Exploration on the Synergistic Development and Optimization of Urban Ecosystems and Spatial Planning

Xiangdong Gao
School of Architecture and Fine Art, Dalian University of Technology, Dalian, China
15998000044@mail.dlut.edu.cn

Abstract. With the acceleration of urbanization, the separation of urban ecosystems and spatial planning has become increasingly prominent, and the realization of their coordinated development has become the core issue of urban sustainable development. This study is oriented by urban ecology and discusses the collaborative optimization path of urban ecosystem and spatial planning. Through case analysis, this paper systematically studies the impact of urban ecological space network construction and green infrastructure layout on urban resilience. The results show that: first, ecological network layout (such as ecological corridors and green space connectivity improvement) can significantly enhance biodiversity and climate regulation ability; Second, mixed land use and compact spatial planning can reduce resource consumption and alleviate the heat island effect. Third, the combination of green infrastructure (sponge facilities, vertical greening, etc.) and smart technology can improve the efficiency of urban ecological services. The conclusion shows that the collaborative optimization strategy can improve the urban ecological environment and provide theoretical support and practical reference for urban planning under the guidance of ecological civilization.

Keywords: Synergistic Development, Urban Ecosystems, Spatial Planning.

1. Introduction

In the progression of urban spatial development, the amelioration of urban ecosystems has perennially been characterized by a state of passivity, culminating in the emergence of a spectrum of ecological spatial dilemmas during urban expansion, notably imbalance, incoordination, and unsustainability.

The rapid development of urbanization has had a great impact on the environmental ecosystem, urban climate, water, and soil resources. For example, problems such as the destruction of natural habitats, the impact on urban residents' environment, the damage to ecosystem functions, and the intensification of the urban heat island effect have become increasingly prominent.

The coordinated development of urban ecosystems and spatial planning is of great significance in many aspects of urban environmental ecology. By synergistically integrating the structural and functional aspects of urban ecosystems, cities can establish a more efficient environmental ecosystem organization, while also optimizing service functions through rational urban spatial planning.

In terms of improving the quality of life of urban residents, collaborative development can create more healthy and green space for the city. Collaborative development can optimize resource utilization. Urban pattern ecosystem function coupling theory reveals the direct impact mechanism of urban spatial morphology (such as density and connectivity) on ecosystem services (such as the carbon sink and biodiversity) [1]. Therefore, cities should consider the carrying capacity of ecosystems in spatial planning, reasonably arrange the layout of urban industries, improve resource reusability, and reduce energy consumption. At the same time, should improve the ability of cities to cope with climate, pollution, and other environmental problems, and enhance the activity of healthy urban development. Urban development and industrial development will lead to the urban heat island effect, and the urban development spatial planning under the coordinated development can increase the urban green space and water area, optimize the industrial layout, improve the urban air quality, effectively alleviate the heat island effect and regulate the urban microclimate.

At present, the coordinated development of urban ecosystems and spatial planning has some defects in the planning methods and concepts, the coordination of industrial development and ecological protection, and the implementation and guarantee of policies. For example, some cities pay attention to economic development and ignore urban ecology. The concept of environmental ecology cannot be integrated into urban development planning. The public's awareness and participation in the importance of the environment and the improvement of the urban environment is low. The planning policy can not evaluate the ecosystem more accurately, there is a lack of more efficient scientific evaluation methods and indicator systems. And the index system, and the application of new technologies in development planning is less.

In terms of industrial development and ecological environment protection in urban areas, the industrial layout in some cities is not reasonable. Industrial factories with serious pollution are close to residential areas and ecological protection areas, affecting residents' health and causing negative effects on the natural environment and other aspects.

Based on this, this paper aims to explore the coordinated development of urban ecosystems and spatial planning. Combined with the current background of the times, it conducts collaborative research with Hong Kong, Singapore, and Vancouver, and optimizes the integration of urban development and environmental ecological concepts, regional spatial planning technology, and the relationship between urban industry and ecology.

2. Theoretical Foundations of Urban Ecosystems and Spatial Planning

The urban ecosystem is a complex system formed by the integration of natural ecosystems and socio-economic systems, with human activities at its core. Its defining characteristics lie in the dominance, openness, and dynamism of humans within the urban context. According to the theory of composite ecosystems, the urban ecosystem is the result of the co-evolution of nature, economy, and society [2].

