (Lisbon and Oporto) are located as are large urban agglomerations, e.g., in the region of the Algarve located south of Portugal.

This phenomenon is augmented by growing annual rates of land consumption per capita. For example, in American cities and metropolitan areas, the amount of land consumed by urbanization far exceeds the rate of population growth [120]. To counteract this trend in the USA movements such as "New Urbanism" and "Green Urbanism" promote, among other concepts, more compact urban development and walkable communities, similar to the design of a large number of European cities [29,77]. The fact is that cities tend to expand by frequently destroying their local resource base, increasing dependency on remote areas.

3.3.3. Post-Oil Cities

I argue that planners should be able to envision what can be called "post-oil cities", anticipate the effects of such transformations, and act on it in order to provide solutions that can deal with a new, oil-scarce world that sooner or later will be a reality. Oil was for a long time, and still is an (presently relatively) abundant and cheap, and most of all highly "portable" source of energy (*i.e.* very easy to store and transport, when compared to other alternative energy sources such as electricity and natural gas, among others). It supported a diffuse pattern of urbanization, such as urban sprawl and associated urban mobility levels, mostly with individual transportation as cars, that we can observe today in most cities around the world—the "automobile cities" [70]. It also supports the transportation of many goods that, in the present era of globalization, travel thousands of kilometers from their origin to cities' destiny making ""the operationally inseparable" (primary production is spatially removed from consumption and consumption from most subsequent decomposition)" [26]. However, oil is an increasingly scarce resource. "The world supply of oil is projected to last approximately 50 years at current production rates." [121] "(…) These estimates, however, are based on current consumption rates and current population numbers. If all people in the world enjoyed a standard of living and energy consumption rate similar to that of the average American, and the world population continued to grow at a rate of 1.5%, the world's fossil fuel reserves would last about 15 years" [122]. One cannot avoid wondering how long the world will have abundant and cheap oil. Furthermore oil has no known substitute which bring together those three characteristics that made it such a popular source of energy: abundant, cheap, and most of all highly "portable". "For transport, it is very difficult to find viable alternatives to oil in sufficient quantities to meet current and future demands" [70]. When considering gasoline consumption from the transportation viewpoint, based on a considerable sample of cities worldwide, studies suggest that urban structure within a city is a fundamental factor, with a clear link to urban density [58]. As an example, when looking at Toronto, Canada and the five U.S. cities with lowest gas consumption among their sample, all have a strong inner city area. However Toronto outer area is more compact in population and jobs by, on average, nearly three times. The existence of strong subcenters developed in the suburbs around transit stations seems to play an important role. As a result Toronto presented an annual gasoline use per capita of 265, where the average for the five U.S. cities is *circa* 400. These authors suggest that "(…) subcenters could be the means for more intensive outer area land use", which would decrease gasoline consumption, probably due to the combination of higher concentration around transit stations and the more intensive use of transit as compared to automobile. More recent data on 84 cities across all continents points out to a clear increase in car use (and transport energy) as a city sprawls [70].

3.3.4. Polycentric Urban Structures and Network Cities

The path to cities' regional sustainability is complex and multi-dimensional. A pivotal issue is the ongoing discussion on the importance of urban form to city sustainability. Noteworthy is the debate between (a) compact, monocentric, and high-density, (b) diffused, low density, and (c) intermediate forms of urban development [12,13,29,68,70,71]. I argue that polycentric urban structure holds promise as an intermediate, alternative to the present urban form of compact monocentric cities or to diffused city patterns. The "compact city" metaphor "has been put in question by some scholars as too

broad, generic and ideological [123]. A relevant issue raised is at which urban scale it should apply, arguing that "beyond certain levels of density and size, it could produce 'town cramming' and scale diseconomies which are among the main causes of present suburbanization tendencies" [124]. In a different tone studies relating social and health problems and concentration of people have never pointed to a clearly negative connection; "the top four "alpha" cities of the global economy—London, Paris, Tokyo and New York—still appeal to their residents and visitors despite their being large and dense". However the optimal population size of cities in order to attain various social goals has not yet been determined [71]. A study on Baltimore in the 1980s points out that it is not density *per se* but population size that influences urban dwellers, e.g., emotional stress and other negative psychological conditions. It concludes urban compactness is neither a necessary or sufficient condition for city sustainability, claiming that there is an overemphasis on urban form strategies, which should be refocused into a new dynamic conception of urban planning, where process must have the final word [69].

On the other hand, sprawl has tremendous effects on the surrounding natural resources and the environment, and on rural landscapes and the people who live in it [2,4,5,10,58,69-71]. The disadvantages and costs associated have been incremental—increased travel time, transports costs, pollution, degradation of the rural landscapes, and so on [125]. The "dispersed city" requires costly infrastructure, intensifying financial burdens to communities [73], it is blamed for creating suburban gridlock and amplifying social polarization [126], intensifying political fragmentation, increasing homogeneity (including physical character) by the proliferation of "mass culture" (via the traditional industrial service chains, e.g., Wall Mart, McDonald's in the US, with parallels in Europe) thus eroding regional and local "sense of place" [73]. On the other hand suburban areas (I presume for some high-income urban dwellers) often offer better life quality than the inner city and relatively lower costs to fulfill the dream of a "home of one's own" can often only be realized there [19]. Some even argue that large scale planning aiming at controlling urban sprawl is above all socially undesirable. The argument is that this type of unplanned development offers an increasing opportunity to people to express their own free will and design their own spaces [12]. The discussion is also about the merits of low- *versus* high-density living and generally "living green", deemed possible only in low-density rural or semi-rural context; it revolves around two opposite views: the "rural commons", a view stemming from strong-urban sentiments that are opposed to "density". The "urban commons" view, which is pro-urban and values the city, promotes an overall "greener" functioning, as in Zurich, Stockholm, Helsinki and Freiburg [70]. In the city of Milan responses to urban sprawl can be illustrated by recent proposals that imagine alternatives within the compact inner city that offer the living conditions, comfort, and equivalent costs to those offered by the suburbs; it envisions limited, governed and selective densification in nodes where public transport is a deterrent for car use and consequently does not imply an increase in private traffic (much in tune with the polycentric mode); finally, under development since 2009 within the heart of the city, the project "vertical forest" aims to provide the equivalent of four hectares of forest in a limited urban space, conveyed by two towers, together with 43 floors, with 2100 plants both in the interior and in tree-shaded terraces [127].

