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Article

High carbon sink goals in the regeneration of waterfront industrial heritage

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Abstract: In the context of high carbon sink targets, the regeneration of China's waterfront industrial heritage faces both opportunities and challenges. This paper takes Hanggang Park as an example to study its transformation along the Grand Canal. In terms of planning strategy, the park redefines its functionality, including the reuse of construction equipment and multifunctional transformation of space, increasing green space and remediating polluted soil; in terms of transformation direction, the park is environmentally oriented, focusing on vegetation restoration, soil and water restoration and protection, using low-carbon materials for construction and restricting high-carbon emitting enterprises; and the government actively participates in the park by re-planning the site, incorporating top-level design, and managing the development and operation of the park. The successful transformation of Hangzhou Steel Park is a reference for other waterfront industrial heritage. In the future, we should continue to promote technological innovation, sustainable industrial planning, and strengthen public participation and financial investment, so as to realise a win-win situation for both environmental protection and urban renewal, and help achieve the goal of carbon sinks.

Keywords: waterfront steel industrial heritage; high carbon sink transformation; eco-friendly; heritage transformation

1. Introduction

In the context of high carbon sink initiatives, the effective regeneration of industrial heritage is a key issue in the global industrial heritage sector. The response to and resolution of this issue have garnered widespread attention. China, with its extensive river systems, including the Yangtze River, Yellow River, Pearl River, and the Grand Canal, along with a coastline exceeding 18,000 km, possesses a vast number of waterfront industrial heritage sites [1]. This positioning makes China one of the countries with the richest collection of waterfront industrial heritage globally.

Waterfront industrial heritage is an important type of industrial legacy, intricately linked to water conservation and soil preservation. The management of water-based carbon sinks is crucial for achieving high carbon sink objectives. In recent years, significant achievements have been made in the regeneration of China's waterfront industrial heritage, with multiple cases demonstrating the country's substantial experience in this domain, some of which hold considerable research value.

In 2012, the administration under Xi Jinping was established, subsequently integrating the "Two Mountains Theory" (the idea that "lucid waters and lush mountains are invaluable assets") into national planning, which is seen as a program for achieving carbon peak at the national level. Notably, this perspective was first proposed during Xi's tenure in Zhejiang Province (2002–2007), leading to Zhejiang being regarded as a testing ground for enhancing carbon sinks in China. In 2016, China joined the Paris Agreement, and the same year held the ceremony for the deposit of the Paris Agreement ratification documents in Hangzhou. In 2019, the Xi administration proposed the establishment of the Grand Canal National Cultural Park, emphasizing not only the protection of cultural heritage along the canal but also the enhancement of ecological and environmental governance along its route, with the southern starting point of the Grand Canal located in Zhejiang. Concurrently, the Grand Canal in Zhejiang is rich in industrial heritage resources. The regeneration and reuse of these industrial sites largely reflect the Xi administration's urban renewal policies under high carbon sink objectives.

This study focuses on the Hanggang Park, located along the Grand Canal. Faced with the challenges of reasonable protection and reuse, a pressing question arises: how can the Hanggang site transform its complex natural landscape into a competitive advantage for regeneration, and how can it enhance its carbon sink capacity by adopting bio-based materials with high carbon storage potential and low embedded carbon emissions? This challenge reflects the contemporary dilemma of effectively protecting industrial heritage while achieving harmonious development among regional social, economic, natural, and cultural aspects.

This study compiles global high carbon sink industrial heritage regeneration schemes, identifies the essential elements of waterfront industrial heritage park construction, and focuses specifically on the Hanggang Industrial Heritage Park. The analysis evaluates its regeneration measures and pathways, providing development and improvement suggestions, thus seeking meaningful reference models for the reuse of waterfront industrial heritage under high carbon sink objectives.

2. Literature review

2.1. Transformation of waterfront industrial heritage

As a significant testament to industrial civilization, waterfront industrial heritage sites embody rich historical, cultural, and social value. With urban development and the adjustment of industrial structures, many of these once-flourishing steel industry sites are now facing decline and abandonment. However, their unique waterfront locations and distinctive industrial architectural features present substantial potential for transformation and adaptive reuse.

