Synergic Evidence-based Design Principles and the Demonstration of their Integrated Implementation in Green Construction Zone: A case study of Jiangsu Green Building Expo Park

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Abstract. This paper reviews the synergic evidence-based design principles and interprets their related design methods and development approaches. It explores the importance of using such concepts to inform the integrated development of green construction zones, which can facilitate the large-scale development of green buildings in a given region. Based on a case study of the development process of Jiangsu Green Building Expo Park, which is known as the first theme park in China including a range of experimental projects to show the integrated design and construction methods for green buildings, it analyses the targets, concepts and key technologies that have been used to support the integrated development of green buildings by now. Finally, this paper summarises the innovative thinking on integrated development of green buildings and the related implementation approaches, developmental strategies and potential business values.

1. Introduction

As urbanization accelerates across the globe, cities that are the centers of population, architecture, transport, industry and logistics are areas with the most energy consumption and most susceptible to environmental degradation. In many developing countries, the conflicts between urban construction and ecological conservation intensify, and large-scale environmental crisis draw the governments’ attention to environmental problems and urge them to find solutions.

As an important element of the urban landscape, architecture plays a crucial role in constructing the urban space and providing houses and offices. Green building units seek to save energy, reduce emissions and enhance the environmentally-friendliness in the whole life cycle of buildings and consider the local adaptability and economic efficiency of building technologies[1]. However, while green buildings achieve the goal of reducing emissions, saving energy and optimizing the architectural quality, urban construction is still facing some protruding problems and urban ills – poor management of buildings, insufficient protection of environment and resources, lack of characteristics in development, low standards for infrastructure, traffic congestion, environmental contamination, water shortage, urban hazards, etc.

Therefore, it is necessary to transform the development modes of urban and rural development and architectural development, follow the principles of people-oriented and coordinated sustainable...
development, and achieve the goal of saving energy and reducing emissions by developing green buildings.

The core and nature of integrated development of green buildings are to take theories of synergetics and evidence-based studies as the guidance to develop a coordinated, efficient and objective planning mode. The essence of “synergetic, efficient and objective” comprises three objectives: the first is the objective of synergetic development that features low pollution, low emissions and low impacts; the second is a synergetic coupling mode of development that is operable and quantifiable; the third is to establish an evaluable and optimizable management mechanism. In the initial stage of project planning, the basic principle of “passive priority and active priority” should be followed, and the principle of evidence-based research should be followed to predict the effect of different designing strategies on environmental improvement, reduction of emissions and energy conservation, and a local and intra-system self-synergetic decision-making and analysis framework should be established.

2. Principles of synergetic and evidence-based design

Cities are complicated self-adapting systems where human and other organic systems co-exist[2]. Regional integrated development of green buildings involves synergetic coupling of urban subsystems including energy, resources, transport, solid waste disposal and industrial development. It is necessary to extend architectural units into regional systems from the perspective of research, and introduce the “green – ecological - smart” synergetic evidence-based decision-making mechanism that features new thinking, new goals and new measures into the legal system and decision-making process of traditional urban planning. Cities should optimize the decision-making process of traditional urban planning and architectural design to promote the ideas of green, ecological and smart development in the traditional decision-making process, and integrate the idea of green ecology into the traditional urban planning and management system.

Synergy & evidence-based design is a creative design idea based on theories of synergy and evidence-based studies and is a coupling design system for integrated development of sub systems of green buildings based on credible and objective evidences [3].

The synergy & evidence-based model is a new thinking model that combines theories of different disciplines including evidence-based medicine, synergetics, environmental psychology, behavioral economics, and is founded on rigorous reasoning and quantified analysis of multiple systems. The scientific data serve as convincing evidences for the multi-system coupling and decision-making; the evidence database is improved constantly through analysis of specific terms and accumulation of cases to provide comprehensive and systematic support for similar projects in the future [3-6].

3. Decision-making process and technologies for synergy & evidence-based design

Implementation of regional integration of green buildings incorporates different aspects including the implement dimension, the implement system, the implement stages and implement subjects. Because of its connotation, it optimizes and innovates the traditional planning mode, makes combined use of green, ecological and intelligent technologies, introducing the idea of ecological conservation and sustainable development into the microscopic and macroscopic aspects of urban development to realize the goal of green development of cities.