This debate has been enriched by looking at alternative, intermediate forms between these two opposite spatial strategies, such as polycentric urban structures (PUS) [12,13,68], also called network cities [60]. Network cities combine various nodes to form a unique yet flexible exchange (economic,

creative) environment. Creative network cities promote "a creatively diversified environment for all citizens through the amalgamations of urban functions for living, working, learning and playing", and "the formation of cultural and knowledge "corridors" to stimulate interaction among creative minds". Note that in the late 80s, seven of the ten most creative European regions were corridor or network cities [60].

A concept of PUS was introduced in European spatial planning in the last two decades or so by the European Spatial Development Perspective (ESDP) as one of the three policy guidelines aiming at a more balanced (sustainable) development: development of a balanced and polycentric urban system and a new urban-rural relationship, overcoming the outdated dualism between city and countryside [19]. However the emphasis is on economic development and cohesion to promote global economic integration in the EU, although it strives also to consider (within PUS) the corresponding rural areas and their small cities and towns. Indeed it aims for an integrated treatment of the city and countryside as a functional, spatial entity with diverse relationships and interdependencies and acknowledges that small and medium sized towns and their inter-dependencies form important hubs and links, especially for rural regions. As presented the focus of ESDP is also on promoting the concept of the "compact city" (the city of short distances). Sufficient agreement exists about the desirability of PUS composed of small and medium-sized, compact urban centers, combined with strong connectivity provided by an efficient network of public transport [12].

The planning principle or spatial concept behind polycentric urban structures is concentrated deconcentration [60]. This concept was originally introduced in the 1966 in the Netherlands, resembling the expanded-towns policy in Britain. The city region concept became the complement of concentrated deconcentration. Concentrated deconcentration was included in the Second National Physical Planning Report (1966) "as a chief innovation", being the Dutch government' planning solution to put an end to uncontrolled suburban growth in the Randstad-Green Heart complex (a classical network city), a large territory located between Amsterdam-The Hague-Rotterdam-Utrecht. The intent was not to reject altogether suburban-type development, but to concentrate new development in and around existing towns and cities to relieve pressure on central cities [59].

There are strong advantages of a planned form of urban development (growth management and wiser planning and design) as compared to market-guided suburbanization, e.g., savings of 20–45% of land resources, 15–25% of costs in providing local roads, and 7–15% for water and drains [128]. Not surprisingly, according to other studies cited by the latter, the lower the density of development and the greater the distance to the metropolis center the higher the public costs of road construction, public services, and school management. Studies on urban development patterns in the Barcelona Metropolitan Region (BMR) refute the polarization between absolute versions of the dispersed and the compact urban forms raising arguments favoring alternative, intermediate urban environments as for example those described for the BMR where dispersion was attenuated by polycentric urban structures [68]. However this is not to say that the BMR has solved entirely this issue as some of its landscapes affected by sprawl are described as "territories without speech" and "landscapes without imaginary" [129]. In the words of Josep Acebillo (Chief Architect for the Mayor of Barcelona, in 2000) ''We're wasting land!", particularly in the urban region [46]. A slightly different perspective are provided by the results of a research project (1997–2001) entitled 'Housing as a basis for sustainable consumption' [67]. This study was based on two large surveys in the Norwegian towns of Greater Oslo

and Forde, using ecological footprinting as an analytical tool: "These ecological footprint analyses suggest that sustainable urban development points towards decentralized concentration, *i.e.*, relatively small cities with a high density and short distances between the houses and public/private services" [130]. Finally the polycentric approach increases the interface between built-up structures and the natural-rural environment as compared to compact cities, and in a more balanced way than in the "diffuse city" —it's a middle term, providing also for an increased sense of place.

3.3.5. Towards an Extended Perspective for Cities' Regional Planning

I argue that from a sustainable city planning and management point of view it is important to consider a wider perspective that includes explicitly both cities and their hinterland or region of influence, both spatially and functionally. Again it is a shift from parts—the built-part of cities, and a notion of cities as confined by the limits of the built-part, isolated from its context, to the whole —"city+hinterland". Therefore it is crucial to acknowledge the most important role of the hinterland or "region of influence" of cities and its reciprocal relationships. In the last decade or so a 19th century concept—the "city region" has been incrementally "reclaimed" by advocating for a broader concept of the city, to include its "influence" zone. As discussed previously cities depend critically on inputs from and outputs to a space outside the city, establishing the so-called chorological relationships with its "context" —the hinterland or "region of influence". The term "hinterland" literally means back country (hinter = behind, land = land). The word includes any area under the influence of a particular human settlement, e.g., by providing necessary energy and materials, and to absorb the waste generated by that settlement. Thus, an aggregated human settlement and its hinterland are often bound by their production-consumption relationship [131]. "In agricultural societies, limited by technology and high transportation costs, locales or regions, *i.e.*, "hinterlands," had to provide all or most functions necessary for the everyday life of the local population. Under industrial conditions, the spatial division of labor increased. This spatial expansion improved people's ability to meet their needs and fulfill their social functions because the supply of goods and services was no longer constrained by local resource availability or costly transport. The connections between people's way-of-life and their cultural landscapes weakened, and it became increasingly difficult to link local and regional ecologies with the behavior and consumption patterns of their human inhabitants." [132] Most important is that the relationship between settlement and hinterland is one of dominance of the former over the latter. This view is however changing, especially through the discussion of sustainable urban development [131]. For example, the European Union spatial planning policies embedded in the ESDP promotes an "integrated treatment of the city and countryside as a functional, spatial entity with diverse relationships and interdependencies. A sharp distinction between city and countryside within a region ignores in most cases the fact that only regions can form labour, information and communication markets. The region is, therefore, the appropriate level for action and implementation" [19].