A study indicates that reconfiguring and redeveloping waterfront industrial sites by converting certain industrial buildings into museums, art studios, and creative industry parks enhances the environmental quality and appeal of these areas. Additionally, implementing techniques such as wetland construction, water purification, and vegetation restoration can significantly improve water quality and ecosystem health, contributing to ecological restoration and enhancing the ecological service functions of waterfront spaces [2].

In the Ruhr region, another study suggests that preservation of the authenticity of industrial heritage should be prioritized during transformation projects, using adaptive reuse strategies to repurpose buildings such as factories and warehouses into exhibition halls, theaters, and office spaces. By framing the industrial heritage landscape as a core component of urban development, these transformations aim to integrate urban space and functions through landscape design, creating a multifunctional waterfront area that combines culture, leisure, and commerce. Such integration not only facilitates the industrial heritage's transition and upgrade but also establishes the transformed waterfront space as a new city landmark, enhancing the overall urban image and vitality [3].

The successful transformation of the Rust Belt in the United States from industrially polluted cities into models of green and sustainable development highlights the crucial roles of citizen participation, innovative planning, and capital investment [4]. There are differences in the participation of small cities in the Rust Belt in climate change policies, cities with high levels of participation pay more attention to expenditure management and innovation in economic development, and are also more widely influenced by other cities [5]. By combining industrial upgrading with environmental improvement to create new urban areas that are economically prosperous, environmentally friendly, and culturally attractive [6]. Rust Belt cities can emerge from the plight of industrial decline and achieve economic recovery [7]. Moreover, the transformed cities have become popular destinations for attracting talent and investment, enhancing their competitiveness and attractiveness at the regional and even national levels [8].

Research on industrial areas in the UK indicates that by taking the industrial heritage landscape as a key element of urban renewal, during the transformation process, emphasis should be placed on protecting the characteristics of industrial heritage [9]. Innovative development strategies are employed to transform buildings such as factories and workshops into civic park squares, art galleries, creative studios, and residential spaces [10], achieving a transformation from heavy industry to high-tech industries, creative industries, and service industries [11]. These transformations aim to integrate urban resources and functions through spatial planning, creating a comprehensive area integrating history, culture, and tourism [10]. This integration not only promotes the revival and development of industrial heritage but also makes the transformed area a new urban highlight, creating a diversified urban community and enhancing the cultural connotation and attractiveness of the city [12].

Research on a transformation project involving parts of the Baosteel Group's facilities in China proposed converting industrial buildings into creative office spaces, attracting numerous cultural and creative enterprises to the area [13]. Additionally, leveraging the advantages of waterfront locations by constructing waterfront platforms and riverbank pathways has created popular recreational spaces, significantly boosting residents' quality of life and happiness. Another example is an industrial heritage of Wuhan, which emphasizes the preservation and display of industrial culture by renovating and repurposing representative industrial buildings into a steel industry museum to showcase the history and cultural significance of the steel industry [14].

However, the steel production process often causes severe pollution to soil, water bodies, and air, necessitating large-scale environmental remediation prior to transformation. This process not only incurs high costs but also poses significant technical challenges. Furthermore, waterfront industrial heritage sites typically involve multiple stakeholders, including enterprises, government agencies, and local residents. During the transformation process, these stakeholders often have differing interests, making it essential to address and coordinate property rights and interest distribution—a critical issue that urgently requires resolution for successful project implementation.

2.2. Transformation of industrial heritage for high carbon sequestration

Industrial heritage, as a critical witness to the process of industrialization, holds unique historical, cultural, and artistic value. With the increasing global focus on climate change, transforming industrial heritage sites to achieve high carbon sequestration has become a prominent research area.

In the context of the proposed carbon-neutrality goal, researchers have begun to attach great importance to the carbon-sequestration function of heritage sites after renovation. Carbon sequestration plays a vital role in the process of achieving carbon neutrality in renovation projects [15]. Waterfront industrial heritage can enhance its carbon-sequestration-increasing capacity through means of transforming the abundant natural resources within the heritage site. The ecosystem composed of these resources is a key carrier of the carbon-sequestration process.