The core objective of urban spatial planning is to achieve a synergistic development of economic efficiency and ecological sustainability through the orderly allocation of land, resources, and functions. Its main objectives include coordinating the spatial layout of residential, industrial, transportation, and ecological land, saving resources, promoting agglomeration economic benefits, improving the level of urban economic development, improving urban ecological health, and enhancing the economic development and green vitality of the city. Through several measures to optimize urban environmental space, Hong Kong's carbon emissions peaked in 2014, and by 2022 Hong Kong's carbon emissions had been reduced by about a quarter.

Urban spatial planning not only pays attention to economic development but also has a positive impact on the natural ecosystem. The city protects biological habitats through green space planning, realizes urban ecological diversification, improves the connectivity of natural ecological function areas, reduces carbon emissions, and alleviates the urban heat island effect. Permanent basic farmland and various types of natural ecological protection areas shall be designated in the urban regional spatial planning to maintain the basic ecological resource regeneration ability of the city. Based on Mcharg's concept of ecological stratification, urban spatial planning should give priority to identifying ecologically sensitive elements (such as floodplains and habitat corridors) as rigid constraints on development behavior. The negative risks include the over-exploitation of urban natural space, which leads to the fragmentation of natural basement, the weakening or damage of ecological regulation function, the disorderly development and expansion of urban space, which aggravates the consumption of energy and land ecological resources, and causes environmental pollution.

However, urban spatial planning may also entail negative risks, such as the fragmentation of natural substrates and the weakening of ecological functions. At the same time, in the urban ecosystem, the natural conditions such as the topography, basic ecological resources, and geological disaster risk of the city determine the feasibility of urban space expansion, and its initial ecological carrying capacity limits the size of the urban population and the layout of various forms of industries.

3. Exploration of Synergistic Development Strategies for Urban Ecosystems and Spatial Planning

3.1. Theories of Urban Ecosystems and Spatial Planning

The theory of ecological carrying capacity constraints emphasizes that urban development must operate within the limits of the ecosystem's carrying capacity to avoid excessive resource consumption and environmental degradation [3]. For example, a small landscape green space is deployed inside the urban residential area or an ecological buffer zone is planned outside the industrial area to improve the ecological carrying capacity of the city. Urban development should be based on ecological thresholds, which include, but are not limited to, green space coverage, carbon sequestration capacity, and water resources carrying capacity. For example, the construction of a sponge city can not only improve the flood control capacity of the city, but also reduce the cost of infrastructure construction, enhance the sustainability of urban buildings and infrastructure, and optimize the urban climate. In addition, the design and construction of urban ecological infrastructure, and initiatives such as wetland parks and rain gardens can enhance a city's adaptive capacity to climate change, mitigate losses caused by natural disasters, and thereby improve urban resilience.

3.2. Practical Strategies: Synergistic Pathways for Spatial Planning and Ecosystems

Ecological Restructuring of Urban Functional Zoning. To promote the coordinated integration of urban ecosystems and urban spatial planning, cities need to consider multiple dimensions, including function partitioning, transportation and resource cycling. The comprehensive design of urban functional areas should break the relative isolation of traditional urban functional areas, and advocate the implementation of the "15-minute life circle" mode in urban spatial planning. This model can **significantly** reduce the time, economic cost, and carbon consumption of urban residents' cross-regional commuting, to reduce carbon emissions and promote the sustainable growth of the urban economy. Additionally, it is necessary to ensure the effective implementation of ecological planning within each functional zone of a city by establishing and integrating ecological corridors. For example, linear green space and ventilation corridors are planted between the commercial district and the residential district. In the case of the Shenzhen River Dianying Belt, by establishing and integrating ecological corridors along the river, water temperature in a specific region was reduced by 2°C. Additionally, the diversity of biological species in that area increased by 15%.

Urban Transportation and Resource Circulation. Through the rational planning of urban layout, reduce the transportation cost of cross-city functional areas and reduce carbon emissions. For example, relying on the connection of urban green transportation network, realize the multidimensional integration of green transportation systems and achieve the ecological transportation network. At the same time, urban traffic space will be redistributed, the width of motor vehicle lanes will be reduced, ecological isolation zones will be added, and urban ecological improvement measures such as rainwater retention and PM2.5 filtration will be implemented simultaneously. Berlin's bike lanes account for 40% of the city’s roads, forming a zero-carbon traffic network. Currently, the city's traffic carbon emissions are down by 40% compared to 1990.