In order to plan and manage the "extended city" it is important to be able to define its boundaries. In theory this hinterland or "region of influence" is constituted by the surrounding rural landscapes located at a relatively closer distance and or with places located very far, even in other continents due to global markets. From this perspective the region of influence is a functional hinterland [19] that together with cities and towns involved form a functional urban region [46]. The latter adopted a set of criteria to define the boundaries of urban regions, ranging from landscape physical features (e.g.,

mountain ranges), outline of major drainage basins around major water supplies, major biodiversity areas, one day recreation and tourism sites, to major political/administrative borders combined with the relative size of the core city and the other(s) cities in its surroundings. When none of those criteria seemed appropriate, a radius of *circa* 100 km was adopted, partly reflecting a typical maximum distance on paved highway that people would travel in one day shopping travel. "Several attributes initially thought to be important turned out not to be so, because they usually did not extend very far beyond the metropolitan area (ends of commuter rail lines, communities with substantial commuter populations, airports, sewage-treatment facilities, solid-waste disposal sites, reduced air-quality sareas)" [46]. Advancing the principles of sustainable regionalism, Ndubisi proposed to restore the concept of ecological region to manage metropolitan growth, enlarging the urban planning "lens" to a regional perspective; the boundaries, the latter argues, should be defined by watersheds or interacting mosaics of watersheds, modified by political-regulatory boundaries [73].

When considering the sustainability of urban agglomerations, such as metropolitan areas and polycentric cities and urban regions the relationships between a city and its context could be seen at two levels: (1) intra-urban, considering the hinterland located within the space formed by the urban network, and (2) with the surrounding landscapes located outside the urban agglomeration boundaries (that again can be close or far). More or less isolated, compact cities fall into the latter. As a whole, this functional "region of influence" will necessarily reflect cities ecological footprint, which can be spatially defined in combination with the carrying capacity of the "region of influence" that enables the production of the several inputs cities need and the absorption of the products of its metabolism.

An important point to make at this stage is that, according to the conducted literature review, the planning and management of polycentric cities or urban regions in the EU are focusing mostly on socio-economic development. Despite the broader goals stated in the ESDP policy document, at least for the European context, and despite the debate and research on the role of multifunctionality, the implementation of this planning concept has been relatively shy regarding the explicit involvement and incorporation of landscape resources and ecological services, reflecting the dominant attitude of the city over its hinterland, which derives essentially from the narrow perspective of Man over Nature (see Section 3.1). According to a new vision for European landscapes explored in the Report "Blueprint for Euroscape 2020—Reframing the future of the European landscape" [133] "(…) the focus on land use only is lacking a spatially coherent vision and regional focus. The concept of European Polycentric Regions is an answer to that as a meta-scale regional planning instrument for integrating multi-functional land use into a spatial framework based on landscape functions. Polycentric Regions can be characterized by: designation of region-specific resilience centers that provide essential compensation and buffer functions for adjacent high agglomeration and that can support structurally weak zones; spatial distribution of landscape services that reflects the bio-physical structure as well as socio-economic necessities at various levels of scale (…); governance structures that build upon bottom-up civil society initiatives (…); awareness of the importance of linking regional identity with global sustainable development objectives (…)". I believe this vision could advance the concept of PUS towards a more balanced approach.

In the above context it is important to acknowledge the important contribution of several spatial concepts (or metaphors [54]) in territorial planning throughout the last two centuries. A spatial concept expresses through words and images an understanding of a planning/design issue and the actions

considered necessary to address it [39]. Some of these spatial concepts were already referred to before in this article—the "Randstadt" and its counterpart the "Green Heart". These translate the organic urban architecture perspective of the 1950s, interpreting cities as living organisms [65]. Together these spatial concepts have also close relationships with those of the "Garden City" and the "Green Belt" introduced at the end of the 19th century by city planners. These have proven to be very powerful and effective and some endure still until today. For example the Green Belt it is a major instrument of land use and urban planning in the U.K. Not surprisingly the ideas behind these concepts have been revisited and re-used under the new perspectives of urban ecology, where cities are approached as living organisms, with strong relationships with the surrounding landscape [22]. Here urban metabolism plays a central role to understand those co-dependencies and is modeled to understand the fluxes of energy, materials and organisms that flow between built-areas and the hinterland that permeates between those.

Inspired on landscape ecology I proposed a spatial concept aiming to contribute to address uncertainty and the need of flexibility in planning and thus to increase landscapes adaptive capacity and resilience [24]. It is based on the idea that cultural landscapes needs a dual approach—a more deterministic, for areas where critical ecological resources concentrate, and a more flexible approach to the remaining areas. The former is supported by an "ecological backbone", an ecological infrastructure that supports the overall functioning of the landscape [38]. "This idea asserts that for sustainable human development, planning must recognize those ecological structures that are most fundamental to assure overall ecological sustainability, including abiotic, biotic, and cultural functions and processes, and to provide the capacity for the landscape to compensate for impacts caused by human uses and activities" [134]. A similar approach was proposed under the "casco" or framework concept [135] representing a systematic decoupling of functions, where low-dynamic functions or slow-change variables [44,79], *i.e.* long-term ecological processes, such as groundwater recharge or soil formation are combined into a coherent spatial framework, and the high-dynamic functions (*i.e.*, production agriculture, extraction industries, urban development) are located in other spaces providing them with the essential spatial flexibility and freedom they operate under [135,136]. From an operational perspective the "ecological backbone" concept is complemented with the approach of differential prioritization [24] proposed by Haaren: stricter, mandatory goals for the areas where to implement the ecological backbone, and flexible rules for the remaining areas [64].

The notion of landscape as infrastructure or as a service matrix put forward by landscape urbanism is most appropriate to envision the multifunctional role of hinterlands. Landscape urbanism evolved from design theory, combining high-style design with ecology [80]. It looks at ecology as a meta-science that allows the integration of culture and art, and where the landscape is seen as a "hybridization of natural and cultural systems" [137]. Here the landscape is seen as the "background" of urban agglomerations, *i.e.* the matrix where the city is embedded. The hinterland is conceived as the infrastructure for the development of the human habitat under a broader concept allowing for the integration of infrastructures (water, energy, transportation, *etc.*) and public spaces [76]. Recently a related concept evolved that promoted ecological urbanism [77]. Although drawing heavily on the former, it pays little attention on advances of urban ecology [80]. The latter argues for a synthesis incorporating those advances to form a new, integrative approach under the term "landscape ecological urbanism". The concept of green infrastructure is closely related to the latters. Green infrastructure is

an emerging planning and design concept that applies landscape ecology principles to urban environments [78]. Its main structure is supported by hybrid hydrological/drainage network, complementing and linking relict green areas with built infrastructure that provides ecological functions. This approach uses a suite of strategies intended to build urban resilience capacity: multifunctionality, redundancy and modularization, (bio and social) diversity, multi-scale networks and connectivity, and adaptive planning and design [79].