To achieve the carbon-neutrality goal, it is necessary to emphasize the carbon-storage and-sequestration work at heritage sites. Forests, grasslands, soil, and the ocean in each region are all important carbon-sequestration resources [16]. Scholars have already measured the carbon-sequestration capacities of ecosystems such as forests [17], grasslands [18], cities [19], farmlands [20], and the ocean [21]. Forests significantly absorb and store carbon dioxide through photosynthesis, which is crucial for balancing the carbon emissions generated by tourism activities [17]. Grassland ecosystems, through the accumulation of their roots and soil organic matter, play a key carbon-sequestration role, especially in arid and semi-arid regions [18]. In urban ecosystems, natural elements such as vegetation and soil, as well as artificial elements such as urban green spaces, rational building layouts, ventilation systems, and materials and facilities with carbon-sequestration functions in the construction space, jointly promote carbon fixation and storage and reduce carbon emissions [19,22]. Farmland ecosystems can effectively enhance the carbon-storage capacity of the soil through sustainable agricultural practices [20]. In addition, wetland and marine ecosystems, such as mangroves, coral reefs, salt marshes, and seagrass beds, are also important carbon sinks, effectively absorbing carbon dioxide from the atmosphere through biological processes [21]. Although the research findings on these ecosystem carbon-sequestration capacities mainly focus on the fields of ecology and environmental science, they provide important scientific evidence for understanding the carbon-sequestration potential and practical impacts of the renovated ecosystems at heritage sites.

The carbon-sequestration function of heritage sites after renovation plays a crucial role in offsetting carbon emissions from production and daily life. This function not only helps to reduce the negative impacts of human activities on the ecological environment but also has great significance for promoting the local ecological sustainable development. When calculating the carbon-sequestration of heritage sites, it is necessary to separate the overall carbon-sequestration amount to obtain the carbon-sequestration amount available for renovation. Current research mainly uses the contribution rate of the economic development after the development of the heritage site as a coefficient to separate the carbon-sequestration from carbon-sequestration subjects such as ecosystem carbon absorption and forest carbon sequestration [23]. There is also research that uses the Analytic Hierarchy Process (AHP) to evaluate the value of heritage elements, establish "carbon-space nodes" to construct a carbon network, and determine the key factors affecting the carbon performance of industrial-heritage communities [24].

The rational and effective utilization of the carbon-sequestration capacity of renovated industrial-heritage sites is of great importance for achieving the carbon-neutrality goal. The high-carbon-sequestration transformation of industrial heritage requires a variety of technologies, such as Carbon Capture, Utilization, and Storage (CCUS) technology [25]. Carbon capture refers to the use of specific technologies to separate and collect carbon dioxide from the atmosphere. Carbon utilization is to convert the captured carbon dioxide into valuable products. Carbon storage is to store the remaining carbon dioxide after utilization for a long time, isolating it from the atmosphere. In addition, this kind of transformation requires a large amount of capital investment, and the shortage of funds remains a common problem [24]. Moreover, the transformation of industrial heritage involves multiple stakeholders, and their interests vary [26]. Therefore, a successful high-carbon-sequestration transformation requires balancing these different interests to ensure the effectiveness of implementation. Forest-based carbon sequestration is still the main component of China's ecosystem-based carbon sequestration. To achieve the high-carbon-sequestration goal, China needs to address the challenges in the ecosystem-carbon-sequestration framework, promote the development of urban carbon sequestration and a well-established carbon-trading system [27,28], and adopt strategies such as establishing a database, improving the legal framework, ensuring dedicated-fund investment, and expanding the cultural-production function of industrial heritage to achieve sustainable development [26].

High carbon sequestration transformation of industrial heritage is a research field of great significance, and several successful case studies and research findings have emerged. Nevertheless, such transformations still face challenges related to technology, funding, and stakeholder coordination. Future efforts should emphasize technological innovation, diversified funding sources, and multi-stakeholder collaboration to advance the development of high carbon sequestration transformations in industrial heritage, contributing to global climate change mitigation and sustainable development.

3. Case study

The transformation of industrial heritage in China is inherently complex, extending beyond a straightforward policy or technical issue to encompass a systematic social governance challenge. In evaluating the effectiveness of industrial heritage projects, three primary dimensions are often considered: the level of cultural conservation, the sustainability of the economic system, and societal harmony [29].

