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Architectural Evaluation of Eco-Industrial Parks: Promoting Sustainable Human Development

Eko-Endüstriyel Parkların Mimari Değerlendirmesi: Sürdürülebilir İnsani Kalkınmanın Desteklenmesi

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ABSTRACT

The purpose of this study is to evaluate eco-industrial parks' architectural performance in relation to sustainable human development objectives. To mitigate the adverse environmental impacts of industrial activities, eco-industrial parks are crucial. These parks have a major positive impact on lowering greenhouse gas emissions and industrial pollutants. In this context, the study evaluates the architectural performance of "eco-industrial parks" based on the sustainability criteria established by the "United Nations Industrial Development Organisation". Among the most prominent and long-standing "eco-industrial parks" in the world are "Kokkola Eco-industrial Park", "Kalundborg Eco-industrial Park", "The Ecofactorij", "Tianjin Economic Development Area", "Eco3 Industrial Park", and "Daedeok Technovalley Park". These parks make up the study sample. Table 3 summarizes the findings from the study, which employed a qualitative analysis method, using a scoring system. Despite their many excellent aspects, eco-industrial parks lack innovative design, transportation and accessibility, and interior quality. The most effective criteria are waste management, water management, and material selection. The two with the highest scores are TEDA and Kalundborg. Kokkola and Ecofactorij get the lowest ratings among the parks. The study's findings demonstrate that taking sustainable design principles into account while creating eco-industrial parks produces more effective outcomes in terms of environmental sustainability. By highlighting the shortcomings and advantages of parks that might be regarded as forerunners in the field of eco-parks, the study seeks to develop a resource for architects and urban planners.

Keywords:, Sustainable human development, Eco-industrial park , Low carbon zone, Green industrial areas, Sustainable development goals, Architecture review, Social inclusion, Environmental sustainability

ÖZ

Bu çalışma, sürdürülebilir insani kalkınma hedefleri doğrultusunda eko-endüstriyel parkların mimari performanslarını değerlendirmeyi amaçlamaktadır. Eko-endüstriyel parklar, sanayi faaliyetlerinin çevresel etkilerini azaltma stratejileri arasında kritik bir öneme sahiptir. Bu parklar, sanayi kirliliğini ve sera gazı emisyonlarını azaltmak için önemli avantajlar sağlarlar. Bu bağlamda çalışma kapsamında United Nations Industrial Development Organization'nun belirlemiş olduğu sürdürülebilir kriterler üzerinden eko-endüstriyel parkların mimari performansı değerlendirilmiştir. Araştırmanın örneklemini dünyada eko endüstriyel park alanında öncü konuma sahip ve uzun süredir faaliyette olan Kokkola Eco-industrial Parkı, Kalundborg Eko Endüstriyel Parkı, The Ecofactorij, Tianjin Economic Development Area, Eco3 Industrial Parkı ve Daedeok Technovalley Parkı oluşturmaktadır. Yöntem olarak nitel analiz yönteminin kullanıldığı çalışmada elde edilen veriler puanlama sistemine göre Tablo 3'de özetlenmiştir. Eko endüstriyel park alanında öncü olan parklar pek çok açıdan olumlu nitelikler taşımalarına rağmen,

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iç mekan kalitesi, ulaşım ve erişilebilirlik ile yenilikçi tasarım açısından yetersiz kalmaktadır. Malzeme seçimi, su yönetimi ve atık yönetimi ise parkların en başarılı oldukları kriterlerdir. Değerlendirme sonucunda en yüksek puanı alan parklar ise Kalundborg ve TEDA'dır. En düşük puanı alan parklar ise Ecofactorij ve Kokkola'dır. Çalışma bulguları, eko-endüstriyel parkların tasarımında sürdürülebilir kriterlerin dikkate alınmasının, çevresel sürdürülebilirlik açısından daha verimli sonuçlar doğurduğunu göstermektedir. Sonuç olarak, çalışma eko park alanında öncü sayılabilecek parkların zayıf ve güçlü yönlerini ortaya koyarak mimarlar ve kentsel tasarımcılar için kaynak oluşturmayı hedeflemiştir.

Anahtar Kelimeler: Eko-endüstriyel park, Sürdürülebilir insani kalkınma, Yeşil endüstriyel alanlar, Düşük karbon bölgesi, Sürdürülebilir kalkınma hedefleri, Mimari değerlendirme, Sosyal katılım, Çevresel sürdürülebilirlik

1. INTRODUCTION:

In order to promote sustainable human growth in the twenty-first century, it has become necessary to look for new and alternative resources due to rising energy consumption and the careless exploitation of natural resources. As a result, the most important paradigm of the twenty-first century is sustainable development, which includes sustainable human development. "A comprehensive strategy for resolving social, environmental, and economic issues" is the sustainable development movement. One dynamic idea that enables future generations to meet their requirements while still addressing the needs of the present is the sustainable development movement (Brundtland, 1987). This movement includes goals such as the proper and effective use of resources, management of investments in harmony with the environment, use of renewable energy, economic efficiency, resource efficiency, and social welfare (Sev, 2009). The main goals of sustainable development are especially the effective use of energy and harmony with nature and the natural environment (Edwards, 2007). In 2015, "the United Nations" summarized the main goals of sustainable development in 17 items: Zero Hunger, Industry, Innovation and Infrastructure, No Poverty, Life Below Water, Quality Education, Sustainable Cities and Communities, Good Health and Well-being, "Partnerships for the Goals", "Gender Equality, Justice and Strong Institutions, Affordable and Clean Energy, Clean Water and Sanitation, Decent Work and Economic Growth, Reduced Inequality, Peace, Climate Action, Responsible Consumption and Production, Life on Land" (Sustainable Development Goals, 2015).