Regional integrated development of green buildings should accord with the four aspects in synergetic urbanization – “implementation dimension – full dimension”, “implementation system – full system”, “implementation stage – full process”, and “implementation subject – full involvement”. The development includes five steps: diagnosis and analysis, system of objectives, evidence-based plan, implementation operation, monitoring and evaluation. Regional integrated development of green buildings follows a shape of ascending spiral; the first stage lays a foundation for the latter stage; the latter stage verifies and provides feedback for the first stage, reaching the macro-objectives defined at the start.

Regional integrated development of green buildings should focus on the whole-life-cycle control instead of merely introducing the idea of green ecology and indicators into traditional planning models.
Cities should organically integrate the traditional construction process and the innovative synergy & evidence-based design model to develop a synergetic integrated solution system, emphasize comprehensive, objective and scientific analysis, and establish multi-level objectives and indicators. Meanwhile, according to the regional features and existing evidence-based databases, cities can design multi-system coupling synergetic solutions for integrated development, guide integrated development of green buildings according to the objectives and implementation paths. Also, during the implementation stage, authorities should collect timely feedback and make adjustment to reach the optimal ecological effect, make systematic data analysis and evaluation, and establish an evidence-based database to serve as a basis for subsequent design and construction.

4. Analysis of practice based on the synergy & evidence-based design model

4.1. Project overview
Green Building Expo Park of Jiangsu (hereinafter referred to as “the Park”) is located in Wujin District, Changzhou, Jiangsu. As the first green building expo park in southern Jiangsu, is a theme park featured by “green buildings” and “green construction”, covering an area of 204 mu, with an area of construction about 40,000 m².

The park explored and demonstrated the application of architectural structural systems including assembly concrete structures, steel structures, steel bar & concrete structures, bamboo-wood composite structures. The major technologies used include applicable, repeatable and promotion-worth technologies including integration of renewable resources and buildings, architectural intelligence, green building, rain collection, upgrading the urban construction model towards a green, ecologically-friendly and smart urban development model.

4.2. Sustainable park development of environmental response
The Green Building Expo Park is a park that demonstrates green technologies and green construction ideas. The park has five module parks: sponge park, low-carbon park, ecological park, smart construction park and intelligent park (Figures 1).
4.2.1. Sponge park. To build a sponge city, the park follows the idea of “low-impact development”, and uses such technologies as permeable pavement, ecological wetland, clean-water terraced fields, rainwater park, ecological shallow ridges, recessed green land, solid green belt, water drainage system, permeation increment facilities, roof-top greening technologies, making the sponge park like a sponge that absorbs, stores, permeates and purifies water when it rains, and “releases” and utilizes the stored water when necessary [6].

As measured, the control rate of annual runoff in the park reached 75%; also, the rain water from the roof and on the ground is collected and purified to spray on the green land or clean the ground. Analysis shows that the non-traditional water source utilization rate reaches 23%.

4.2.2. Low-carbon park. Technologies are used from the energy source side to the energy use side in the park, including the renewable energy micro-network, the efficient envelope enclosure system, the air-conditioning system and illumination system. With these systems, the buildings in the park meet the requirements for green construction, and the road lamps and sunshade in the park are equipped with solar energy facilities, making the park reach the goal of saving energy, reducing emissions and cutting carbon emissions.

The solar energy landscape is organic integration between green and low-carbon technologies and the idea of sustainable development. It fully utilizes solar energy to meet the needs for energy for dynamic water landscape, illumination and self-sufficient operation of the park. Via renewable energy micro-network control technologies, the park organically integrates the solar energy landscape, roof-top photovoltaic power generation systems (with an installed capacity of 100kWp), wind power generation systems (with an installed capacity of 6kWp). By integrating these systems into the power grid of the park (Figures 10~12), the park can distribute the power according to the actual load of the power consumption units, making full use of the green power generated by renewable resources to meet the power needs in the park. As estimated, this project will produce 110,000 kWh power by the solar photovoltaic power generation system and 10,000 kWh by the wind power generation system, accounting for 30% of the power needs in the park (Figure 2).

