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Design and Structural Innovation of Wetland Landscape Installation Based on Silk Culture Imagery: Case Study on the Chaohu National Wetland Park

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ABSTRACT

This study proposes an innovative structural design method for landscape installations by systematically applying the design principles of textile engineering and fiber materials. Focusing on silk culture imagery, this research deconstructs fundamental textile elements, such as the smoothness of silk threads and the warp-and-weft interweaving structure of fabrics. These elements were reassembled and applied to the morphological language and spatial logic of an adjustable, modular installation at the Chaohu National Wetland Park. The design features a weather-resistant steel framework mimicking a textile's warp-and-weft structure, clad in a flexible fiber membrane with parametric perforations that replicate silk weave patterns. A comparative experimental evaluation against conventional installations demonstrates that this textile-inspired innovative design significantly outperforms traditional designs in cultural imagery expression, aesthetic artistry, and visitor experience. Furthermore, a life cycle cost analysis confirms its superior long-term economic benefits and sustainability, despite a higher initial investment. This research provides a new paradigm for the innovative application of textile structures and fiber-based aesthetics in modern landscape architecture.

KEYWORDS

textile engineering, silk culture, landscape installation, fiber materials, warp and weft structure

INTRODUCTION

Silk culture, as a treasure of Chinese traditional culture, has carried the mission of Eastern aesthetic wisdom and cultural exchange with the outside world since the opening of the Silk Road. Silk has a long history, and it is exquisite, rich, elegant, luxurious, environmentally friendly and natural. Moreover, it has played a positive role in the development of the textile industry, literature and arts and crafts, the derivation of folk culture,

and the integration of world culture [1]. Wetlands, known as the "kidneys of the earth," not only have ecological functions such as purifying water, regulating climate, and maintaining biodiversity, but their unique mudflats, waters, and vegetation landscapes also provide spaces for humans to connect with nature [2]. In the current trend of integrating cultural tourism and ecological protection, incorporating the imagery of silk culture into wetland landscape design is an innovative inheritance of traditional culture and an important approach to enhancing the quality of wetland landscapes through cultural empowerment, strengthening public cultural identity, and raising awareness of ecological conservation. The Chaohu Wetland Park is renowned for its remarkable cultural and ecological uniqueness, making it a valuable subject of study. In the middle reaches of the Yangtze River, various ecosystem services exhibit considerable spatial heterogeneity, and the overall spatial pattern shows the change characteristics of stratified interweaving. The intensity of the interaction between habitat quality and carbon storage and between carbon storage and soil conservation increases with the increase in scale, while the relationship and intensity between landscape aesthetics and other ecosystem services are less affected by scale changes [3]. Its natural texture bears a striking resemblance to silk, and its hydrological cycle aligns closely with the "water" element in silk production. Historically, Hefei was an important port on the Chaohui Canal route. It was famous as a canal transport and a distribution center of goods between the north and south, providing supplies for the Silk Road [4]. The preserved silkworm and mulberry relics, along with the traditional silk weaving techniques, embody a deep cultural heritage of silk. Integrating the imagery of silk culture into the landscape design of Chaohu Wetland not only revives its historical context but also achieves a mutual enhancement of ecological functions and cultural narratives through innovative design. This approach provides a highly distinctive model for the modern expression of traditional culture, addressing the issue of homogenization in wetland landscapes and promoting the coordinated development of ecological protection and cultural tourism.