A fundamental idea in many fields is sustainable development. Sustainable development has emerged as a key prerequisite for building design in the field of architecture. Discussions on sustainable development primarily center on the effects that industrial structures and infrastructure have on the economy, society, and environment (Oh et al., 2005). Globally, industrial regions are the main causes of environmental contamination. These regions emit a lot of greenhouse gases and pollute the air and water. The primary cause of greenhouse gas emissions is industrial activity (Waisman et al., 2019). Numerous contemporary issues, including resource depletion, climate change, global warming, and biodiversity loss, are directly caused by industrial activity. Despite significant efforts to lessen industrial pollution, these operations continue to significantly harm the environment (Maha, 2021). Strategies to lessen the effects of industrial activity on the environment are therefore required on a global scale. Eco-industrial parks have gained prominence in the past three decades as a means of promoting the sustainable growth of industrial regions. According to sustainable development goals, these parks offer crucial advantages for the growth of industrial communities.

With the advent of urban planning and spatial studies in the 1950s, eco-industrial parks initially appeared. The concept of industrial ecology emerged as environmental issues became more pressing at the end of the century (Saikku, 2006). Since their initial definition at "the 1992 United Nations Conference on Environment and Development (UNCED)", eco-industrial parks have gained popularity across numerous nations. According to Stewart (2007), eco-industrial parks, also known as "sustainable industrial parks," "low carbon zones," or "green industrial areas," are a collection of companies founded on collaboration and dedicated to reducing resource consumption. These are industrial zones where businesses collaborate with one another and the community to guarantee sustainable development. Efficient resource sharing is the primary objective of these parks. Economic benefits, enhanced environmental quality, and resource equity are all made possible by this collaboration (Lowe & Evans, 1995). According to Hein et al. (2015), "eco-industrial parks promote resource efficiency", industrial development, environmental and social sustainability, and the circular economy. Globally, eco-industrial parks are becoming more and more significant. They improve the health and well-being of employees and establish safe working environments (Temiz & Sağlık, 2021). By recycling garbage, these parks reduce energy use and offer considerable energy cost savings. Reducing energy use, recycling garbage, lowering hazardous gas emissions, safeguarding the local environment, effective use of energy and water, and creating a healthy work environment are all advantages of eco-industrial parks, according to Stewart (2007). Additionally, eco-industrial parks provide social, environmental, and economic advantages. Economically speaking, recycling waste creates jobs and cost savings. They have several beneficial effects on the environment, including lowering waste and pollution, conserving biodiversity, using resources efficiently, and lessening the effects of climate change. The creation of social infrastructure, chances for educational and professional skill development, and increased community services are some of the social advantages of eco-industrial parks (Van Beers et al., 2017).

Numerous criteria and guidelines have been created for "the establishment of eco-industrial parks". A structure that is applicable to all industrial parks has been proposed by UNIDO ("United Nations Industrial Development Organization"). Additionally, China and Finland have created rules that will serve as models for them (UNIDO, 2023). The UNIDO recommendations set forth the requirements for sustainable development in industrial parks. When choosing park site, factors including land size, industry type, energy networks, raw material availability, accessibility, transportation, labor force, and closeness to water resources should all be taken into account. It is also necessary to assess the risks associated with ecosystems, climate change, and biodiversity loss. To reduce the dangers of fire and the release of hazardous materials from industrial processes and natural disasters, a centralized management unit should also be established. Zoning laws and customs unique to nations, states, or localities should be considered in legislation. Future growth and development estimates should inform plans. For collaboration, information exchange, space management, engagement, and communication, parks ought to have separate departments. The establishment of an industrial symbiosis network takes into account environmental sustainability criteria like waste and resource management, life cycle costs, health, comfort, user satisfaction, economic efficiency, functionality, flexibility, accessibility, and quality evaluation (Nessim et al., 2024).

Ten evaluation criteria were chosen for this study based on those created for eco-industrial parks by the United Nations Industrial Development Organization (UNIDO). Five innovative eco-industrial parks are assessed based on these standards. The evaluation's goal is to identify the advantages and disadvantages of the parks that have been eco-park pioneers for a considerable amount of time. The purpose of these assessments is to serve as a foundation for the creation of new eco parks and the enhancement of already-existing parks. The study employed the qualitative analysis approach, and within the parameters of the criteria, the parks were compared to one another using a specific score system. The study's distinction from other studies. There is little information on the architectural design of eco-industrial parks, despite the fact that there are numerous studies on the subject in various fields (Eilering and Vermeulen, 2004; Oh et al., 2005; Saikku, 2006; Shi et al., 2010; Shao et al., 2013; De Sousa Silva et al., 2017; Khaled and Shalaby, 2021; Abu-Qdais and Kurbatova, 2022; Nessim et al., 2024). This study assesses eco-industrial parks from an architectural standpoint in light of this deficiency.

2. Method

In the study, the architectural performance of eco-industrial parks is evaluated using a qualitative analysis method. The examples examined are pioneers in the field of eco-industrial parks and have been in operation for a long time. In the study where six examples from different parts of the world are evaluated, "Kokkola Eco-industrial Park" and "Eco3 Park" are located in Finland, Kalundborg Park in Denmark, The Ecofactorij in the Netherlands, TEDA in China and Daedeok Technovalley Park in Korea. The evaluation of the parks is based on the criteria developed by UNIDO ("United Nations Industrial Development Organization"). "UNIDO" is an organization that promotes sustainable industrial development and eco parks are directly in line with UNIDO's objectives. In this context, ten (10) criteria were determined within the framework of the standards developed by UNIDO. The criteria cover the environmental, economic and social dimensions of the parks in line with sustainable development goals.