Figure 2. Micro-network control system of renewable energy in the park.
4.2.3. Ecological park. Interweaving water systems are one geographic feature of areas in southern China. Thus, the park planners should make use of this natural feature to improve the ecological effect of the park. The park should make use of the local water systems to build a green land system and introduce ecological networks into the park during construction to protect the environment of the park and create a resident-friendly water front area.

The vegetation landscape of the park should adopt the community allocation method in light of the actual conditions. To be specific, plants should be assigned to different locations in light of their own characteristics and enough growth space should be reserved for each plant. Establishing a plant community system that can maintain and restore natural ecological structures can lay a foundation for environmental improvement.

For water quality improvement, the water in the park can be pumped into the artificial wetland and then pumped back to the water system, so that the water quality can be improved via the wetland in the park. The water is circulated between the wetland and the water systems, which accelerates the flow of water in the landscape and prevents the excessive growth of algae. In addition, the automatic monitoring system in the park can provide real-time monitoring of the water quality and present the specific water-quality indicators in each unit. To increase circulation of water and reduce the replacement time, circulation bumps are installed to circulate the water once every week. The overall circulation flow is calculated as follows: the area of water bodies is 247,000 m²; and assuming that the average depth is 2 m, then the overall water capacity is 49,400 m³, and the circulation flow is 7057m³/d = 294 m³/h. Therefore, to maintain the water quality, the water is circulated and purified by natural purification plant communities at a flow rate of no smaller than 324m³/h (10% surplus) to keep the water quality at the Level III Water Quality Standards for Surface Water. Multiple circulating water pump pits were set in the water body to circulate and supply water to the southern and northern part of the park, and meanwhile provides solutions for flood discharge in the upstream.

4.2.4. Smart construction park. In the whole life cycle for construction of the green building expo park, the building information modelling (BIM) technology is used to realize digital design, construction and maintenance of buildings. The introduction of BIM can greatly improve the work efficiency and the reliability of evidence-based analysis.

As a platform for “visualized” communication and collaboration for different kinds of work, the BIM platform not only provides a digital management solution to improve efficiency and reduce risks, but provides continuous support and real-time interaction of the evidence-based database. In this way, resources can be shared on the big data platform to provide statistical support for optimization of operation and facilitate evidence-based design.

All buildings in this project are constructed with prefabricated components from factories (the proportion of industrialized building components reaches 100%); for some buildings, the proportion reaches above 95%. The fabricated components are assembled or welded on the construction site, which reduces the energy consumption and the environmental impact of construction. As calculated, the industrialization rate of buildings in the park reaches 60%.

4.2.5. Intelligent park. Based on new technologies like IoT technologies, the park is constructed into an intelligent park that is equipped with intelligent infrastructure, follows the people-oriented philosophy, provides a safe, comfortable, convenient and efficient environment, and realizes refined management. The natural system and the green, ecologically-friendly IoT technologies are combined to develop a green system which senses, monitors, analyzes, integrates and controls the key links in the park including resources and energies, information and wastes, so that the park can provide an efficient and convenient service space, optimize the operation of the city and create a park supported by highly-intelligent facilities. With the BIM 3D operation monitoring platform, the basic information of each building in the park can be checked and processed in real time to provide statistical support for smart operation of the park.
4.3. Evidence-based analysis of green technologies of synergetic coupling

To realize evidence-based design of green technologies of synergetic coupling, it is necessary to perform systematic and objective analysis of massive data on the basis of fundamental research on evidence-based design, judge, screen and summarize different design strategies and technologies to provide scientific reference for decision-making. On that basis, comprehensive evaluation is made for different integrated technological solutions, including their effect on saving energy and cutting emissions, their environmental efficiency, and their impact on the users. Meanwhile, the “economy-efficiency” analysis model is used to assess these different solutions to ensure that within a proper range of incremental cost, the objectives of saving energy and cutting emissions can be reached in the whole life cycle of the building. In the meantime, constant feedback for results and experience is used to create, update and supplement the evidence-based database to provide guidance for planning and design of similar building projects.

