

SYMBIOSIS IN ECO-INDUSTRIAL PARK: LESSONS ON PLANNING A SYMBIOTIC CITY

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Introduction

Theory of Urban Planning and Development has been open to integrating other models and practices towards the goal of developing better and sustainable cities. In context of this progressive and open assimilatory thinking, this paper discusses the concept of symbiosis and model of eco-industrial park as a resource for enhancing urban-planning discourse. The paper delineates the scientific theories of symbiosis, resource loops, equilibrium, diversity pattern, hierarchy, metapopulation and island biogeography, as the most pertinent resource for drawing lessons on planning a Symbiotic city and recommends further in-depth study for selection of principles that can be directly integrate with and inform the theories and practice of urban planning.

SYMBIOSIS AND ECO-INDUSTRIAL PARK

A lively discussion of inter-industrial exchanges began in 1989, when Frosch and Galloupolos introduced the concept of “waste of one industry as a resource to another” (Frosch and Galloupolos 1989, 144-152). The concept applies the process of symbiotic exchanges to industrial establishments. The industrial establishment that applies this concept is called an “Industrial Ecosystem” or an “Eco-Industrial Park -EIP.” A recent publication by Sharma (2013), on the landscape of industry presents a transformation of eco-industrial park through history but to orient you briefly, the EIP was inspired by food webs in natural ecosystem and was conceptualized as a network of (co-located) industries engaging in resource exchanges [1]. Gradually the research shifted focus from food webs to the concept of symbiosis as nature-analogy framework for eco-industrial park; counter-arguments followed soon after. Many cautioned that the analogy of industrial ecology to natural ecosystems should not be taken literally and the possible evolution of industrial ecosystem should be explored. A natural, biotic system is self-regulatory and self-sustainable, existing as part of the surrounding ecosystem and hence adapting and responding to changes

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occurring therein. In contrast to a natural ecosystem, a mechanical system is not self-sustainable and is regulated externally by humans. Nor is the mechanical system obliged to adapt or respond to changes in the surrounding ecosystem. McManus and Gibbs (2008), also point to the disjunction related to the natural analogy and attribute it to the flaws in the fundamental tropes themselves such as, nature as metaphor, balance and food and bodies.

When one industry closes it is either replaced by another; many times by building a link with another industry in the region. So in terms of inter-linkages the system stays stable either by growing or by expanding from a co-located system to a non-co-located one. In any case, inclusion of the waste upgrading industry, which is the intermediary between the primary donor and recipient industries, forms an essential, secondary tier of exchange (Ayers 1996), requiring some input of resources from sources in addition to the donor industry. Hence, even when the eco-industrial park optimizes its core material flow, this industry forms another resource-consuming loop, destabilizing the system again according to the law of entropy, thus emphasizing that the increase in the number of inter-industrial exchanges does not indicate a stable or a sustainable eco-industrial park (Hardy and Graedel 2002). The resource-sharing based interpretation of industrial symbiosis influenced numerous manifestations of symbiosis through the eco-industrial park developments; propositions on development of bio-refineries and sugar refineries centred on the concept of resource-sharing among co-located facilities are some examples or manifestations of industrial symbiosis. Digital models are being developed to optimizing resource loops within eco-industrial parks, such as the fuzzy bi-level programming model (Tan et al. 2011). This model assists with negotiating a reasonable compromise between the EIP and individual industries by balancing the park goal of fresh water conservation and individual goals of industries to save on water-use related costs (Tan et al. 2011). These explorations on industrial symbiosis primarily focus on inter-industrial processes.

Approaches such as design for environment and life cycle analysis contribute to the objective by conserving resources, minimizing waste and reducing pollution. However, issues pertaining to preservation of ecological flows and degraded local ecosystems persist beyond the geographical boundary of an eco-industrial park. The problems most critically arise due to spatial aberrations in flows of natural ecosystem, at the interface of the eco-industrial park and its context.

Although symbiotic networking is central to development of eco-industrial park, there are not many recommendations on design strategies to achieve the symbiotic network. The explorations such as the one that begins conceptualizing the role of designed landscape planned to function as a green-switch at the interface of urbanized context and natural ecosystem by Sharma (2006) need to gain strength. Subsequent section explores studies in ecosystem from the lens of spatial design.