The categories examined in this study are energy efficiency and management, material selection and use, waste management, landscape, water management, indoor quality, and green spaces, community participation and social sustainability, transportation and accessibility, economic sustainability, innovative and flexible design. The relationship of the criteria with the 17 items identified "within the scope of sustainable development goals" is shown in Table 1. The items to which the study contributes are categories 3, 6, 7, 8, 9, 10, 11, 12 and 17 respectively.

Table 1. Relationship between SDGs and Evaluation Criteria (created by authors)

Energy Efficiency and Management	Item 7: Affordable and clean energy
Material Selection and Usage	Item 9: Industry, ınovation and infrastructure
Water Management	Item 6: Clean water and sanitation
Waste Management	Item 12: Responsive consumption and production
Interior Space Quality	Item 3: Good health and well being
Landscaping and Green Areas	Item 11: Sustainable cities and communities
Social Engagement and Sustainability	Item 17: Partnerships for the goals Item 10: Reduced inequalities
Transportation and Accessibility	Item 11: Sustainable cities and communities
Economic Sustainability	Item 8: Decent work and economic growth

In the study 5-6 questions were created for each criterion. Table 2 shows the list of criteria and questions. After the criteria and questions were determined, a rating system was developed to evaluate each criterion. The purpose of the rating system is to measure the extent to which the parks fulfill each criterion. Each criterion is scored as 1 and 0. A score of 1 was given if the park fulfills the relevant criterion, and a score of 0 was given if there was no data on the criterion or if the park did not fulfill the relevant criterion. The scores were then summed, and the extent to which each criterion was fulfilled was determined. 0 points indicating that the criterion was not fulfilled at all, 1-2 points indicating that the criterion was not sufficiently fulfilled, 3-4 points indicating that the criterion was well fulfilled, and 5-6 points indicating that the criterion was very well fulfilled. In the evaluation table, the scores are expressed with coloring to provide a better understanding of the relevant scoring system. With the data obtained, the current condition of the parks were revealed.

Table 2. Eco-industrial parks evaluation criteria and checklist (created by authors)

A	Energy Efficiency and Management	A1	Are renewable energy sources used?
		A2	Are energy-saving measures implemented?
		A3	Are energy monitoring and management systems in place?
		A4	Is energy symbiosis and sharing taking place?
		A5	Are strategies in place to reduce carbon footprint?
B	Material Selection and Usage	B1	Are recycled materials being used?
		B2	Are local materials preferred?
		B3	Are non-toxic materials being used?
		B4	Are the materials durable and long-lasting?
		B5	Is the amount of waste materials minimized?
C	Water Management	C1	Are there water recycling systems?
		C2	Are water-saving measures implemented?
		C3	Are there rainwater collection systems?
		C4	Are wastewater treatment systems working?
		C5	Is water quality monitored regularly?
		C6	Is it easy to access water sources?
D	Waste Management	D1	Are waste minimization strategies in place?
		D2	Are recycling and reuse encouraged?
		D3	Are hazardous wastes managed safely?
		D4	Is organic waste appropriately handled?
		D5	Are waste monitoring and management systems in place?
		D6	Are environmental impacts minimized?
E	Interior Space Quality	E1	Is the indoor air quality good?
		E2	Are natural light and ventilation sufficient?
		E3	Is thermal comfort provided?
		E4	Is noise control implemented?
		E5	Is the interior design ergonomic?
		E6	Are health and safety measures in place?
F	Landscaping and Green Areas	F1	Is the proportion of green space sufficient?
		F2	Is biodiversity being protected?
		F3	Is the natural landscape protected?
		F4	Are there green infrastructure elements?
		F5	Are there public green spaces available?
		F6	Are ecosystem services being provided?
G	Social Engagement and Sustainability	G1	Are local communities involved in the projects?
		G2	Are training and awareness programs organized?

		G3	Are social justice and equality ensured?
		G4	Are social areas provided for employees?
		G5	Are social benefit projects being conducted?
		G6	Are there social responsibility projects?
H	Transportation and Accessibility	H1	Is it easy to access public transportation?
		H2	Are there bicycle paths and pedestrian access?
		H3	Are parking facilities sufficient?
		H4	Is transportation integration ensured?
		H5	Is sustainable transportation encouraged?
		H6	Is disabled accessibility available?
I	Economic Sustainability	I1	Is economic efficiency ensured?
		I2	Is employment being created?
		I3	Are cost-saving measures being implemented?
		I4	Is it attractive for investment?
		I5	Is market competitiveness achieved?
		I6	Is it contributing to the local economy?
J	Innovative and Flexible Design	J1	Are innovative technologies being used?
		J2	Are there flexible and adaptive design elements?
		J3	Are R&D activities being conducted?
		J4	Is innovation encouraged?
		J5	Is technological adaptation being ensured?
		J6	Are continuous improvement strategies in place?