These three dimensions align with the core strategic components of planning strategies, retrofit orientation, and the role of government [30].

Planning strategies provide the directional framework that dictates the functional evolution of industrial heritage sites. Retrofit orientation sets the overarching trajectory, determining the intended function and scope of heritage transformation. Meanwhile, the government's role acts as both a catalyst and adhesive throughout the transformation process, managing spatial planning responsibilities after the site is designated as heritage and enhancing project efficiency and performance. As such, the government serves as the bond that integrates societal, corporate, and project interests. These three underlying logics are essential dimensions for assessing the success of industrial heritage projects.

A defining characteristic of industrial heritage transformation is the shift from "smoke-producing industries" to "smokeless industries". This type of transformation, whether driven by subjective intentions or objective needs, generally aligns with carbon sequestration goals, and the extent of its impact closely correlates with the three aforementioned dimensions.

The success of Hanggang Park can also be measured through these three dimensions. This section will analyze Hanggang Park's redevelopment measures, functional planning, funding strategies, and the role of government from the perspectives of planning strategy, retrofit orientation, and government involvement. Through this lens, we aim to gain a comprehensive understanding of how the transformation of waterfront industrial heritage can achieve stable high carbon sequestration goals, as well as the advantages and challenges associated with this redevelopment model.

3.1. Research cases and methodology

The Beijing-Hangzhou Grand Canal is the world's longest ancient canal, with a total length of approximately 1794 km. It connects the five major river systems in China from south to north and serves as an important transportation waterway in China. The Grand Canal has bridged the natural barriers formed by the Yangtze River and the Yellow River, promoted the industrial and commercial exchanges between the north and the south of China, and a large number of industrial and commercial cities have emerged along its banks. Thanks to the convenient transportation conditions provided by the Grand Canal, resources such as coal and ore can be transported to important industrial and commercial cities more conveniently. Therefore, it has played a significant role in the process of China's industrialization and modernization.

Hanggang Park is located in the northeast of Gongshu District, Hangzhou City, Zhejiang Province, on the north bank of the Grand Canal and at the western foot of Banshan National Forest Park. It is adjacent to the Hangzhou Library and is the intersection of the Grand Canal and the national forest park. The park covers an area of 55 hectares and was originally the site of the Hangzhou Iron and Steel Plant, which was founded in 1957. Hangzhou Iron and Steel Plant is one of the earliest steel enterprises in Hangzhou and also one of the first-batch steel enterprises in New China. Due to the dual pressures of environmental supervision and resource allocation, as well as the construction of the Hangzhou Grand Canal National Park, the main production area of Hangzhou Iron and Steel Plant ceased production and completed relocation at the end of 2010. The industrial relics on-site, including historical buildings and production equipment, have become important objects of research and protection.

From July to September 2024, we conducted three tourist surveys in the open-area of the park on weekdays, weekends, and public holidays (Mid-Autumn Festival) respectively. The purpose of this survey was to explore the development potential of Hanggang Park. The daily tourist volumes of these three surveys were 193, 660, and 1425 respectively. These data are comparable to those of mature parks such as Zhongshan Qijiang Park, Beijing Urban Green Heart Forest Park, Xi'an Film Studio Theme Park, and Wuhan Longlingshan Mine Pit Park. For a newly-opened park, such tourist flows indicate that Hanggang Park is highly attractive.

This research collates and analyzes the documents and plans during the transformation process of the Hangzhou Iron and Steel Plant, evaluates the regeneration measures and paths of the Hangzhou Iron and Steel Plant, and puts forward suggestions for development and improvement, so as to seek a meaningful reference model for the reuse of waterfront industrial heritage under the high-carbon-sequestration goal.

3.2. Planning strategy

The introduction of new functions entails the reconfiguration of existing physical spaces and remnants, leading to newly derived uses. On a macro level, the development of Hanggang Park represents a comprehensive redefinition of functional positioning, which follows two primary planning pathways.