Not surprisingly both landscape (ecological) urbanism and green infrastructure concepts share a common interest on human habitat and man-nature integration. To do so they more or less explicitly draw from landscape ecology an interest not solely on landscape structures *per se*, but also and foremost on landscape processes, functions and services, its reciprocal relationship, and its dynamic nature. The latter spatial concepts briefly explored above build on closely related concepts proposed in a more recent or distant past. They do so to envision alternative solutions to accommodate the need for a more efficient planning and design for cities and metropolis where Man can find a truly satisfying habitat to live. These concepts hold per se a large potential to attain this purpose. I believe they can have an enhanced contribution when associated with which other and with others such as the polycentric urban form [34].

4. Strategies for Self-Reliant Cities

Strategies for self-reliant cities emerging from a new thinking context include local production for local consumption [22,33,29,65,70,73,77] local markets and ecological commerce [29,139], multifunctional, redundancy and modularization for the hinterland's ecological infrastructure [78,79] and maximizing circular organization (or closed loops) of inputs and outputs [22,29,41,70,71]. The keywords are "reduce, re-use, and recycle" (the 3Rs). The use of local materials and techniques boosts the regional economy [138]. Local markets bring together production and consumers, and the community as a whole, e.g., as proposed for London's 160 sq km of farmland by the Sustainable London Trust [29]. In this context a new understanding of economy is urgently needed, as for example the so-called "ecological commerce": "Economic development, the foundation for human settlements, seldom acknowledges ecological limits in either capitalist or socialist systems. However, the ecological footprint demonstrates the need for economic restructuring aligned with the natural world. Sustainable urban development therefore needs an ecology of commerce. Such an economic system would move beyond resource conservation to promote adaptive reuse of existing natural resource and built resources, emphasize renewable resources, and restore environmentally degraded areas such as brownfields. As an example in the USA, Chattanooga, Tennessee is committed to eco-commerce. It has created lucrative new industries such as electric vehicle production, ecotourism" among others [139]. Gauzin-Muller provide for extensive examples in Europe, namely twenty-three on the "environmental approach" to architecture of housing, public buildings, and commercial and service buildings, and six on urbanism and sustainable development [138]. Beatley provides also for numerous examples in Europe, from ecocycle balancing in Stockholm (Sweden), to Ecover—a sustainable factory in Oostmalle (Belgium), an ecological approach to commerce and economic development in Graz (Germany), or industrial symbiosis in the eco-industrial park (EIP) of Kalundborg (Denmark). Ecocyle balancing in Stockholm is promoted via sewage treatment plants that produce energy (biogas)

and fertilizer (to be re-introduced in the farms nearby) [29]. The municipality of Graz contracted with farmers to accept and compost (source-separated) organic and lawn wastes collected in the city farms (located within a 60-km radius of Graz) and then apply to their fields. Farmers are paid providing an additional source of farm income, as well as a way to substantially reduce the city's composting costs. Finally, at the finer scale of houses and buildings bioclimatic design, based on site conditions and buildings shape and orientation, promote the rational use of energy [138].

5. Case-Study—Kalundborg

Kalundborg is a city of 50,000 inhabitants located on the seashore of the island of Zealand, *circa* 100 kilometers East of Copenhagen, Denmark (Figure 1). Here we can find the first EIP formally identified as such, later followed by others, e.g., in Styria, the Austrian province where the city of Graz is located (see above), and in the Ruhr region (Germany) [140]. Despite its small population Kalundborg is the largest industrial center on the island with an industrial turnover similar to that of a middle-sized European city, and is still growing. The area includes e.g., two of the world's leading producers of enzyme and insulin (Novo Nordisk), the largest water treatment plant of Northern Europe and the second largest oil refinery of the Baltic Region (Statoil). On the other hand, due to the heavy-industry located here, there are, among others, pollution problems to be solved, e.g., the production of green-house gas (GHG) emissions: Kalundborg is responsible alone for *circa* 9% of the total Danish CO_2 emission. However, and according to the municipality, Kalundborg is striving to become a green industrial municipality by 2020; its policy is to make compatible its continued growth with the protection of the environment [141].

