INDUSTRIAL ECOLOGY TO PLAN AND DESIGN INDUSTRIAL AREAS

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Abstract
The planning and design of an industrial park are a complicated process due to the number of stakeholders concerned and time taken because of the own magnitude of the action: location selection and planning, physical infrastructures and industrial facilities design, building design, construction, operation, and management systems and disassembling-deconstruction design. Environmental criteria throughout all the design steps are fundamental to guarantee a long lifespan operation and the coexistence with surroundings in where the park is located. In this communication, the framework, concept and types of Eco-Industrial Parks (EIP’s) have been analyzed. The study led to the industrial ecology as the main strategy to obtain a new model based on a sustainable economy. Different types of EIP’s have been established according to the geographic scale of the industrial system. This offers new challenges and opportunities of searching strategies and alternative solutions for the resources consumption efficiency, negative environmental impacts minimization and economic benefit maximisation.

Key words: industrial ecology, industrial areas, sustainability

1 INTRODUCTION

1.1 Industrial area concept

The term industrial area refers to the idea of more or less intensive clustering of industrial activities with shared infrastructures in a certain territory (Trinder et al. 1993, Walcott 2009). The definition of a typology of industrial areas can be as diverse as areas exist, thus any classification that is made could be incomplete. In practice, the typology of productive spaces can be formed based on the consideration of one or several of the following features: predominant use or uses depending on the type of activity (basic or mixed industrial and special activities), area size and plot subdivision. This type of clustering represents a large part of the economic strategy followed by many countries since 1970, especially the more developed countries, where their planning and development are an essential part of the urban and territorial planning programs (Smith 1971).

1.2 Environmental problem and life cycle

Nonetheless, there is a significant environmental risk, because industrial parks concentrate all of the environmental problems of each one of the companies that are located there, in a relatively small area, to which we must add the impact caused by their infrastructures and services. The lack of environmental management mechanisms may cause impact from the generation of waste, atmosphere and water pollution and safety conditions in a relatively small space, which may also interfere with the neighbouring urban, tourist or recreational areas.
The current environmental legislation framework focuses on individual activities, which hinders its application to the industrial area system. This is partly due to the difficulty in establishing regulations that are applicable to all cases, because each park is different. This situation could be solved by means of industrial park self-government, and the consequent freedom of environmental self-regulation, depending on the degree of competitiveness that businesses may achieve. However, the essential element for improvement resides in the lifecycle perspective during the planning and design stages of new projects (Thabrewa et al. 2009, Pennington et al. 2007). Therefore, we should identify and address each of the lifecycle stages of an industrial area, in depth:

Location selection. Analysis of the localisation factors of influence and application of the techniques for assessment and selection of the optimal location.

Planning of the area and the physical infrastructures. Zoning and use of the land, precise delimitation of accesses and dimensioning suitable to the infrastructures required for the area to function, water and energy supply, sewage facilities, public lighting, waste collection...

Design of the buildings. Selection of the type of industrial buildings to be installed, their orientation, building materials and development of the ancillary installations required for the business operations.

Construction. Performance of the civil engineering works, which include the buildings and infrastructures required for the future companies that will locate to the industrial area to operate.

Operation and management. Stage at which the companies located in the industrial area operate generating products and services; maintenance operations and improvement of the installations are also carried out to guarantee their competitiveness.

Disassembly and dismantling. End of the lifecycle, when the location is vacated of the industrial installations so that it may be used for other purposes.

Throughout this lifecycle a negative environmental impact is generated, which must be reduced by means of new planning, design and management methods that are capable of conceiving industrial areas as socio-economic development elements that are in equilibrium with their surroundings. The emerging concept of sustainable industrial area should therefore be based on each and every one of the stages of its lifecycle. The planning and zoning stage has already been addressed in previous papers (Fernández & Ruiz 2009). The operation and management stage is the longest of the lifecycle and its design entails a higher efficiency in the consumption of resources and a lower generated impact on the surroundings, especially and with priority through the creation of cooperation networks of businesses for the exchange of materials and energy.

2 SUSTAINABILITY AND DESIGN OF INDUSTRIAL PARKS

2.1 Sustainability strategies based on industrial ecology

Since the energy crisis of 1971, many are the events that have conditioned international politics and have provided the essential impulse to begin the process of change towards a new model of sustainable development (WCE 1987). The 1992 Rio de Janeiro summit was the milestone after which many states and even the European Union began to define and apply plans to achieve equilibrium between economic, social and environmental interests. The achievement of this goal has led to the creation
of a variety of strategies that affect processes or products (Munier 2005): pollution prevention, eco-efficiency, lifecycle analysis, green design, environmental management systems and industrial ecology. Figure 1 shows the relationship between these sustainability strategies, with a systemic focus.