3.3. Exploration of Strategies for Achieving Sustainable Urban Development

The core objective of sustainable urban development is to achieve a balance between economic growth, social equity, and ecological conservation through measures such as ecological restoration and the construction of green infrastructure. In the context of ecological restoration and the construction of green infrastructure, cities can enhance their resilience by restoring degraded ecosystems, such as wetlands, forests, and rivers [4]. For instance, the development of sponge cities facilitates the improvement of the urban environment and the sustainable utilization of resource-based economies through the regulation of urban water resources, while simultaneously mitigating the risk of natural disasters such as floods. Incorporating green spaces, parks, and ecological corridors into urban planning can enhance the service capacity of ecosystems [5]. Additionally, cities should pursue the transformation towards a low-carbon and circular economy by reducing carbon emissions through the promotion of renewable energy and the optimization of transportation systems, such as bus priority and shared travel [6]. Implementing urban carbon pricing mechanisms, such as carbon taxes or carbon trading systems, can incentivize urban enterprises and individual residents to lower their carbon emissions. Furthermore, promoting green building technologies, including energy-saving materials and vertical greening, can foster technological innovation and reduce the carbon footprint of cities [7]. The establishment of small clean energy microgrids in urban communities can diminish cities' dependence on traditional fossil fuels and enhance urban sustainability.

4. Case Study Exploration

The coordinated development of urban ecosystems and spatial planning aims to realize the harmonious coexistence of urban development and the natural environment through scientific spatial layout and ecological design. Its core idea is to integrate the service functions of the ecosystem (such as climate regulation, water resources management, and biodiversity protection) into urban planning, to improve urban resilience, sustainability, and the quality of life of residents.

4.1. Hong Kong: Challenges and Innovations in Ecological Space Synergy within a High-Density City

As a high-density city, Hong Kong's ecosystem exhibits the composite characteristics of the "matrix-patch-corridor" pattern. In Hong Kong, the densely built-up areas serve as the matrix (accounting for 24% of the land), while ecological patches include country parks (covering 40% of the land), wetlands (such as the Mai Po Nature Reserve), and urban green spaces. The corridors encompass greenways, rivers, and ecological coastlines. Hong Kong promotes the coordination of urban ecology and spatial planning, and the rigid protection of ecological space such as mountains and coasts. Through the Country Parks Ordinance, 44% of the urban land is designated as a legal protection area. Building height restrictions on both sides of Victoria Port ensure the visual connectivity of mountain and sea landscape corridors, protects urban ecological diversity, and enhances the green visual vitality of the city. Hong Kong has made great achievements in the coordinated planning of urban ecology and space. Its urban green space maintains the highest biodiversity density in the world (the Mai Po wetland supports 50000 migratory birds to survive the winter, accounting for 20% of the population in the migration area from East Asia to Australia). The intensity of the urban heat island is 1.5 C lower than that of Shenzhen (2023 satellite remote sensing data), thanks to the mountain sea wind corridor system. At the same time, Hong Kong is also facing challenges such as the intensification of conflicts between land development and natural ecological maintenance, and the high cost of natural ecological damage caused by reclamation projects. In terms of institutional innovation, Hong Kong has implemented the ecological bank experiment of "wetland mitigation bank" in the north of the new territories. Developers who destroy 1 hectare of wetland need to purchase 2 hectares of restoration indicators.

The case of Hong Kong demonstrates that the ecological sustainability of ultra-high-density cities is not solely determined by the total amount of space, but also by the level of refinement in spatial governance. Landscape security patterns theory indicates that the spatial threshold of key ecological elements (such as water system and habitat) should be identified to build a multi-level ecological security network [8]. Therefore, cities should delimit the growth boundary, control the ecological red line, balance the needs of resource development and ecological protection, maintain the ecological bottom line through the rigid system, develop the three-dimensional planning technology of urban space to expand the urban ecological capacity and realize the mutual benefit and symbiosis between the "concrete forest" of modern cities and the "natural jungle" of urban ecological space.

4.2. Singapore: From "Garden City" to "City in Nature"

Singapore is famous for its high-density Garden City, which integrates nature and the built environment to achieve sustainable development through three-dimensional greening, ecological corridors, and "city in the garden" planning. Based on the mitigation theory of the urban heat island effect, the regulatory effect of vertical greening (three-dimensional patches) on the built environmental microclimate was verified [9]. Singapore's building three-dimensional greening project has proved that green infrastructure can reduce building energy consumption by 15-30%. The 2030 Green Plan imposes a green coverage rate of more than 30% for newly-built buildings (such as the supertree vertical greening system of Binhai Bay Garden). At the same time, the city is stitched with a blue-green network: 17 reservoirs in the island are connected in series as the "ABC water plan" (active, beautiful, clean), to realize the ecological treatment of rainwater runoff in 90% of the land area. The urban green development effect of reducing the intensity of urban heat island by 4 C and increasing biodiversity by 20% (such as the restoration of species in Bukit Zhima tropical rain forest) has been achieved. However, Singapore is currently faced with extremely limited land resources, and the phenomenon that urban development depends on land reclamation has aroused controversy in neighboring countries. Singapore has broken through the spatial constraints with policy rigidity and technological innovation and doubled the ecological benefits through three-dimensional greening and intelligent management.