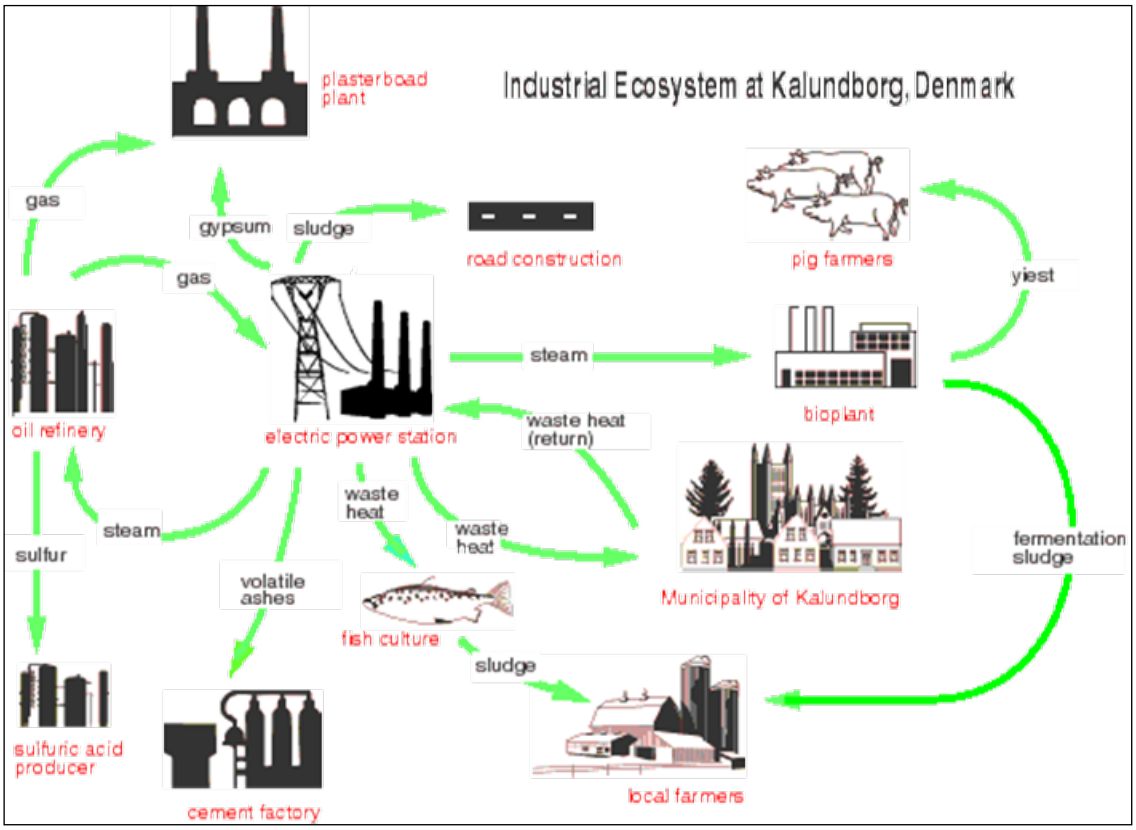
Figure 1. Industrial symbiosis. The Eco-Industrial Park (EIP) at the coastal city of Kalendborg, Denmark. The photo shows the location of the major industries that incorporate the EIP.

"An EIP is a community of firms in a region that exchange and make use of each other's byproducts, in the process improving their environmental and economic performance. The argument is that by working together, this symbiotic community of businesses achieves a collective benefit that is greater than the sum of the individual benefits each company would realize if it optimized its individual performance only" [140]. EIP are based on the concept of ''Industrial Symbiosis''. IS is a central concept in the industrial ecology literature, which describes geographically proximate inter-firm relationships involving the exchange of residual materials, water, and energy. Here one industry's residue is another industry's resource through a structured exchange of resources: water, energy and other industrial residues are exchanged across company boundaries [141].

All started in 1961 when Statoil, an oil refinery newly installed in Kalendborg started to use surface water from Lake Tissø in order to save the existent limited supplies of underground water. Mind that water is a scarce resource in this part of Denmark. This project was developed together with the municipality. The reduction in the use of ground water has been estimated in *circa* 2 M. m^3/year. Later a number of other collaborative projects were introduced and the number of partners gradually increased. By the end of the 1980s, the partners realized that they had effectively "self-organized" into what is probably the best-known example of a working industrial ecosystem, or an industrial symbiosis. Note that the IS is based upon commercial agreements between independent partners [142].

Currently, the EIP is made up of seven key industries and Kalundborg Municipality. Hereby we describe four of them. Asnæs electric power station, the largest in Denmark, is at the core (Figure 2). It provides residual heat to the municipality that feeds up the district heating system, replacing highly polluting oil burning heaters in individual homes, and to another major player—Statoil, presently Denmark's largest oil refinery. Asnae produces other valuable by-products including 170,000 tons/year of fly ash, which is used in cement manufacturing and road building, e.g., by local construction firms. Finally it supplies also a fish farm. The power plant uses salt water, from the fjord, for some of its cooling needs, helping to reduce withdrawals of fresh water from Lake Tissø. The resulting by-product is hot salt water, a small portion of which is supplied to the fish farm's 57 ponds [143,144]. Gyproc, Scandinavia's largest plasterboard manufacturer, uses the power plant's fly ash to obtain gypsum, a by-product of the chemical desulphurization of flue gases. Gyproc purchases about 80,000 tons/year, meeting almost two-thirds of its requirement. By purchasing synthetic gypsum from Asnæs, Gyproc has been able to replace the natural gypsum that it used to buy from Spain. Statoil surplus gas, which used to be flared off, begun to be treated in 1993 by removing sulfur, which is sold as a raw material for the manufacture of sulfuric acid. The clean gas is supplied both to Asnæs and Gyproc as a low-cost energy source. Gyproc switch from oil to gas recorded a 90–95% saving in oil consumption. Finally it supplies its purified wastewater as well as its used as cooling water to Asnæs, thereby allowing this water to be "used twice" and saving additionally 1 M. m^3/year of water. A large pharmaceutical company, Novo Nordisk has its largest production site in Kalundborg. The factory site is shared with Novozymes, Local farmers make use of Novo Nordisk's by-products (sludge) as fertilizers. Industrial enzymes and insulin are created through a process of fermentation, the residue from which is rich in nutrients. After lime and heat treatment, it makes an excellent fertilizer. Some 1.5 M. m^3/year are delivered to local farmers, free of charge [144].

Figure 2. The several components of the industrial (eco) system at Kalundborg, Denmark and its interrelationships, including the flows of energy and materials between the several players [145].



The positive environmental impact appears to be substantial: on an annual basis, CO_2 emissions are reduced by 240,000 tons, 3 M. m^3 of water is recycled, *etc.* In addition numerous by-products should be added, which are sold to industries located outside the industrial cluster. In addition to these reductions, the use of the excess heat from Asnæs for household heating has eliminated the need for about 3,500 oil-burning domestic heating systems [141].

The original motivation behind this industrial cluster was to reduce costs by seeking income-producing applications for unwanted by-products. Gradually companies realized that they were generating environmental benefits as well [141]. It is a win-win situation. The Kalundborg industrial ecosystem could serve as a beacon to sustainable planning aiming at increasing self-reliance of cities [144]. Many policy analysts argue that public planners can copy and even improve on Kalundborg. However some argue that "The planning of a community of companies in a region that exchange and make use of each other's byproducts has been advocated in many academic, business and political circles. The real world examples that justify such an approach, however, were entirely the result of market forces" [140].