Industrial ecology has come to represent a broad set of concepts within which the remaining strategies are contained, its aim being to guide the transformation of the current industrial systems towards a sustainable basis. Industrial ecology theory presents the search for interactions between industrial activity and its environmental and urban surroundings, where the different production processes are considered as dependent and interrelated elements. The main goal is to encourage symbiosis between human activities situated in a certain area through the exchange of materials and energy, use of the know-how contained within the activities, development of shared installations or initiatives (O’Rourke et al. 1996, Graedel & Allenby 2003). This transformation requires changing the linear production-consumption model towards a closed-cycle model, similar to the cyclic flows of natural ecosystems (Lowe & Evans 1995). Industrial ecosystems and sustainable industrial parks represent, for some industrial ecologists, a key strategy for implementing industrial ecology (Côte & Hall 1995).

![Figure 1 Perspective of the relationship between sustainability strategies.](image)

2.2 The concept of sustainable industrial park (*Eco-Industrial Park, EIP*)

The planning and design of EIPs has become especially relevant over the last decade (Côté & Cohen-Rosenthal 1998, Gibss & Deutz 2005). The most common concept is
based on the creation of materials and energy exchange networks. Martin et al. (1996) resort to the definition given by the United States Environmental Protection Agency (USEPA) to describe an EIP as:

A community of manufacturing and services businesses that seek to enhance environmental and economic performance through collaboration in environmental management and reuse of materials. By working together, the community of businesses seeks a collective benefit that is greater than the sum of individual benefits each company would realise by only optimising its individual performance.

Other authors (Lowe et al. 1996, Oh & Kim 2005), also include in their definitions additional elements of industrial ecology that relate to the creation of a community identity, design and rehabilitation of infrastructures and buildings and pollution prevention:

A community of manufacturing and service businesses seeking enhanced environmental and economic performance through collaboration in managing environmental and resource issues including energy, water... Improvement of the environmental and economic performance includes the design and rehabilitation of the park’s infrastructures and buildings, pollution prevention and energy efficiency.

Industrial community in which the neighbours, manufacturing industries and services companies all share a feeling of belonging to a community and basic resources (information, materials, pollution prevention infrastructures) to maximise economic and social benefit and, at the same time reduce their environmental impact. Achievement of these goals requires the design and use of technologies that are efficient in the use of resources, energy and recycling of waste. This also implies the creation of a cultural identity, environmental design of the buildings and construction of symbiotic industrial networks

A common theme in these different statements is the economic and environmental benefit resulting from cooperation between the organisms involved in the performance of a sustainable industrial area. This cooperation entails the shared use of infrastructures, services, information and the creation of exchange networks that are aimed at closing materials cycles throughout the chain. The entire life cycle is taken into consideration, from the extraction of raw materials to the consumption of the product and its disposal. With the creation of these networks EIPs seek to imitate the efficiencies of natural ecosystems in achieving a more sustainable consumption and production, thus attaining a reduction in the amounts of waste generated and the conversion of by-products into reusable resources and products (Erkman 2003, Fiksel 2003). The localisation and integration of organisations that can use each of the waste products is essential, given that the loss of energy and materials at different points throughout the production/consumption/recycling/reuse cycle are unavoidable.

3 TYPES OF EIPs

The typology of EIPs is defined, partly, by spatial and organisational elements. Considering the distance between the companies forming part of the network and the boundaries within which the exchange of resources take place, Tudor et al. (2007) have produced a summary of terms used in the literature to define these networks of companies: Eco-Industrial Network, Eco-Industrial Park, Eco-Industrial Development, Networked Eco-Industrial Parks, Integrated Eco-Industrial Parks, Industrial Ecosystems and Industrial Symbiosis. In spite of the variety of terms, they all relate the clustering of companies to an increase of environmental, social and economic benefits. Based on a
detailed analysis of experiences contained in the scientific literature and on the taxonomy of types of exchange of materials carried out by Chertow (2004), Fernández (2009) proposes a classification based on the geographic scale. A distinction is made between the local and regional scaled EIPs. Despite the fact that there is no distance limit that defines the change from local to regional scale, we can consider that 3 km is the distance between companies for a local scale. The entities that participate in the exchanges vary depending on whether they are traditional parks, individual enterprises or EIPs.

3.1 Local scale

The local scale comprises all those situations in which the physical distance between companies is small. The possible options can be conceived through the design or redesign of pre-existing areas. In general, rehabilitation will achieve less environmental and economic benefits than designing a new area that starts from scratch based on the principles of industrial ecology. These strategies are applicable to companies or firms, localised companies and companies not localised in an area defined as industrial park, Figure 2.