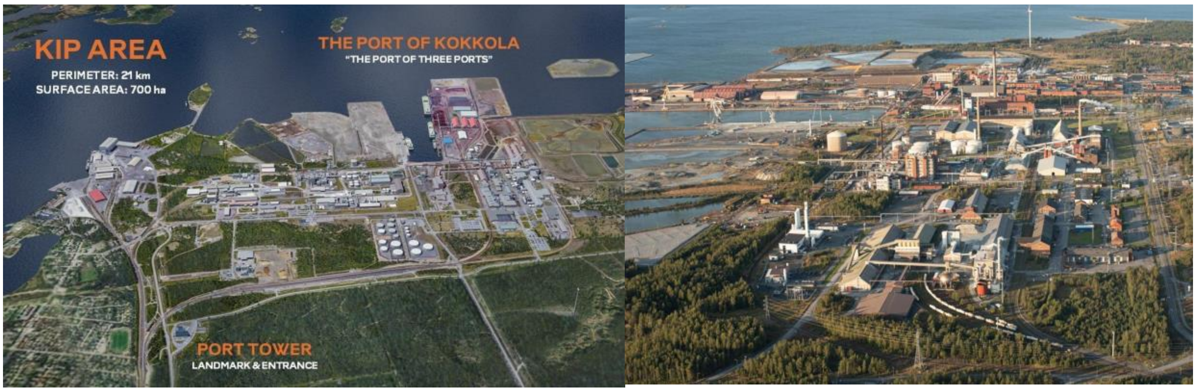
3. Results

Within the scope of the study, six (6) eco-industrial parks from different regions of the world were analyzed. The data on the parks is based on information obtained from literature studies and park websites. A comparative table presents and evaluates descriptive information about each park (Table 2).

3.1. Eco-industrial Park in Kokkola

Located in Kokkola in the Ykspihlaja region of Finland, the 700-hectare area is a new development zone (Nessim et al., 2024) (Figure 1). Kokkola Park includes various industrial activities such as hydrogen production, cosmetics, zinc plants, sulfuric acid plants, calcium chloride plants, air gas plants, carbon dioxide plants, potassium sulfate plants, and mining. It is an industrial area that specializes in the chemical and metal industries. The park is 5 km northwest of the city center and accessible by road, rail, air, and public transportation. The park's production activities produce shared and reused by-products in a symbiotic (collaborative) manner. The park has developed solutions for waste management, energy efficiency, and carbon footprint reduction. Renewable energy is targeted in the design of green structures in the park. Utilizing “renewable energy sources like solar panels, wind turbines, and biomass power plants lowers” the carbon footprint. The buildings in the park are designed in accordance with LEED and BREEAM international green building certificates. The use of “natural light and ventilation” is encouraged in the design of the buildings. The park also encourages green mobility among employees. In addition to public transportation, there are bicycle and walking paths in the area. Electric vehicle charging stations are available throughout the park to support the use of electric vehicles. Natural elements such as green areas, vegetation, and water features are preserved and developed. The park aims to increase biodiversity by protecting local flora and fauna. In this context, various ecological projects and conservation programs are implemented. In addition, universities and vocational schools are located in the park for vocational training. These educational institutions offer qualified labor opportunities to companies in the park (New Boliden, 2021).

Figure 1. Kokkola Eco-industrial Park Land Use



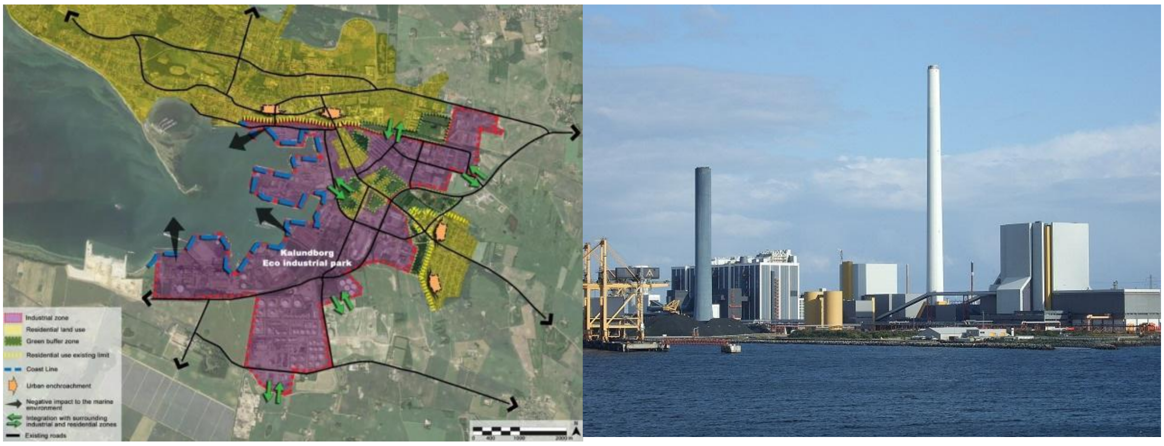
Source: Nessim et al, 2024; Encyclopaedia Fennica
https://fennica.pohjoiseen.fi/fi/2020/12/09/kokkola-city/

Comprehensive environmental control measures are implemented at Kokkola Eco-industrial Park as part of its commitment to sustainability and industrial symbiosis, contributing to “sustainable human development” by promoting “environmental stewardship”, “economic resilience”, and “social well-being”. Environmental management, including noise control, is a vital part of the park's operations. Companies within the park collaborate with environmental authorities and stakeholders to reduce environmental impacts. This cooperation covers air quality, marine, and groundwater assessments. The park also collaborates with universities and research institutes to develop innovative solutions. In terms of material use, the park makes extensive use of recycled materials, especially metals and chemicals. Locally sourced raw materials are preferred to reduce logistics costs and minimize environmental impacts. The use of non-toxic chemicals in environmentally friendly production processes is encouraged. Durable materials are used to ensure the longevity of products and structures. In addition to its positive features, the Kokkola Eco-industrial Park is also criticized. Due to its focus on the chemical industry, environmental impacts are not fully controlled, and potential pollutants create problems. As the park expands, it puts pressure on local communities and negatively affects the quality of life in the environment. In addition, sustainable technology investments are challenging for companies due to their high cost (Nessim et al., 2024). When the layout of the park is examined, it is seen that green areas are limited (Figure 1). It is an area where industrial buildings are dense. Natural landscape elements are limited. Apart from the surrounding water body and some green areas, there are few natural landscape elements. Public green space is also limited.