Contributing to the gradual and evolutionary process initiated in 1961 there seems to be several keys for success [29]:

1. The energy crisis of the 70s and 80s prompted many of the energy efficiencies;
2. The economic benefits and an enhanced environmental image: "(…) environmental altruism has little to do with the symbioses that have been developed" ([29], p. 244);

3. The flexible and cooperative Danish regulatory systems (see a discussion on the difficulties to develop such an approach in otherwise less flexible regulatory systems, e.g., in the USA [140,146]);
4. Physical proximity of the companies involved in the process in an area of circa 4 km^2, and the fact that Kalundborg is a small town, with a strong sense of community (see below);
5. Cooperation and complementarity between the companies, the municipality, local environmental NGO's, and others actors. The governance system led by Asnæs—the environmental "club" started in 1989 with the abovementioned main players, that promoted discussion and brainstorming in order to expand this symbiotic system.

There are further lessons that we can learn, derived from some comments from those directly involved:

- All contracts have been negotiated on a bilateral basis;
- Each contract has resulted from the conclusion by both companies involved that the project would be economically attractive;
- Opportunities not within a company's core business, no matter how environmentally attractive, have not been acted upon;
- Each partner does its best to ensure that risks are minimized;
- Each company evaluates their own deals independently; there is no system-wide evaluation of performance, and they all seem to feel this would be difficult to achieve.

Jørgen Christensen, Vice President of Novo Nordisk at Kalundborg, identifies several conditions that are desirable for a similar web of exchanges to develop:

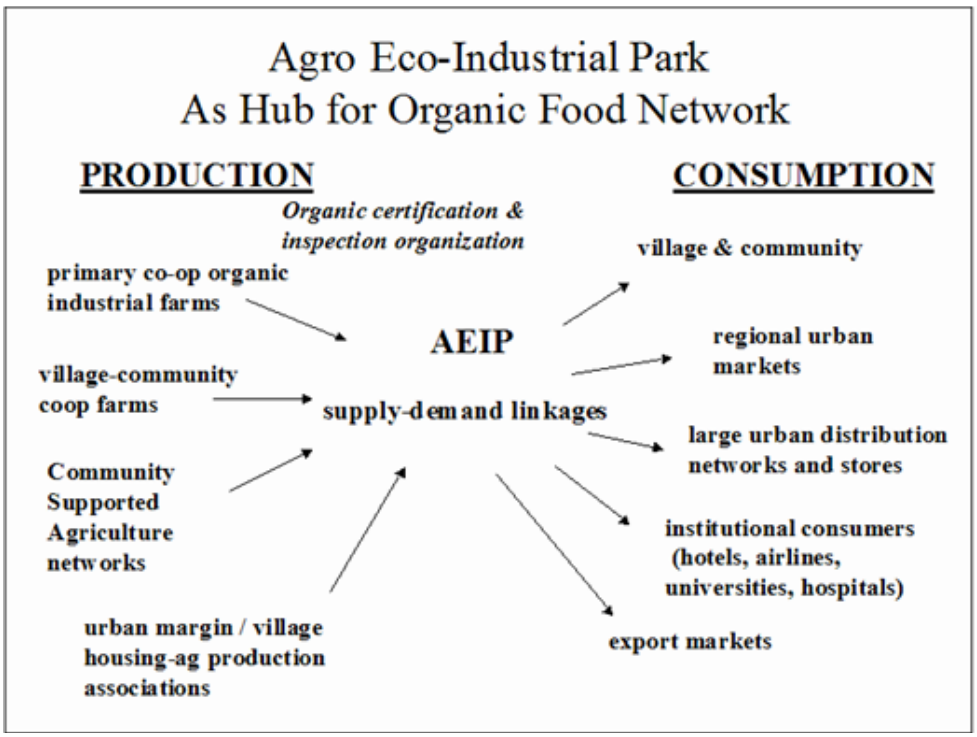
- Industries must be different and yet must fit each other;
- Arrangements must be commercially sound and profitable;
- Development must be voluntary, in close collaboration with regulatory agencies;
- A short physical distance between the partners is necessary for economy of transportation (with
- heat and some materials);
- At Kalundborg, the managers at different plants all know each other" [143].

According to P. Desrochers "numerous EIPs have been planned in North and South America, Southeast Asia, Europe, and southern Africa" ([146], p. 345). THE EIP concept is also extending to developing a food and agriculturally focused EIP (Figure 3) [147].

This real-world case-study illustrates the need to further incorporate in city planning, design and management much of the emergent concepts presented in earlier sections in this manuscript. Cities will not be completely self-reliant in a near future. As we could see it takes time to build such systemic relationships as those in Kalundborg EIP. Furthermore some argue that the known examples of success were not planned activities (see above); Kalundborg EIP emerged as a result of self-organizing capacities of the many players involved: industry, municipality, agro and fish-farmers, NGO's, *etc.* It is important to acknowledge that, purposefully or not, the Kalundborg industrial cluster was envisioned as a system, where components (players) are interacting through a bundle of horizontal (or chorological relationships) flows of energy and materials. Across time a circular organization with a network pattern emerged—the EIP, showing similar characteristics as those in living systems

discussed earlier (Section 2.3). Here we can recognize some of the principles of systems and complexity theories and of the science of landscape ecology (see Section 3.3).

Figure 3. The concept of Agro Eco-Industrial Parks [147].



The metaphor of urban metabolism is also applicable to Kalundborg (see Section 2.6). Inputs and outputs are integrated to the benefit of all, reducing some of the exports coming from outside the city, sometimes very far such as the natural gypsum coming from Spain to Gyproc. Linkages were established between the city and its hinterland, e.g., via the input of fertilizers for local farming or fly ash to local construction firms.

Notably the IEP was achieved via cooperation between institutions (governance mechanisms) and complementarity across companies and other actors (actors with different functions which input-outputs feed into each other in quasi-closed loops). These are two most important characteristics of polycentric urban systems (see Sections 2.7 and 3.3)

5. Concluding Remarks

Earth population is increasing substantially at large, and tends to concentrate in large cities and urban agglomerations. Urbanization growth patterns are unsustainable, leading to the degradation of water resources, productive land, biodiversity and quality of life, particularly for urbanites. Cities are increasingly vulnerable to global climate change and are highly dependent on landscape resources located outside cities, sometimes very distant. Forecasts on oil supply point to an increasing depletion of existent deposits. Modern mobility patterns are much oil-dependent. The oil crisis will arguably affect tremendously urban life as we know it. Many of the reviewed authors challenge us to think about the so-called "post-oil cities", and provide extensive examples globally on how to promote a more circular, closed-loop pattern in using energy and other natural resources in cities [22,29,70,71,77,138].