METHODOLOGY

Method employed for this inquiry was multi-modal and draws from literature review, personal interviews and field research. Seminal books and articles on the development of industrial ecosystems and eco-industrial parks, that have been published over two decades since 1989- the year of revitalized discussions on the topic, were reviewed. Personal discussions with prominent thinkers in the field, over a period of time, were used in structuring the narrative. About a dozen of EIP establishments were reviewed and the Kalundborg EIP was personally visited to appraise symbiosis as currently operational. Symbiosis in natural ecosystem is studied, a comparative review undertaken and recommendations offered using deduction induction approach.

ECOLOGICAL CONCEPTS APPLIED IN EIP

For a symbiotic co-existence of an eco-industrial park with its local ecosystem, it is imperative that the interactions not be competitive or parasitic. Since the primary functions of an eco-industrial park and its contextual ecosystem (urbanized or natural), are different, the systems do not primarily compete for same resources thus an eco-industrial park and its local ecosystem being in commensal co-existence to certain extent. For instance, the urbanized community provides the eco-industrial park with labor and the eco-industrial park pays the community back with consumer goods and employment. However, an eco-industrial park competes with the local ecosystem for land, water and air. This interaction borders the parasitic relationship as an eco-industrial park consumes pure water and air and releases them after they have been polluted. On the positive side, water is recycled intensively within industries, thus decreasing the burden on other water resources and indirectly contributing to water conservation. As for other natural resources such as land, and air, the eco-industrial park indirectly contributes to their conservation by ameliorating the degradation of land and water and alleviating air pollution.

These ecology theories and concepts are not independent of each other but have correlations and associations, which are not always linear in time or operational sequence but layered and mutually informing.

- 1) **SYMBIOSIS.** The literal meaning of symbiosis is “the living together in close association of two unlike organisms, especially when mutually advantageous” (Odum 1971). In ecological science, symbiosis means “living together” and the term, generally, has a positive connotation [2]. The symbiotic associations occur between two organisms, two ecosystems or between an organism and an ecosystem. These interactions could take place among organisms of same or different species. Involved organisms and ecosystems could either be autotrophic or heterotrophic.
- 2) **EQUILIBRIUM.** The underlying intent of these associations is to attain and maintain equilibrium. Symbiosis could be occurring as either ecto-symbiosis or endosymbiosis depending on the type of interaction. In ectosymbiosis, one of the components or the symbionts live on the body surface of the host while in endosymbiosis, the symbiont lives either in the host’s intracellular or the extracellular space. Thus the symbiotic exchanges could be inferred as occurring at intra-system and inter-system level among the biotic and/or abiotic components.
- 3) **RESOURCE LOOPS.** An ecosystem maintains equilibrium by balancing the positive and negative feedback loops. For example, population equilibrium is maintained through birth (positive feedback) and death (negative feedback). Resources like light, water, soil, land area and food, limit symbiosis in a natural ecosystem. The lack or excess of these resources could disrupt its equilibrium. For example, if the demand for food increases because of excess population, high mortality could result from starvation although the birth rate would remain the same; this would disrupt the equilibrium of the system. As per widely accepted Darwin’s theory of evolution, the disruption in the equilibrium of an ecosystem could lead to extinction of one of the species (Darwin and Barrett 1980). According to Margulis and Sagan (1997), the disruption could result in other kinds of symbiosis and stimulate the evolution of the ecosystem.
- 4) **HABITAT facilitating RESOURCE LOOPS.** Ecosystems are either terrestrial or aquatic, and all have a range of sub-categories, depending on whether the composite environment is land or water based. A meadow, the pond and a watershed are classic examples of terrestrial, aquatic and intermediate ecosystems, respectively. Land and the water

provide the physical habitat for ecosystems and facilitate a range of intra- ecosystem and inter-ecosystem flows. Land and water thus form significant spatial aspects that house a wide range of ecosystems. The shape, size and structure of these spatial aspects influence the inhabited ecosystem. For example, if the pond is small and shallow, the type, density and distribution of the component biodiversity, are different from those of a large, deep pond (Odum1971). Any change in land and water features, have an important impact on the functioning of ecosystems.