3.2. Eco-industrial Park in Kalundborg

The “Kalundborg Eco-industrial Park”, established in 1959 in Denmark, is an example of industrial symbiosis (Figure 2). The park covers an area of approximately 20 square kilometers and includes various industries such as oil refineries, power plants, cement factories, chemical plants, and paper factories (Khaled & Shalaby, 2021). The companies in the park form a strong cooperation by using each other's products. The symbiotic relationships, which initially emerged completely unplanned, have been consciously managed over time. There is, therefore, a complex network structure between enterprises. Environmental and economic efficiency is achieved by sharing waste heat, energy, water, steam, materials, and by-products. Significant gains such as reduction in carbon dioxide emissions, water savings, and waste recycling have been achieved. All activities in the area aim for environmental and financial sustainability, advancing sustainable human development by fostering a healthy environment, robust economy, and vibrant community. The park is recognized as a model for sustainability and innovation. The park also hosts educational and research activities. Utilizing renewable energy sources is something the park promotes in terms of environmental sustainability. Many facilities meet their energy needs with solar panels on their roofs. Some of the buildings in the area are built in accordance with LEED and BREAM standards (Saikku, 2006).

Figure 2. “Kalundborg Eco-industrial Park Land Use “



Source: Khaled & Shalaby, 2021; https://en.wikipedia.org/wiki/Kalundborg_Eco-industrial_Park

Regarding material use, the park encourages the reuse of waste and the integration of recycled materials into production processes. In addition, materials are obtained from local sources. The focus is on using durable and long-lasting materials that “do not harm the environment and human health”. In addition to its positive features, the Kalundborg eco-industrial park is criticized. Since the firms within the park have a high degree of interdependence, their impact on each other is relatively high. The industrial symbiosis model does not include flexibility, which makes it difficult for new firms to integrate and also makes existing firms highly interdependent (Jacobsen, 2006). When the park layout is examined, green areas are visible (Figure 2). Green buffer zones and the green regions along the coastline support biodiversity. While natural landscape elements are present, green infrastructure elements are also visible. The park also includes public green spaces and transportation infrastructure.

3.3. The Ecofactorij

The Ecofactorij Park is a new development area of 95 hectares in Apeldoorn, the Netherlands (Figure 3). The park is accessible from two highways in the nearby province of Gelderland. For environmental sustainability, the park includes an information center, green spaces, solar panels, biomass, wind turbines, heat pumps, fuel stations for alternative fuels, and charging points for electric vehicles and bicycles (Nessim et al., 2024). Rainwater is collected and reused throughout the park. 80% of the facilities have heat pumps and 20% have biopellet heating systems. There aren't many industrial symbiosis activities in the park because logistics companies make up the majority of the businesses there. Therefore, industrial symbiosis opportunities cannot be provided in the park. The facilities in the park fulfill green building criteria. Adiabatic cooling (cooling with water vapor), maximum use of daylight, insulation with natural materials, renewable energy production, smart lighting, and smart sunshades have been developed (Eilering & Vermeulen, 2004).

Figure 3. Ecofactorij Industrial Park Land/Water Use

Source: https://digitaleplannen.apeldoorn.nl/NL.IMRO.0200.bp1304-vas1/t_NL.IMRO.0200.bp1304-vas1.html; https://ecofactorij.nl/

In terms of material usage, Ecofactorij makes extensive use of recycled resources, particularly in the building and manufacturing operations. To boost the local economy and lessen environmental effects, local, non-toxic, strong, and long-lasting materials are used. In terms of waste minimization, effective waste management and recycling systems are in place. In addition to its positive features, the Ecofactorij eco-industrial park is also criticized. It is not effective enough in achieving sustainability goals. The high costs of sustainable practices cause economic pressures. Local people have limited employment opportunities, and the park has failed to create jobs (Pellenbarg, 2002). When the park layout is examined, green areas are visible (Figure 3). There are green areas and green buffer zones. These areas also support biodiversity. While natural landscape elements are available in the park, green infrastructure elements are also visible. Public open green spaces and transportation infrastructure are also present.

3.4. Tianjin Economic Development Area

It is a new development zone established on an area of 4500 hectares in the southeast of Tianjin in China (Figure 4). Of this area, 3400 hectares are used for industry and 1100 hectares for housing (Nessim et al, 2024). The Tianjin eco-industrial park includes various industrial activities such as microelectronics, petrochemicals, automobiles, and biotechnology. The park is located in the port area, about 45 km from the city. The park has a public transportation system and is accessible by air, rail, and road. The park provides various incentives and funds for companies for wastewater treatment, recycling water, solid waste reduction, utilization of by-products, energy saving, and symbiosis (collaborations). Waste recycling, "emission control, a water treatment plant, a wastewater treatment and recycling plant, a cogeneration power station, a waste-to-energy plant, a seawater desalination plant, an electronic waste recycling plant, a thermal power plant, and a groundwater extraction plant" are all included in the park's environmental sustainability features. Within the scope of industrial symbiosis, there are cooperation activities involving energy, water, and solid waste exchanges. The facilities in the park fulfill green building criteria. Waste minimization and energy conservation measures have been developed in the buildings. Noise control is also provided at TEDA as part of a comprehensive environmental management strategy. Advanced production technologies and automation systems are used. There are numerous R&D centers and laboratories. Furthermore, the park offers services and social amenities for both staff and guests (Shi et al., 2010).