The first pathway focuses on redefining the functions of existing buildings and equipment. This approach entails the preservation and adaptive reuse of facilities within the former Hanggang industrial base, including boilers, blast furnaces, coke ovens, rail tracks, chimneys, factory buildings, and workshops. Some industrial structures, such as pipelines and blast furnaces, have been creatively repurposed as climbing frames or structural supports for vegetation, thus expanding space for plant growth and enhancing carbon sequestration capacity. Additionally, certain elements, like the dry gas tank originally used to store gas for blast furnace operations, have been converted into spaces such as a diving center. This approach not only preserves the industrial cultural heritage but also minimizes future carbon emissions by reducing the need for new construction.

The second pathway involves repurposing existing spaces. Abandoned spaces are transformed into multifunctional areas with cultural and ecological value. For example, the former green space in the industrial area has been redesigned as a wedding lawn, while old mining sites have been reshaped into scenic hills. Leveraging the distinctive spatial characteristics of the industrial heritage site, the park incorporates layered green landscapes, including vertical and rooftop greenery.

It is worth noting that, before being designated as heritage, the site's buildings, equipment, and spaces operated as two distinct functional systems geared towards production needs. For instance, green spaces, sports fields, workshops, and warehouses were managed separately with unique functions and operational practices. However, following the site's designation as heritage, these systems were unified as they no longer served their original purposes. Through technical modifications, they have been transformed into an integrated industrial cultural landscape with new, cohesive functions (see **Figure 1**).

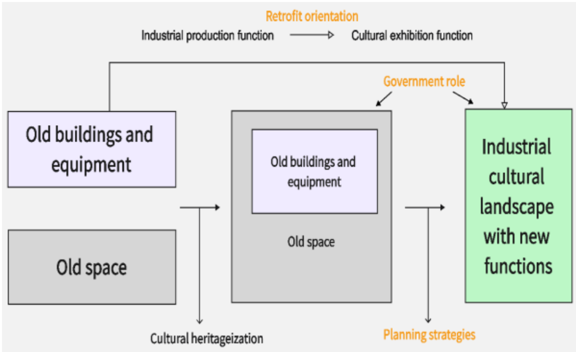

Figure 1. The functional system transformation of industrial heritage sites: From independent production-oriented systems to integrated industrial cultural landscape.

In fact, the aforementioned pathways are commonly applied in industrial heritage transformations. However, Hanggang Park differs due to its designation as a large-scale waterfront industrial heritage site, which adds unique considerations to its transformation. Specifically, in Hanggang Park's transformation, the collaboration among subjects (enterprises, residents, visitors) and objects (terrestrial and marine ecosystems) is carried out through voluntary and mandatory compensation mechanisms (see **Figure 2**). This approach coordinates carbon supply-demand relations and enhances carbon sink capacity, embodying the overarching high carbon sequestration goal. Therefore, the project aims not only to reduce carbon emissions during the transformation process but also to enhance carbon storage capabilities in the post-transformation landscape.

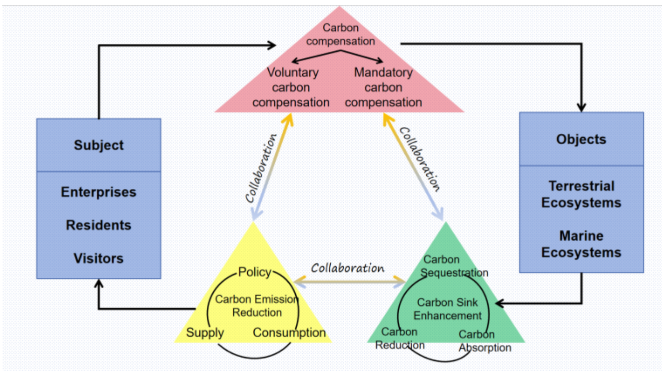

Figure 2. Approach to achieve carbon sink targets.

From a strategic perspective, the transformation of Hanggang Park has been planned with the goal of creating an urban park, fully integrating and harmonizing the site's existing buildings, equipment, and spaces into a cohesive landscape. Our research indicates that, as of May 2024, green space within Hanggang Park occupies 93.7% of the total area—an increase of 35% compared to pre-transformation levels.

Additionally, the project has completely remediated 25 hectares of polluted soil, gradually integrating with the nearby Half Mountain National Forest Park and effectively addressing contaminated soil along the canal bank. These measures have substantially increased the park's internal carbon storage capacity.