Another research by Gutierrez, Jones and their colleagues (2003), on the spatial realm of ecosystem attempted to identify the role of mollusk shell in an aquatic ecosystem. The researchers found that the shells provide refuge to microorganisms, attached to exterior shell surface, from predation, and, control transport of matter. Changes in shell production also impacts the provision of the above services to microorganisms; lack of microorganisms affects all the ecological cycles associated with the microorganisms thus impacting the regulation of the micro-environment and other organisms connected to micro-organismic ecological cycles. In both examples the physical medium of one or both the involved components is used for exchange.

In cities, land is a limiting factor for the technological-human-biophysical symbiosis in the urban context. Similar to the natural ecosystem, where, a habitat has the limited potential to feed its population, the urban context has a limited potential to provide land to the industrial, human and plant population.

5) DIVERSITY PATTERN emerges from the distribution of organisms in the environment and from the interactions between the organism and its environment. Arrangements that influence the diversity pattern are: stratification, zonation, activity, food-web, reproductive patterns, social patterns, coactive patterns, resulting out of competition, mutualism etc. and stochastic patterns, resulting from random forces (Odum 1971, 154).

6) HIERARCHY THEORY perceives the ecosystem as an organization of organisms, species, trophic levels and the processes that drive the ecosystem (Beeby1993, 13-14). “This theory allows us to organize systems of widely different scale and character into coherent patterns that fit...the landscape” (Golley 2000). The nested hierarchy establishes a scale ranging from large to small and complex to simple, where, the whole system is controlled by the smallest to largest level of functioning sub-system. Identification of the levels of hierarchy is based on the relevant critical aspect, for instance, the rate of photosynthesis could

be a relevant critical aspect for a tree since it affects all scales of a tree ranging from a single leaf to the collective tree (Golley 2000).

7) **METAPOPOPULATION THEORY.** The metapopulation theory studies the interactions among and within populations. The interactions within the metapopulation are influenced by the size, shape, and mutual-distances of the component populations, and by the mobility and reproductivity of the species. The availability, quality and proximity of habitat to the populations affect the colonization and extinction of component species (Beeby1993, 153).

8) **ISLAND BIOGEOGRAPHY THEORY.** When the colonization and extinction rates are equal, the habitat is in a state of equilibrium. The colonization and extinction of species in a particular patch are influenced by the intrinsic traits of species as dispersal, aggression, crowding and isolation, body size, reproductive output and life expectancy combined with extrinsic factors such as climatic conditions and food availability (Odum 1971, 3). These theories focus on species-area relationships (minimum viable metapopulation- minimum amount of suitable habitat) and the best configuration of land for the habitat, processes and movements of species (Whittaker and Fernandez-Palacios 2007).

9) **DISCUSSION**

The symbiotic construct of a generic natural ecosystem is described through: components involved, whether the symbionts belong to a homogenous ecosystem or a heterogenous ecosystem, substance of exchange, medium of exchange, if it is spatial or non-spatial on paper, loop of exchange, it is a one way, open loop or, two ways, closed loop: source to sink or, source to sink and back, governing aspects, impact on other ecosystems, neutral, ameliorative or regenerative. Symbiotic construct of one of the natural ecosystem, could be delineated as:

- Components: Autotrophs and heterotrophs
- Substance of exchange: Food (material) and habitat (spatial)
- Level of interaction: Spatial + others
- Loop of exchanges: Two ways, closed loop, since both components gain
- Governing aspects: Temperature and light
- Impact on other ecosystems: None to Positive

Based on this understanding of symbiotic construct of natural ecosystem, the substance of sharing and aspects influencing the sharing for an EIP are shown in Table 1.

Table 1: Symbiosis within natural ecosystem

Substance of Sharing	Aspects influencing Sharing Based on theories of meta-population, island geography, hierarchy and diversity pattern
Energy Food Matter	Laws of thermodynamics (physics) Presence or absence of an organism (island biogeography, meta-population theory) Size, configuration and mutual-distances among population (island biogeography, meta-population theory) Criteria for defining levels (hierarchy theory)
Habitat	Distribution of organisms (diversity pattern) Habitat area- Population size relationship (diversity pattern, meta-population theory) Resource availability-Population size relationship (island biogeography)

The symbiotic exchanges within an eco-industrial park occur mostly amongst the industries located in the eco-industrial park or among the eco-industrial park and other complimentary outlier industries. The inter-exchanges are: either one-way, open loop, or two ways, closed loop. Ecology theories only marginally used in EIP are listed in Table 2 below.