Figure 4. Tianjin Economic Development Area Land Use

Source: (Shao et al., 2013); https://regional.chinadaily.com.cn/tianjin/binhain/2023-06/15/c_895000.htm

Regarding material use, TEDA encourages using recycled, local, non-toxic, durable, and long-lasting materials. In addition to its positive features, there are some points where TEDA is criticized. The rapid industrialization of the park contributes to environmental pollution. There are social and economic imbalances due to rapid growth. There are challenges in the management and supervision of large-scale projects (Research Report on the Investment Environment of the TEDA , 2017). The park layout is characterized by green areas, parks, and natural reserves, indicating a high potential for green space and biodiversity (Figure 4). Natural landscape elements have been preserved. Green infrastructure elements are supported by parks, green spaces, and waterways. Transportation infrastructure is well planned with main roads and connections. There are also public green spaces and parks in the park.

3.5. Eco3 Industrial Park

Located in Nokia City, Finland, the park is a new development area of 600 hectares (Figure 5). The park is located on the city's outskirts and is connected by a highway. The park includes various industries, such as construction activities, recycling, and the waste processing. The park focuses on "renewable energy sources" such as "biogas production" and "biomass energy". The biogas plant and waste processing center are common areas used by the enterprises. Sewage and biological wastes are converted into biogas and fertilizer. Electrical and electronic waste, metals, plastics, and construction waste are processed for reuse (Nessim et al., 2024).

Figure 5. Eco3 Industrial Park Land Use

Source: http://www.screen-lab.eu/Presentazioni/London21-Seppanen.pdf; http://www.screen-lab.eu/Presentazioni/London21-Seppanen.pdf; https://eco3.fi/en/eco3/

The park offers innovative solutions such as energy efficiency, water management, waste recycling, and low carbon footprint. In terms of green building design, the buildings in the area are designed to have high energy efficiency. These technologies include solar panels, energy-efficient lighting systems, and energy-efficient window and door systems. Energy is consumed using renewable resources including wind, solar, and biogas. Green roof solutions reduce the energy consumption of the buildings. Environmental certifications like "BREEAM (Building Research Establishment Environmental Assessment Method) and LEED (Leadership in Energy and Environmental Design)" are followed in "the design of the buildings" at "ECO3 Business Park". The park promotes the extensive use of recycled materials in production processes in terms of material consumption. The use of local, non-toxic, low-carbon footprint, durable, and long-lasting materials is preferred to provide regional, economic, and environmental benefits. Waste minimization strategies also aim to minimize waste production. In addition to its positive features, Eco3 has some criticisms. There are difficulties in finding financing for sustainable projects. There are also implementation gaps in achieving sustainability goals. Legal and bureaucratic processes negatively affect the speed and efficiency of projects (Nordregio, 2016). When the park layout is examined, large green and forested areas are noticeable (Figure 5). This indicates that the park has a high green space ratio and biodiversity potential. Natural landscape elements are also preserved and integrated within the park. Green infrastructure elements are supported by sustainability-oriented structures such as a biogas plant, waste management center, and water treatment facilities. The park also includes public green spaces and recreational areas. In addition, the park's transportation infrastructure is well-planned, with main roads and connections.

3.6. Daedeok Technovalley Park

It is the first eco-industrial park initiative in Korea (Figure 6). The 427-hectare park is located close to the city of Daejeon. 70% of the site is flat, and the rest is steeply sloping land. The park has made significant progress in environmental sustainability with its mixed land use. The network of green spaces in Daedeok Park, artificial land planting, daylighting, natural ventilation, passive and active solar energy utilization, non-toxic material use, and green roofs are all notable aspects of green building design. To cut down on water use, there is a facility for recovering rainwater and gray water as well as a reuse system. To boost the generation of renewable energy, energy-efficient facilities and photovoltaic energy production have been developed. In order to preserve the variety of species in the region, efforts are being made to create biotopes, build ecological parks, design the coastline ecologically, and plant artificial land. Additionally, the park's green area ratio is 17.7% (Yim et al., 2004). Regarding material use, various research and development projects are being carried out on using recycled materials in the park. Local, non-toxic, durable, and long-lasting materials are encouraged for regional development and environmental sustainability. In terms of waste minimization, advanced waste management and recycling technologies are used. In addition to its positive features, Daedeok has also been criticized. Intense competition in the high-tech sector creates pressure among companies within the park. R&D activities require high resource consumption, which increases costs. There are also challenges in terms of collaboration between companies from different sectors. In particular, the development of a symbiotic network (Oh et al., 2005).

Figure 6. Daedeok Technovalley Park Land Use


Source: Oh et al., 2005; https://www.hanwha.com/newsroom/media-library/media-assets/daedeok-techno-valley-in-south-chungcheong-province-korea.do

Looking at the park layout, green spaces and parks are visible (Figure 6). Natural landscape elements are limited and primarily focused on buildings. Green infrastructure elements are supported by sustainability-oriented structures such as waste management and water treatment facilities. Publicly accessible green spaces are available. Transportation infrastructure is also well planned, with major roads and connections.