Following the tradition of many disciplines even today a reductionist approach to urban planning focuses on the (built-up) space within city boundaries. It does not look at cities as a whole, by ignoring or undervaluing the non-urban space in cities as an integral part and the linkages between ecological and cultural structures, processes and functions, and not acknowledging cities as social-ecological systems. Additionally it does not consider the horizontal or chorological relationships within cities taken as whole, and those with the surrounding landscapes and resources at large that support them. Most important for the argument of this essay, frequently the environment is a secondary consideration (if considered at all), dominated by economic development policies. Moreover it is mostly fragmented, sectorial-based, and often within the narrow time-frame of political cycles. Strategic planning in the 1980's onward argues for almost nonexistence of explicit urban image-planning, focusing on fragmented urban operations framed by a strategic planning framework that solely provides general guidelines for urban development. Some even argue against controlling urban sprawl through large scale planning in the grounds that is impossible, pointless, and most of all socially undesirable since "la ville a la carte" or the "ville aux choix" offers freedom of choice for people to design their own "life-spaces" [148]. Some adopt the "rethoric of uncertainty" in architecture and town planning as a reaction to legacies of determinism, legitimizing different forms of relativism: "if anything is uncertain then anything can be possible", warning that it seems "a device to keep out of the decision processes the weaker part of the society" [149].

Kuhn and Capra argue for a paradigm shift, both scientific and social, that is occurring in the turn of the last century and entrance to the XXI [150]. This paradigm shift is contributing to a new vision, where those emerging concepts and ideas presented in this article are important contributions emerging from varied sources of knowledge areas, from life and social sciences to planning and design. Most look at living systems functioning as a metaphor that enable building useful analogies to better plan and design human habitat—cities and functional hinterlands taken as a whole. Most important is the notion of context and interdependence, stemming from a landscape ecological chorological approach to planning, as the SLP framework [38]. System thinking is about context and relationships, and acknowledging networks as an organizing pattern for living systems. Networks of cities have been gathering consensus as alternative urban forms—the polycentric paradigm in Europe (but also in California, USA, China, Japan, *etc.*), forming complex socio-ecological systems (SESs). Self-organization of spatial structures is characteristic of urban patterns evolution. It is fundamental for its adaptation to disturbances and catastrophic events such as those triggered by climate change, e.g., floods and draughts, or more dramatically earthquakes, tsunamis, hurricanes and so forth [5]. SESs consider cities as the arena where two autopoietic systems (nature and society) interact in a dynamic process [55]. From a self-reliance viewpoint cities are not sustainable or autopoietic. One of the challenges posed to cities is to make cities more resilient [30,51,53,55,79,80,85], *i.e.* more adaptable to overcome, sometimes, critical situations. I concur with [79] inter alia that we should manage for resilience, and learn to live within SESs instead of trying to control them, recognizing that systems are safe to fail. In this context we need adaptive urban strategies, e.g., by engaging into a "learning-by-doing" process [38,44,56,57] via experimental design [54,79] or reflective learning through practice [80], by promoting diversity [79,80], multifunctionality [79] or by built-in redundancy into urban systems [79].

I argue that acknowledging explicitly the relationships between built-up and its functional hinterland contributes also to the overall system's resilience, where adaptive capacity is supported by local landscape resources within an urban ecological region (UER). The spatial conflict caused by existent urban forms, particularly by sprawl but also by the expansion of compact cities needs to be resolved by taking into account the land capabilities for production of food and fibers, waste re-absorption, recreation, and more intangible functions as aesthetics and contact with nature, and a diverse set of ecological services essential for human quality of life that are provided by the functional hinterland of a polycentric city-region. City planning, including PUS, needs to balance its present focus on mostly economic concerns to consider other important roles of the hinterland [34], e.g., as the landscape matrix of the UER, functioning as an multifunctional infrastructure to human (urban) habitat.

The discussion on urban form—compact, intermediate and diffused settlement patterns provided the stage for arguing for an urban network, polycentric solution, which is the cornerstone of the European spatial planning policies. It argues for the explicit consideration of a chorological perspective when planning cities and urban agglomerations at large from a regional perspective, in the context of extending the present concept of polycentric urban structures and network cities to include explicitly, and plan and manage for a multifunctional hinterland of rural and natural resources aiming at increasing regional's self-reliance, structured by a network of ecological systems that provides for key-ecological services (the region´s "ecological backbone"), considering the interrelationships between cities and its functional hinterland. It does so by combining principles of landscape ecology with those deriving from complexity science, such as self-organization and autopoeisis, resilience and adaptation, and others close related such as self-reliance and cooperation. In order to plan for this broader concept of PUS, tools as urban metabolism and land suitability analyses, ecological footprinting, strategic environmental assessment and more recently sustainability assessment [71], combined with other methods [151] can contribute to support the spatial delimitation of the functional urban ecological region. In a time of uncertainty [48,57,90] a dual planning approach [64] could arguably be appropriated—the ecological backbone [24] or a green infrastructure [78,79] on smaller, strategically located portions of the landscape matrix, a space-efficient strategy based on the resource concentration theory [56], focusing on slow variables or more stable landscape structures that are crucial to resilience management [44-46], where more mandatory rules could or should be adopted. On the remaining parts of the landscape, including areas for urbanization, industry, agriculture, recreation and so forth, one could adopt a more flexible planning approach [24,135,136].