![Figure 2 Local scale applicable to the concept of EIP.](image)

**Company.** Companies that can recycle water, co-generate steam and electricity, use gas emissions and re-process waste products and materials, can considerably reduce their operating costs. However, there are limitations regarding the degree and quality of waste and by-products that affect recovery costs. Although the measures employed may at times be partial, large plants such as refineries and electrical plants provide good opportunities for applying industrial ecology at firm or factory level. This is the case of the Corporation EBARA in Fujisawa ([http://www.ebara.co.jp](http://www.ebara.co.jp)).

**Localised companies.** The group of companies located in a defined and delimited area is the next stage in the evolution of industrial parks. Development of new synergies is stimulated and so the added value of the company individually and of the collective group of businesses increases. Within this type of parks we in turn find a further four types depending on the strategy applied (Figure 3): by-product exchange, recovery of resources and recycling, green design around a specific theme and combination of industrial, commercial and residential uses. Some examples of this type of industrial parks are the eco-industrial park Guitang Group in China (Zhu & Côte 2004) or the Phillips Eco-Enterprise Centre in the United States (Gibbs & Deutz 2007).
Non-Localised companies. These are industrial activities of a very diverse nature, mainly small and medium businesses, which are concentrated over more or less extensive areas. The separation between the companies is dictated by the economic feasibility of the shared services and usually does not exceed 3 km. Although the environmental and economic benefits increase with the geographical scale, the difficulties in their creation increase as well, given the need to coordinate the rising number of organisms involved. An example of this type of park is Kalundborg in Denmark (Lowe & Evans, 1995).

3.2 Regional scale

The regional scale affects the systems of eco-industrial networks whose distance between companies exceeds 3 km. The national and global scope is included within these limits. As shown in Figure 4, this system represents the development at a macro level of strategic linkages or alliances between eco-parks, classical industrial parks and/or individual companies through metropolitan regions or even global network structures, thus boosting both environmental and business actions (Lowe 2001). This system emerges where industries actively seek opportunities for linkages and relationships that promote synergies through networks and spatial association. Interconnected parks are not only a market or exchange system, they can be designed to boost synergies between industries that will allow reprocessing of products and waste. These synergies stimulate the creation of new industries, which will contribute to the diversity or expansion of existing industrial activities or groups. There are many more opportunities for the application of industrial activities in the larger areas, as it is more probable that there is a greater variety of activities and, therefore, also the possibility of establishing a greater number of synergies. One of the main drawbacks of the eco-industrial networks is the increase in risks. These risks are derived from the strong dependence created between the different companies that make up the synergies. Network design requires a careful planning process that will make the system strong. Two examples of eco-industrial networks are Singapore’s Jurong Island (Yang & Lay 2004) and Kola Peninsula Mining-Industrial Complex in Russia (Salmi 2007).

4 SUMMARY AND CONCLUSIONS

“Selected Proceedings from the 13th International Congress on Project Engineering”. (Badajoz, July 2009)
Application of the industrial ecology principles in the development of EIPs generates a series of advantages and disadvantages in the different scales of application. The main features are summarised in Table 1.

The possibilities for creation of synergies increase in proportion to the geographical size, because the number of companies involved is larger and therefore the possibilities for establishing exchanges are also higher. This requires an increase in awareness on the principles and benefits of industrial ecology, thus facilitating collaboration between the different organisms involved in the development and performance of these areas of economic activity. There are more opportunities for creation of networks between companies in the EIP, as well as between EIPs and the community, higher economies of scale are obtained as the result of an extensive network of organisms, connectivity between different organisms increases and absolute production capacity rises regarding the base resources and skills that can be found in this environment.

On the other hand, this creation of synergies increases dependence between the network members. A high degree of dependence leads to company vulnerability. Changes in a company’s production process can lead to new by-products and waste and the consequent modification to the raw materials supply chain. The search for new suppliers may lead to costs that are too high for company feasibility. The risks and costs associated with by-product and waste transactions also increase, thus leading to further difficulties in management activities. Lastly, a greater distance between companies also impairs the use of communal services and infrastructures, which does not allow cost-sharing. Likewise, innovation in other areas such as architecture or new technologies is more difficult.

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<th>FEATURES</th>
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<td>Communal services and infrastructures</td>
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<td>Ease of management</td>
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<td>Possibilities for creation of synergies</td>
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<td>Economies of scale</td>
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Table 1 Features of the different scales of application of sustainable industrial areas.


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