Table 2. Ecology theories and concepts, marginally explored within context of EIP

Ecology theories and concepts, marginally explored within context of EIP
<p>SPATIAL DISTRIBUTION AND ORGANIZATION</p> <p>Island biogeography: Theorizes that the distance between the source of colonizing species and habitat, and the size of the habitat influences the rates of colonization and extinction.</p> <p>Metapopulation theory: Renders a platform to study interactions among intra and inter-populations</p>
<p>SCALE AND DYNAMICS BETWEEN THE ORGANIZATIONS</p> <p>Hierarchy theory: Identifies the “relevant critical aspect” as a basis to organize systems of widely different scale and character into coherent pattern.</p> <p>Diversity pattern: Delineates factors influencing the diversity pattern, such as: Stratification patterns (vertical layering), zonation patterns (horizontal segregation), activity patterns (periodicity), food-web patterns (network organization in food chains), reproductive patterns (parent-offspring associations), social patterns (flocks and herds), coactive patterns (resulting out of competition, mutualism etc.) and stochastic patterns (resulting from random forces).</p>

The eco-industrial park can be understood as an ecosystem that is comprised of component industries (organisms), that interact with contextual ecosystem (diverse species), and that shares land as a substance and medium of exchange (habitat), with its context.

The aspects influencing symbiosis in the natural ecosystem if adapted for eco-industrial parks will read as below:

- Presence or absence of an industry
- Size, configuration and mutual-distances among: industries within EIP; EIP and context
- Criteria for defining levels: size of an industry within the EIP; size of the EIP
- Distribution: of industries within EIP; EIPs within context
- Relationship between: EIP land area and, number and size of industries; land area of the context, and number and size of EIPs
- Artificial or natural resource availability

LESSONS FOR PLANNING A SYMBIOTIC CITY

The natural ecosystem is a bit of a distanced model for city design since natural ecosystem has the ability to achieve homeostasis or stability after disturbance with cycles of interim chaos, EIP offers more of a close one for it is after all a part of the city but a more carefully controlled construct. Cities designed as an eco-industrial park, would be an interesting hypothesis to explore. This hypothesis posits several implications. One is the Odum's energy exchange diagrams inspired model where different parts of the city operate as producers, consumers, store or recyclers, discussed by many, including a recent investigation in terms of metabolism by Codoban and Kennedy (2008). The other that I am exploring, through a series of investigations including this paper, is where parts of the city are developed as a complex independent industry that engages in resource exchanges, such that most resource loops are closed, operational efficiency is maximized and waste generation minimized. The science and methods of symbiosis, resource loops, equilibrium, diversity pattern, hierarchy, metapopulation and island biogeography, should be further investigated in-depth to draw lessons on planning a Symbiotic city.

CONCLUSION

Having drawn parallel between the natural ecosystem and eco-industrial park, this paper delineated the scientific theories of symbiosis, resource loops, equilibrium, diversity pattern, hierarchy, metapopulation and island biogeography, as the most pertinent resource for drawing lessons on planning a Symbiotic city. Additionally, I believe that the eco-industrial

park developers and planners could be more creative in employing land and water resource as spatial mediums of resource exchange through ecologically conscientious landscape architecture. Consideration of scientific principles and potential role that landscape architecture play in enhancing symbiosis in urban mosaic, while developing comprehensive plans for cities and industrial areas will ensure cities that are sustainable and in sync with other land-based ecosystems.

The next step in this research is to apply EIP model to a particular city and investigate the feasibility, strengths and challenges of planning and designing a Symbiotic City.

Notes:

[1] While Frosch (1992, 800) made an observation about the analogy between the food webs and the material supply chain in industrial systems, Chertow (2000) made the point about resource exchanges occurring among traditional industries located in close geographical proximity. In combination, the two thoughts provide a vision for eco-industrial park, See Frosch, R.A. *Industrial Ecology: A Philosophical Introduction*. National Academy of Sciences Proceedings. Washington, D.C, February 1992 and Chertow, Marian.R. *Industrial Symbiosis: Literature and Taxonomy*. *Annual Reviews Energy Environment*. *Annual Reviews*, 25 (2000): 313 –337.