4.3. Vancouver: Ecological Density and Community Co-Governance Model

Vancouver takes ecological resilience as the core, relying on green networks, compact planning, and coastal protection. Its core strategy of implementing the "green texture" plan requires that each community in the city walk 5 minutes to the park (the existing park density is 4.3/km ^{2}). At the same time, the city conducted a zero-carbon community pilot, and the Southeast Fuxi community (SEFC) adopted a regional energy system (sewage source heat pump) to achieve 100% renewable energy heating. Urban planning and construction and urban Aboriginal collaborative governance, such as Musqueam and other aboriginal tribes and urban planners jointly build ecological corridors to restore salmon migration paths. Vancouver has been ranked among the top three eco-cities in the world for ten consecutive years, and its air quality is three times better than the WHO standard.

The synergistic development of urban ecology and spatial planning requires support from three aspects: reasonable policy rigidity, innovative technological concepts, and social mobilization, rather than breakthroughs in a single dimension. Urban social-ecological systems theory proposed that cities are the dynamic coupling of natural, social, and economic subsystems, and need to be integrated across scales [10]. Therefore, a city should explore a development path with distinctive characteristics under the framework of ecological civilization based on its resources, urban spatial structure, development strategies, and other advantages.

5. Conclusion

The essence of the coordinated development of urban ecosystems and spatial planning is to achieve the "triple balance" of natural ecological benefits, social equity, and economic efficiency through urban spatial reconstruction. International experience shows that a successful collaborative path of urban development needs to be constrained by ecological carrying capacity, guided by resilient goals, supported by technological innovation, and guaranteed by institutional change. For example, a city aiming to promote environmental sustainability should carefully assess and design functional zones within its infrastructure, ensuring that these functions are complete and cohesive. This balance between functional partitioning in urban planning ensures that cities maintain eco-friendly status while also achieving green, sustainable development.

First, the breakthrough in the technological frontier: energy ecological synergy system: integration of urban construction materials and urban ecology to realize the trinity of development, ecology, and low carbon. Second, the reform of the governance system: the establishment of the urban economic and environmental ecological community, the unification of ecological standards and the compensation mechanism. Thirdly, the relationship between urban ecosystems and spatial planning is essentially the spatial projection of the relationship between humans and nature. In the era of ecological civilization, urban planning needs to go beyond the traditional engineering mindset and turn to a systematic design guided by ecological wisdom.

References

[1] Alberti, M.: The effects of urban patterns on ecosystem function. International Regional Science Review **28** (2), 168–192 (2005)

[2] Ma, S.J.: The theory of composite ecosystems and urban ecological planning. Acta Ecologica Sinica **4** (1), 1–9 (1984)

[3] Liu, X., Borthwick, A.G.L.: Measurement and assessment of carrying capacity of the environment in Ningbo, China. Journal of Environmental Management **92** (8), 2047–2053 (2011)

[4] Elmqvist, T., Setälä, H., Handel, S.N., van der Ploeg, S., Aronson, J., Blignaut, J.N., Gómez-Baggethun, E., Nowak, D.J., Kronenberg, J., de Groot, R.: Benefits of restoring ecosystem services in urban areas. Current Opinion in Environmental Sustainability **14**, 101–108 (2015)

[5] Benedict, M.A., McMahon, E.T.: Green infrastructure: Linking landscapes and communities. Island Press (2006)

[6] IPCC: Climate change 2022: Mitigation of climate change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press (2022)

[7] UNEP: Global status report for buildings and construction: Towards a zero-emission, efficient and resilient buildings and construction sector. United Nations Environment Programme (2020)

[8] Yu, K.: Security patterns and surface model in landscape ecological planning. Landscape and Urban Planning **77** (1-2), 1–10 (2006)

[9] Tan, P.Y., et al.: Vertical greenery systems for energy savings in buildings: A comparative study between green walls and green facades. Building and Environment **177**, 106849 (2020)

[10] Pickett, S.T.A., et al.: Urban ecological systems: Linking terrestrial ecological, physical, and socioeconomic components of metropolitan areas. Annual Review of Ecology and Systematics **32** (1), 127–157 (2001)