3.3. Retrofit orientation

Retrofit orientation refers to the primary focus guiding the transformation of industrial heritage. While many industrial heritage projects ultimately contribute to environmental enhancement, not all transformations are environmentally oriented; some are driven by commercial, political, or cultural objectives. In the case of Hanggang Park, however, its transformation is distinctly environmentally oriented, as evidenced by both the planning approach and resulting outcomes [31].

One key aspect of this environmental focus is the emphasis on vegetation restoration. Utilizing natural resources such as Malingshan (Maling Mountain) and Hanggang Lake, Hanggang Park has implemented vegetation restoration measures to remediate environmental pollution and restore natural ecosystems. In areas with soil contamination, ecological remediation is conducted prior to greening. Techniques such as soil improvement and vegetation restoration are employed to enhance soil quality, providing favorable conditions for plant growth and thus improving the site's carbon sequestration capacity.

As of 2023, Hanggang Park has achieved over 72,000 square meters of greening across vacant and abandoned areas within the site. In its greening strategy, the park has prioritized high carbon sequestration plant species suited to local climate and soil conditions. These include fast-growing tree species with high carbon storage potential, such as willows and poplars, alongside dense, layered shrubs used as understory vegetation, including species like holly and boxwood. By planting shrubs and herbaceous plants beneath the tall trees, a multi-layered vegetation landscape is created, simulating a natural ecosystem. This approach builds a carbon sequestration network composed of trees, shrubs, and herbaceous plants, forming a complex, multi-tiered plant community. This layered structure maximizes spatial and resource use, enhances photosynthetic efficiency, and further boosts carbon sequestration capacity.

Another critical focus is soil and water remediation and conservation. Historical steel production in this area generated substantial industrial wastewater and heavy metal deposits, making the Hangzhou Steel Plant one of the most polluted zones in Hangzhou during the 1980s [32,33]. Therefore, a priority in transforming Hanggang Park has been comprehensive soil and water restoration. The initial focus has been on water pollution control, employing an integrated approach combining biological, chemical, and physical treatment methods. For example, biological treatment techniques like the activated sludge method and extensive planting of aquatic vegetation are used to remove harmful substances from the wastewater, ensuring it meets emission standards. Additionally, the creation of an artificial wetland in Hanggang Lake further purifies water, regulates flow, conserves water resources, and restores the natural ecological functions of the water bodies, thereby enhancing the local aquatic environment. In the wetland, high-purification aquatic plants such as reeds, acorus, and cattails are planted to effectively remove heavy metals and organic pollutants, achieving substantial water and soil remediation to support enhanced carbon sequestration.

The artificial wetland also forms a foundation for the water landscape design within Hanggang Park. Leveraging both the wetland in Hanggang Lake and the adjacent Grand Canal water system, the park has developed ecologically distinctive water features, including fountains, streams, and ponds. These water features not only enhance the aesthetic appeal and attractiveness of the site but also provide recreational spaces for the public. Additionally, the circulation and movement of water through these features promote oxygenation, which benefits the growth of aquatic life and the overall health of the ecosystem.

The third focus is on construction methods aimed at achieving long-term carbon sequestration through a pilot-to-optimized rollout approach. In 2021, Hangzhou Canal Comprehensive Protection and Development Construction Group Co., Ltd., the developer and operator of Hanggang Park, conducted a pilot restoration project on a 112,000-square-meter plot known as GS1303-05/06, located in the southern part of the former Hanggang Half Mountain decommissioned site. Before restoration, this area contained over 50,000 cubic meters of contaminated soil, with groundwater pollution present in some sections. During remediation, the developers employed a combination of infrastructure techniques, such as constructing vertical barrier walls (using High Density Polyethylene (HDPE) membranes combined with self-consolidating grout for flexible containment), horizontal barrier layers (anti-seepage concrete hardening), and establishing tree buffer zones with layered protections, including clearing surface soil, installing anti-seepage and drainage layers, adding clean soil, and building concrete enclosures and metal protective fencing. The successful completion and inspection of this pilot in 2022 resulted in the plot's removal from the "Zhejiang Contaminated Land Register". This method has since been broadly applied across Hanggang Park.