[2] As per a range of research emerging from ecological sciences, symbiotic associations could be negative as in competition, amensalism and parasitism however the popular usage of the termsymbiosis is mostly to imply positive mutually beneficial interaction.

References

- [1] Ayers, R. (1996). “Creating industrial ecosystems-A viable management strategy?” *UNEP industry and environment*, October-December.
- [2] Beeby, A. (1993). *Applying ecology*. Chapman and Hall: London, New York
- [3] Gómez, F., Jabaloyes, J., Montero, L., De Vicente, D.V. and Valcuende, M. (2011). “Green Areas, the Most Significant Indicator of the Sustainability of Cities: Research on their Utility for Urban Planning.” *Journal of Urban Planning and Development*.(137):311-328.
- [4] Chertow, M.R. (2000). “Industrial Symbiosis: Literature and Taxonomy.” *Annual Reviews: Energy Environment*. (25):313 –337.
- [5] Codoban, N. and Kennedy, C.A. (2008). “Metabolism of Neighborhoods.” *Journal of Urban Planning and Development*, (134: 1) 21-31.
- [6] Darwin, C. and Barrett, P. H. (1980, 1977). “The Collected Papers of Charles Darwin: 1809-1882.” Phoenix edition, University of Chicago Press: Chicago

- [7] Friedmann, J. (2010). "Place and Place-Making in Cities: A Global Perspective." *Planning Theory & Practice*, (11:2) 149-165
- [8] Frosch, R.A. and Galloupolos, N.G. (1989). "Strategies for Manufacturing. Scientific American." *Scientific American*, 261(3): 144-152
- [9] Frosch, R.A. (1992 February). "Industrial Ecology: A Philosophical Introduction." *National Academy of Sciences Proceedings*. Washington, D.C
- [10] Golley, F. (2000). "Ecosystem Structure." in Jorgensen, S.E., Muller, F., (Ed), (2000). *Handbook of ecosystem theories and management*, Lewis Publishers: Boca Raton, Florida.
- [11] Gutierrez, J.L., Jones, C.G., Strayer, D.L. and Iribarne, O.O. (2003). "Mollusks as ecosystem engineers: the role of shell production in aquatic habitats." *Oikos* Blackwell Publishers Ltd.
- [12] Hardy C., and Graedel T.E. (2002). "Industrial ecosystems as food webs." *Journal of Industrial Ecology*, 6(1):29-38.
- [13] Manville, M. and Shoup, D. (2005). Parking, "People, and Cities." *Journal of Urban Planning and Development*. (131):233-245.
- [14] Margulis, L. and Sagan, D. (1997). *Microcosmos: Four Billion Years of Microbial Evolution*, Reprint Edition, University of California Press: Oakland, CA.
- [15] McManus, P. and Gibbs, D. (2008). "Industrial ecosystems? The use of tropes in the literature of industrial ecology and eco-industrial parks." *Progress in Human Geography*, (32:4): 525-540.
- [16] Nash, R.F. (1989). *The Rights of Nature: A History of Environmental Ethics*, University of Wisconsin Press: Wisconsin.
- [17] Odum H.T. (1971) *Environment, Power and Society*, Wiley: New York
- [18] Sharma, A. (2013). "Landscape of Industry: Transformation of (Eco) Industrial Parks Through History and Underlying Catalysts." *Journal of Arts and Humanities*, Vol 2, No 9: October.
- [19] Sharma, A. (2006). "Green-switch: Reducing the conflict between the industrial and the residential interface" *The Sustainable City: Urban regeneration and sustainability*, 147-151.
- [20] Tan, R.R., Auiso, K.B., Cruzjr, J.B., Culaba, A.B. (2011). "A note on an extended fuzzy bi-level optimization approach for water exchange in eco-industrial parks with hub topology." *Process Safety and Environmental Protection*, (89):106-111.
- [21] Whittaker, R.J. and Fernández-Palacios, J.M. (2007). *Island biogeography: ecology, evolution, and conservation*, Oxford University Press: UK.