Table 3 evaluates the six (6) eco-industrial parks that were looked at for this study. From the lightest to the darkest tone, the scores in the table rise.

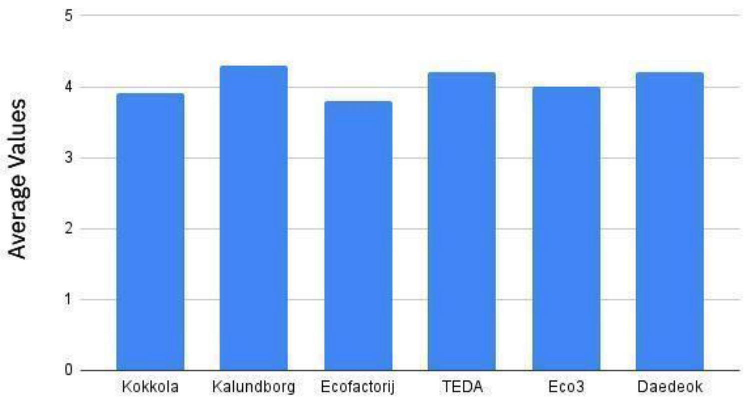
Table 3. Comparison of Eco-industrial Parks by Criteria (created by authors)

		Kokkola	**Kalundborg**	**Ecofactorij**	**TEDA**	**Eco3**	**Daedeok**	Colors	Average values
A **(**Energy Efficiency)	A1	1	1	1	1	1	1		5,4
	A2	1	1	1	1	1	1		
	A3	1	1	1	1	1	1		
	A4	1	1	0	1	1	0		
	A5	1	1	0	1	1	1		
B **(**Material Selection)	B1	1	1	1	1	1	1		6
	B2	1	1	1	1	1	1		
	B3	1	1	1	1	1	1		
	B4	1	1	1	1	1	1		
	B5	1	1	1	1	1	1		
C **(**Water Management)	C1	1	1	1	1	1	1		5,5
	C2	1	1	1	1	1	1		
	C3	0	1	1	0	1	0		
	C4	1	1	1	1	1	1		
	C5	1	1	1	1	1	1		
	C6	1	1	1	1	1	1		
	D1	1	1	1	1	1	1		
	D2	1	1	1	1	1	1		

D (Waste Management)	D3	1	1	1	1	1	1		5,5
	D4	1	1	1	1	1	1		
	D5	1	1	1	1	1	1		
	D6	1	1	0	0	0	1		
E (Interior Space Quality)	E1	1	0	0	0	0	0		1,3
	E2	1	0	1	0	1	1		
	E3	0	0	0	0	0	0		
	E4	1	0	0	1	0	1		
	E5	0	0	0	0	0	0		
	E6	0	0	0	0	0	0		
F (Green Areas)	F1	0	1	1	1	1	1		5
	F2	0	1	1	1	1	1		
	F3	0	1	1	1	1	0		
	F4	0	1	1	1	1	1		
	F5	0	1	1	1	1	1		
	F6	1	1	1	1	1	1		
G (Social Sustainability)	G1	0	1	0	1	0	1		4
	G2	1	1	1	1	1	1		
	G3	0	0	0	0	0	0		
	G4	0	1	0	1	0	1		
	G5	1	1	1	1	1	1		
	G6	1	1	1	1	1	1		
H (Transportation)	H1	1	1	1	1	1	1		2,8
	H2	0	0	0	0	0	0		
	H3	0	0	0	0	0	0		
	H4	1	1	1	1	0	1		
	H5	1	1	1	1	1	1		
	H6	0	0	0	0	0	0		
I (Economic Sustainability)	I1	0	0	0	0	0	0		3,8
	I2	1	1	0	1	1	1		
	I3	1	1	1	1	1	1		
	I4	0	0	0	0	0	0		
	I5	1	1	1	1	1	1		
	I6	1	1	1	1	1	1		
J (Flexible Design)	J1	1	1	1	1	1	1		3,2
	J2	1	0	1	0	1	0		
	J3	1	1	0	1	0	1		
	J4	1	1	1	1	1	1		
	J5	0	0	0	0	0	0		
	J6	0	0	0	0	0	0		
Average Values		3,9	4,3	3,8	4,2	4	4,2		
Color Scales		0 value		1-2 value		3-4 value		5-6 value	

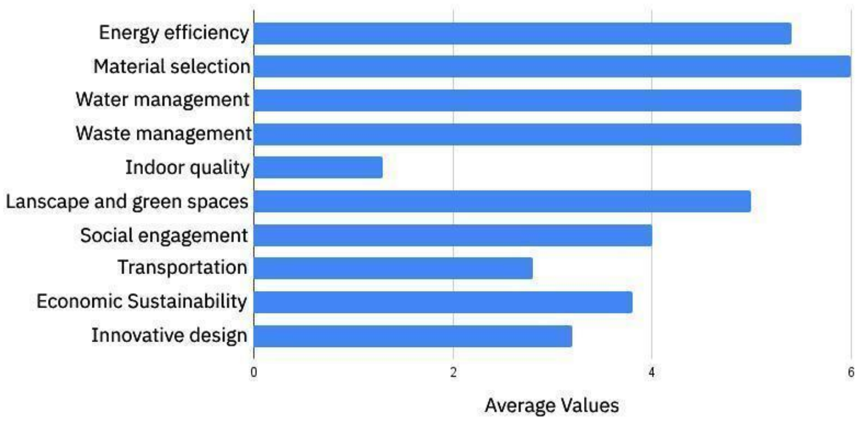
Daedeok Park, TEDA, and Kalundborg Park have the highest ratings. Ecofactorij, Kokkola, and Eco3 are the parks with the lowest scores (Figure 7). The overall performance of the parks is high and close to each other.