Furthermore, during the transformation of Hanggang Park, low-carbon and carbon-absorbing materials were utilized to construct green, high carbon-sequestration buildings. Specific measures, such as updated ventilation systems and increased natural lighting, were incorporated to reduce carbon emissions through low-carbon design principles. For lighting, Hanggang Park plans to use energy-efficient solutions, including solar photovoltaic panels and smart control systems, which adjust energy use based on actual needs, minimizing waste and establishing sustainable, low-emission green buildings.

In its industrial planning, Hanggang Park has also adopted a policy prohibiting high-carbon-emission businesses, such as certain types of dining establishments or secondary industry enterprises. Instead, the park prioritizes urban comfort spaces, including bookstores, cafes, themed shops, diving experience centers, wedding photography studios, and convenience stores. This strategy is directly aligned with the park's high carbon sequestration goals, further supporting its environmental orientation.

3.4. Role of the government

China's unique political system enables various levels of government to play a crucial role in industrial heritage transformation projects. During the transformation of Hanggang Park, both the Zhejiang provincial and Hangzhou municipal governments took an active role. Following research and evaluation, the government decided to cease operations at the Hangzhou Steel Plant and outlined a comprehensive development plan for Hanggang Park, clarifying its functional role in the city's future and emphasizing the goal of supporting the government's carbon peak initiatives. This involvement is evident in three main aspects:

First, the government promptly re-designated the former Hanggang site as public green space and managed the relationship between the future park and nearby communities. The relocation of Hanggang was itself a government-led initiative. After the complete relocation of the steel plant in 2016, the Hangzhou Planning Bureau quickly rezoned the area as public green space in 2017. Concurrently, it facilitated the relocation of adjacent residential areas, such as Hanggang collective dormitories and machinery dormitories, ensuring seamless integration with the park's development.

According to the government's plan, Hanggang Park is situated on an independent plot bordered by Tianxiang Avenue, Lian Tie Road, Chenglian Street, and Kangyuan South Road. This location is intentionally separated from residential and commercial zones, providing the park with a high degree of geographical independence and forming a relatively complete public landscape area.

Second, the development of the park is integrated into the local government's top-level design for achieving carbon peaking goals. In June 2024, the Hangzhou Municipal Government issued the "Notice on the Implementation Plan for the National Carbon Peaking Pilot (Hangzhou)", which officially designated the Hanggang area as a carbon peaking demonstration zone. Our research indicates that in the transformation of Hanggang Park, the collaboration between government departments, design and planning companies, the former Hangzhou Steel Plant, and the local community has effectively clarified property rights and usage rights, enabling rapid and efficient project implementation. Furthermore, the government established a financing platform to attract private investment to the Hanggang Park transformation project, alleviating funding pressure by utilizing designated funds.

Third, the development and operation of the park are managed by a state-owned enterprise, the Hangzhou Canal Comprehensive Protection and Development Construction Group Co., Ltd., a company directly under the Hangzhou municipal government. This entity is primarily responsible for executing major government projects.

In our analysis of 38 tender documents related to the Hanggang Park project, the company listed the park's construction as part of the "Grand Canal Hanggang Industrial Heritage Comprehensive Conservation Project." The tenders explicitly mandated the use of green materials and environmentally friendly construction practices as baseline requirements, effectively reducing carbon emissions from the outset of construction.

This approach aligns directly with the requirements set forth by the Zhejiang

Provincial and Hangzhou Municipal governments. As early as 2018, Zhejiang Province introduced urban renewal policies emphasizing low-carbon emissions, with some historic districts encouraged to pursue "zero emissions". The construction of Hanggang Park is a continuation of these directives, fulfilling the provincial government's low-carbon urban development objectives.

4. Discussion

4.1. Advantages and challenges of transformation

Compared to Western countries, China's high carbon sequestration transformation of waterfront industrial heritage parks, exemplified by Hanggang Park, enjoys distinct advantages. Under the system of public land ownership, the transformation of Hanggang Park does not face delays or halts due to property rights disputes, allowing the project to proceed with a comprehensive approach to land use planning. This enables effective alignment with the dual national objectives of Grand Canal conservation and achieving carbon peaking.

Additionally, as a developing country in the Global South, China enjoys broad public support for new forms of public cultural spaces. This favorable societal attitude provides a strong social foundation for Hanggang Park and significant public support for its high carbon sequestration objectives, especially in terms of fostering low-carbon enterprises and activities within the park.