To implement eco-polycentric urban systems (Eco-PUS) I argue that most of all we need cooperation in city planning, design, and management. The above examples reveal innovative approaches to city planning. These are supported by close cooperation between the several agents involved—farmers, industry, and local governments. Cooperation is needed between (networks of) cities, as in PUS, where it constitutes a basic premise [19]. We need also cooperation across the scientific community (life and social sciences), and of the latter with planners, designers and engineers, under a translational research paradigm [30]. Transdisciplinary efforts are also needed, e.g., collaborative planning and design [83], and collaborative resilience management [90] to increase cities' ability to adapt, including governmental across institutions at its different levels, and the private sector. Inter-institutional cooperation and (planning) legislation is crucial to support integrated

planning of human activities sectors. In the last decade the European Union (EU) has pushed this agenda based on its spatial planning policies: "Spatial development issues in the EU can, in future, only be resolved through co-operation between different governmental and administrative levels. (…) New forms of co-operation proposed in the ESDP should, in future, contribute towards a co-operative setting up of sectorial policies—which up to now have been implemented independently—when they affect the same territory. The Community also requires the active co-operation of cities and regions in particular to be able to realise the objectives of the EU in a citizen-friendly way. This is how the subsidiarity principle, rooted in the Treaty on EU, is realised." [152]. It is also needed increased cooperation within local communities. For example, cooperative housing in Scandinavia accounts for 20% of national housing stock, but only 1% in the USA and in the UK [153]. Housing projects in the Netherlands and in Germany are being developed aiming at social cohesion [29]. Local Agenda 21, a tool for community involvement and partnership (e.g., Middlesborough, UK; Den Haag, NL or Helsinki, Finland) represents a considerable effort to engage citizens in thinking about what sustainability might mean for their neighborhoods and communities [154].

Fortunately a convergence is undergoing, evolving into integrated approaches stemming from both directions, *i.e.* ecology, including landscape (and urban) ecology [27,32,51,54], and from (landscape) planning and design [24,33-40,56,76-80] among many other contributions across the last decade or so. Some argue that if we are to promote an integration of biophysical and cultural approaches, we should be focusing on commonalities instead of focusing on differences [31,38]. The landscape (ecological) spatial dimension provides a common platform with other landscape dimensions and disciplines [38], including integrating the relationships between different resources in landscape modeling [40]. Scientists need to develop more practice-oriented research and orient research to the development of operational tools. Consequently they need to understand planners' goals. Planners, designers and engineers need to work harder in promoting effectively the integration of several disciplines, and to incorporate ecological theory appropriately.

Interestingly, a review showed that it is not the form itself that is sustainable or not but the processes associated to a particular form (or structure) and the reciprocal relationships that are established in a dynamic interaction between form and these processes [69]. Therefore it is paramount to understand urban processes of different nature, and the drivers that are associated with those processes. For example, in the context of environmentally led urban design environmental metrics are seen as potentially beneficial to a "kind of "performalism"—an initially direct relationship between environmental performance and urban form—that can knit up culturally uninformed environmental design and environmentally uninformed urban design, particularly in cities that are growing too rapidly" [155]. Landscape ecology is well posed to address these structure-functions or processes relationships in the context of sustainable landscape planning [24,38], and sustainability science [27]. According to the latter, to develop a rigorous science of sustainability one needs to quantify whatever sustainability means, and landscape metrics can be used for this purpose. A major concern in spatial planning is the study of the spatial characteristics of urban processes, such as urban sprawl [4]. In the last ten years, spatial metrics derived from landscape ecology have been increasingly used to study the spatial characteristics of urban processes, namely the spatial characteristics of urban patches, including their size, shape, and spatial distribution. These useful tools can be very valuable for planners who need to better understand and more accurately characterize urban processes and their

consequences [36]. Since the late 90s research have been produced focusing on applying landscape ecological principles and metrics to sustainable landscape planning, with a focus on urban processes and metropolitan areas [2,8-10,21,24,33-40,47,156,157]. In order to explore the connection between aspects related to spatial processes and their environmental and territorial consequences, analyses such as those explored in the above mentioned articles could be integrated in metropolitan observatories. This would enable to study the relation between the processes and spatial patterns identified by the metrics as well as the changes in these aspects measured by available indicators (e.g., energy consumption, automobile dependence, use of public transportation, alteration of environmental processes, *etc.*) [36], and thus potentially contribute to sustainability assessments (e.g., the SA process was implemented in 2005 in Sydney, Australia) [71]. These applications are deemed important to contribute to better understand the complexity of cities and to address some of the challenges posed to the planning and design of the cities of the future.

Polycentric urban systems are being implemented for some time across Europe. I argue one of the major challenges today is to move the present concept towards Eco-PUS. Taken as a whole it remains a hypothesis to test. Therefore it lacks empirical evidence and case studies. However, some of the ideas discussed in this manuscript that are encapsulated in the proposed concept of Eco-PUS are already being put in practice in Europe and elsewhere, e.g., Australia. As described above there is empirical evidence that these ideas can work, e.g., in Barcelona (Spain), Stockholm (Sweden), Kalundborg (Denmark), Portland (Oregon, USA), Curitiba (Brazil), Surabaya (Indonesia), and many others cities across the world [29,68,70,138], arguably helping cities move towards a more sustainable path. Moreover, general principles of landscape ecology have been proposed to be put in practice to plan metropolitan areas such as in the Barcelona Metropolitan Region by request of the BMR planning authorities [157]. Finally, and as stated from the beginning, the proposal described in the present article is still a work in progress. It will be further developed in new articles of the author to be published subsequently, namely by testing the potential of some of the ideas described to Mediterranean coastal regions in the Iberian Peninsula.

"For now, the most important lesson of complexity theory is that it counsels us against placing too much confidence in deterministic models of economic, social and political behaviour and against over-elaborate analysis of single agency interventions in policy making, strategic management and public governance within policy systems whose interactions are, at best, only partially understood." [72]. As the former Secretary-General of the United Nations, Kofi Annan, said: "The future of humanity lies in cities." [31] However, the core of all the troubles we face today is our very ignorance of knowing [41]. I strongly believe the path of sustainability is greatly dependent on the levels of empathy and cooperation we all—scientists, planners and designers, institutions, the society at large, *etc.* —can achieve to surmount the present "crisis of perception" [42] by bringing forth a new social and scientific paradigm and thus deal with the tremendous task that lies ahead of Mankind in general, and all of us engaged in bringing forth a new sustainable way of life, in or outside cities.

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