Figure 7. Average values of the parks



The highest scoring criteria are material selection, water management, waste management, and energy efficiency (Figure 8). The reason for this data is that material selection offers flexible solutions from the initial design phase of the projects to the utilization process. Water management, waste management, and energy efficiency are the main strategies targeted by industrial companies. The criteria with the lowest scores are interior quality, transportation, accessibility, innovative and flexible design, and economic sustainability. The lack of data on the interiors of the buildings, their distances from urban centers in terms of transportation, the complexity of the systems, and the difficulties in implementing innovative and flexible designs have affected the results.

Figure 8. Averages values of the criteria



When the criteria were evaluated by parks, Kokkola, Kalundborg, TEDA, and Eco3 parks showed successful results regarding energy efficiency and management (A). Ecofactorij and Daedeok were slightly lower than the other parks regarding criterion (A) (Table 2). All parks scored the same for material selection and use (B), water management (C), and waste management (D). For indoor quality (E), Kokkola Park scored slightly higher than the other parks. Kalundborg (E) did not score in any of the sub-criteria. The parks received very low scores in terms of overall indoor quality (E). Regarding landscaping and green spaces (F), all parks except Kokkola received high scores. In terms of community participation and social sustainability (G), Kalundborg, TEDA, and Daedeok parks scored the highest. Regarding transportation and accessibility (H), parks generally scored low. The Eco3 park received the lowest value. All parks scored the same for economic sustainability (I) and innovative and flexible design criteria (J). Parks need to be more economically sustainable and innovative for their efficiency.

4. Conclusion

“The process of designing eco-industrial parks” is multidimensional and intricate. For the parks to be designed efficiently, architectural design elements should be taken into account at every stage of the process, from planning to use. Six (6) park designs that hold a significant place in eco-parks were analyzed as part of the study using the architectural standards established by UNIDO (United Nations Industrial Development Organization). The parks evaluated in the study are large-scale parks that contribute significantly to the national economy and have global recognition. Identifying the positive and negative aspects of these parks will serve as a guide for both the improvement of existing parks and the construction of new parks. The more comprehensive and effective environmental measures are taken in these industrial areas, the more they contribute to the national economy, employment, resource utilization, and technological development.

In terms of energy efficiency and management, Kokkola, Kalundborg, TEDA and Eco3 parks meet the criteria very well, while Ecofactorij and Daedeok parks partially meet the criteria. The lack of energy symbiosis and sharing in Ecofactorij and Daedeok parks negatively affects the energy efficiency of the parks. All parks meet the criteria for material selection and use, water management and waste management very well. Local and easily available materials are preferred in material selection. In terms of interior quality, detailed data on the parks was not available. It is not known whether thermal comfort, health and safety measures are available in the park facilities. In terms of spatial features such as natural light and lighting and noise control, the parks partially meet the criteria. In terms of landscaping and green areas, all parks meet the criteria well except Kokkola Park. Kokkola Park is an area with a high density of industrial buildings and limited green areas. In terms of community involvement and social sustainability, Kalundborg, TEDA and Daedeok meet the criteria very well, while Kokkola, Ecofactorij and Eco3 partially meet the criteria. In terms of transportation and accessibility, economic sustainability, innovative and flexible design, all parks partially meet the criteria. At the same time, the most successful parks were Kalundborg, TEDA and Daedeok, while the least successful parks were Eco 3, Kokkola and The Ecofactorij. The criteria for which the parks received the highest scores were material selection and use, water management and waste management. The lowest scoring criteria were interior quality, transportation and accessibility. Although ecological industrial parks have taken important steps towards sustainability and environmentally friendly technologies, they need to be more proactive and flexible in their continuous improvement and innovation processes. Accelerating R&D cooperation and technological adaptation processes will increase the competitiveness of these parks. The parks should develop more comprehensive sustainability solutions through advanced energy and water management technologies, the development of community engagement and participation programs, and increased international cooperation. While the gains achieved today are significant and important, more effective solutions should be produced in terms of “sustainable development goals” in the future.

Therefore, the information gathered for this study is intended to give architects, urban planners, and legislators advice on how to make parks more efficient during the design and implementation phases.

"Eco-industrial parks" play a critical role in achieving "sustainable development goals". The improvement of existing parks and the consideration of architectural criteria in the design of new parks provide more productive and effective parks in terms of environmental sustainability. In developing of eco-industrial parks, or policy makers should adopt energy efficiency, indoor quality, innovative and flexible design approaches. They should also integrate best practices in energy symbiosis and waste management to enhance environmental sustainability. Factors such as economic sustainability, green spaces and transportation are also criteria to be taken into account during the planning phase. To increase the competitiveness of parks, they should focus on R&D collaborations and technological innovation. Effective communication strategies should be developed to increase community participation. For future studies, it is recommended to develop theoretical frameworks from different disciplines and to integrate fields such as architecture, environmental engineering and urban planning. This study evaluated the design of eco-industrial parks only from an architectural perspective. Future studies can develop theoretical frameworks for "the design and planning of industrial parks" from the perspective of different disciplines and examine their relationship with architecture.

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