4.4. Green park development performance appraisal system

To meet the objectives of the park, the park should consider how to implement the idea of sustainable development in the whole life cycle of the building and introduce green performance appraisal indicators. The perspectives of park planning, interior and exterior environment, proper use of energy and improvement of interior comfort level should be considered in design and construction of buildings in the park, and the informatized data collection and tracking system is used to collect data in the park and assess the operational effect of the park.

Developing a green performance evaluation system in the park is to quantify the impact of the development of the park on the environment. The green performance refers to the level of environmentally-friendliness of the park during the whole life cycle, including the technological rationality, environmental coordination, efficiency of resource utilization and use comfort [8]. These four aspects are represented by four indicators – degree of environmental friendliness, degree of energy optimization, degree of operational comfort and degree of technological rationality to quantify the green performance of the park and the correlations among the four indicators should be considered.

- **Degree of environmental friendliness**: the buildings conform to the local culture and interact well with the surrounding environment; optimizing the resource allocation to reduce the impact on environment in the whole life cycle;
- **Degree of energy and resource optimization**: saving energy and resource to the maximum degree, making proper use of and optimizing energy and resource allocation, improving the energy use efficiency, saving energy and improving efficiency, making full use of renewable and green energies;
- **Degree of operational comfort**: providing a “healthy”, “suitable” and “efficient” environment and space, improving the interior and exterior comfort, creating a healthier environment; establishing an effective management mechanism is an effective solution to save energy and reduce pollution.
- **Technological rationality**: selecting technologies and products according to the principle of economic and technological suitability to reach the optimal efficiency; selecting advanced technologies for demonstration and promotion.

Via comprehensive evaluation of the abovementioned four indicators, the radar chart for development performance evaluation of the park is obtained. As the chart shows, this park achieves good performance in terms of the degree of energy optimization, the degree of operational comfort and the degree of technological rationality. However, due to the restrictions in local conditions, the limited area of the park and the functions of the park, the park shows limitations in terms of biodiversity and land use. Nevertheless, the park still tries to make up for these defects through measures like using diverse local plants, combining trees and bushes, and setting up shared city parks.
5. Conclusion

5.1. Exploration of regional integrated design methods for green buildings
To develop an integrated area of green buildings is a self-adaptive and mutually-coupling process. It should consider the whole life cycle of the buildings and the comprehensive effect of the whole system, use the synergy & evidence-based design principles to guide the practice of green construction. Synergy & evidence-based design is to construct a work chain that integrates “research” and “design” in the whole life cycle of the green buildings via the digital information platform; it follows the principle of guiding design with data and aims to realize synerggetic improvement of the green performance of buildings and achieve sustainable returns. The idea of synergy & evidence-based design plays a role of theoretical guidance in the development of regional integrated green buildings and plays a guiding role in the market transformation caused by the scale development of green buildings.

As the principle and idea of synergy & evidence-based design is used and promoted in the field of green building, the construction experience databases are built, and the traditional fight-it-alone and non-collaborative work mode is replaced by the new mode that features cross-disciplinary and multi-disciplinary collaboration. Besides, cooperation among “politics, industry, enterprises, universities and research institutes” can promote sharing of resources in the synergy & evidence-based database, guiding the construction industry towards a future of whole-life-cycle and green buildings.

5.2. Synergetic integrated solutions
Synergetic integrated solutions fully consider the resource and environmental capacities of cities, take the optimized allocation of major urban resources as the premise, and take urban construction activities including industrial economy, urban space and infrastructure as the subject and innovating policies as the engine to develop a mutually adaptative and synergetic evolutionary relation among elements in each system and among systems, establish quantifiable objectives and systematic solutions to ensure coordinated development of urban construction and ecology [17]. The authorities should
support upgrading of urban industries with preferable policies, accelerate development of technological and managerial systems concerning development of the green building industry, planning and construction technologies, incentive policies and guarantee mechanisms, providing feasible suggestions for the government’s decision-making.

5.3. Implementation of performance appraisal
When seeking innovation on the abovementioned mechanisms, the authorities should accelerate appraisal of integrated green building construction to provide a basis for subsequent optimization so that diverse, duplicable and promotion-worth green building construction samples can be developed to promote the “market-dominating and government-guiding” development strategy and avoid blind construction in a “great-leap-forward” style.

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