Between July and September 2024, we conducted three visitor surveys in the currently open areas of the park, targeting a weekday, a weekend, and a public holiday (Mid-Autumn Festival). The daily visitor counts for these surveys were 193, 660 and 1425 respectively. These figures are comparable to those for established parks like Zhongshan Qijiang Park, Beijing Green Heart Urban Park, Xi'an Film Studio Park, and Wuhan Longling Mountain Quarry Park. For a newly opened park, this level of visitor traffic demonstrates Hanggang Park's high appeal.

However, our research also identified numerous challenges in the park's development, with technological limitations being a primary concern. High carbon sequestration transformations for waterfront industrial heritage require advanced ecological restoration techniques to remediate pollution, improve soil and water quality, and enhance plant survival rates, ultimately achieving sustained carbon sequestration. Currently, however, ecological restoration technology for waterfront industrial heritage remains in developmental stages worldwide, including in China and other developed nations. Even in the construction of Hanggang Park, technological bottlenecks persist, such as carbon sequestration technology and carbon tracking verification techniques.

4.2. Pathway analysis for achieving stable high carbon sequestration

The technical pathway for the construction of Hanggang Park suggests that achieving stable high carbon sequestration in waterfront industrial heritage sites requires comprehensive environmental management. This approach aims to reduce carbon emissions while simultaneously enhancing carbon storage performance.

Based on the experience gained from Hanggang Park, waterfront industrial heritage sites should maximize the use of available space to establish ecological corridors and create a multi-layered vegetation network. This structure enhances carbon sequestration per unit area and enriches the biodiversity of the ecosystem. Moreover, waterfront industrial sites should leverage their proximity to water by developing artificial wetlands and water features. These not only support aquatic plants with purification and carbon sequestration capacities but also complement terrestrial vegetation, creating a diversified, networked, and stable ecosystem that contributes to carbon sequestration.

From an industrial planning perspective, the transformation of waterfront industrial heritage should capitalize on the site's residential and tourism-friendly attributes to enhance its appeal as a tourist destination. The implementation pathway for this objective involves high carbon sequestration-oriented industrial planning. Following the transformation, low-carbon products have seen a significant increase in sales proportion and growth rate within the park's internal industrial structure. Currently, Hanggang Park's industries are all high carbon-sequestration-focused tertiary sectors. According to the park's industrial layout plan, the focus is primarily on tertiary industries or industrial services. However, it is crucial to ensure the stability and profitability of these emerging industries, facilitating their sustainable development and preventing any regression from high carbon sequestration industries back to low-carbon-sequestration ones.

Hanggang Park's experience also underscores the importance of public participation in the transformation of waterfront industrial heritage into a park. Through innovative transformations and creative developments, the site has been shaped into a space where art and ecology coexist, effectively attracting community members and tourists to engage with the park. This increased engagement boosts the return on investment and further attracts social capital to support the park's development. By alleviating financial pressure, revenue generation can also support ongoing upgrades in transformation technologies. This, in turn, raises public awareness about high carbon sequestration transformations, enhances social recognition and engagement, and strengthens public support for such initiatives.

5. Conclusion and outlook

This paper, through the case analysis of Hanggang Park, explores the transformation strategies for waterfront industrial heritage sites under the goal of high carbon sequestration. The study finds that measures such as vegetation restoration, soil and water remediation, and emission reduction—combined with active government involvement and public participation—can significantly enhance the carbon sequestration capacity of industrial heritage sites, achieving a win-win outcome of environmental protection and urban renewal. The successful transformation of Hanggang Park not only provides valuable insights for other waterfront industrial heritage sites but also offers a practical pathway for advancing carbon sequestration efforts.

Looking ahead, high carbon sequestration transformations of waterfront industrial heritage should continue to promote technological innovation, especially in ecological restoration and vegetation cultivation. Additionally, sustainable industrial planning must be emphasized to ensure the stable development of emerging industries. Public engagement and financial investment are also critical factors for successful transformations. The government should maintain a guiding role, establishing financing platforms to attract private capital and ensuring that these projects consistently align with high carbon sequestration objectives.

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