Silk culture and wetland landscape design are hot topics in the fields of cultural and environmental studies, with scholars conducting extensive research. The first field is silk culture studies. On the basis of the collection of the Dongyun Silk Art Museum, Ruohan [5] analyzed silk products and their cultural relevance. From a cross-cultural perspective, Wang [6] discussed the application value, existing problems, and future optimization suggestions of Chinese traditional culture in international education to provide diversified cultural materials for international education, promote the deep application of Chinese traditional culture in international education, and improve students' cross-cultural understanding ability and international vision. Dabringhaus [7] also used the Silk Road as a medium to analyze material culture along the Silk Road, including silk products,

slaves, and pagodas. The second field of research focuses on wetland landscape design. Li [8] pointed out that with the requirements of landscape design, key tasks in urban landscape construction and development include coordinating ecological functions, economic and cultural relationships, and the need to build large-scale urban wetland parks to establish a complete planning management system. He [9] noted that urban wetland parks are crucial to maintaining urban ecological processes and enhancing the health and safety of human settlements. However, as a unique ecosystem, wetlands are facing unprecedented destruction due to rapid socioeconomic development and the unguided and disorderly expansion of human activities, leading to their shrinking or even disappearing [10]. The utilization of native wetland landscape in waterfront park design is studied. Native wetlands in coastal cities are developed into wetland parks, thus driving economic development. The third research field highlights cultural connotations of the Silk Road and wetland landscape installation design. A few scholars have combined these two areas in their research, but some have analyzed issues related to the planning and design of wetland park landscapes in the Silk Road region. Wang pointed out that the wetlands located in the Silk Road area should extract the regional cultural symbols of the Silk Road and plan recreational spaces with different functions by means of winding paths and landscape walls [11].

Analysis on the current research status reveals that studies on silk culture primarily focus on single cultural carriers, such as silk products and the material remains of the Silk Road. These studies analyze their cultural relevance and dissemination impact or explore their roles in education and material culture through the maritime and land Silk Roads. However, they often have a fragmented perspective, with insufficient attention to the differences in cultural dissemination across different historical periods and contemporary cultural reconstruction. By contrast, research on wetland landscape design centers on ecological functions, economic and cultural coordination, and the application of 5G and digital technologies, as well as water resource protection strategies. However, issues such as an imbalance between ecology and culture and the instrumentalization of technology applications remain. While some scholars have attempted to integrate Silk Road culture into wetland landscape design, their efforts have largely remained at the level of form imitation. Overall, current research on silk culture lacks a comprehensive and contemporary perspective, and wetland landscape design has not deeply integrated cultural and ecological elements. Cross-disciplinary research has not established a systematic logical framework, making it difficult to achieve an organic unity of culture and ecology. This study uses the Chaohu Wetland Park as a practical setting, breaking through the limitations of existing research where silk culture and wetland landscape design are disconnected and superficially

integrated. It innovatively deconstructs and recombines silk cultural imagery (such as the smoothness of silk threads and the warp and weft patterns of fabrics) into the form language and spatial logic of the wetland park's landscape installation. By optimizing the layout of the wetland water system and trail network using the concept of warp and weft interweaving in silk, the study uses cocoon-shaped installations to represent the cycle of life metaphorically and integrate ecological monitoring functions. Additionally, digital technology is used to create interactive scenes of silk trade history, achieving a deep integration of cultural narrative, ecological function, and technological innovation, providing a new paradigm for the integration of regional culture and wetland landscape design.

EXPERIMENTAL

Study Area and Field Research

The study was conducted at the Chaohu National Wetland Park. Systematic on-site surveys were conducted from April to June 2023 to acquire baseline data required for the design. The research team employed GPS (Global Positioning System) mapping and UAV (Unmanned Aerial Vehicle) aerial photography to chart the topography, hydrological distribution, and vegetation status of the park's core area. In parallel, a structured questionnaire survey was designed and implemented to assess public satisfaction with existing landscape facilities and cultural needs. A total of 800 questionnaires were distributed, with 720 valid responses collected, yielding an effective recovery rate of 90%. Respondents represented a broad cross-section of visitors and local residents across age groups (18–65 years), professions, and geographic origins, ensuring wide representativeness of the sample. Additionally, in-depth interviews were conducted with five park management personnel to obtain professional feedback on operational and managerial issues.

Landscape Installation Design

Material Selection and Performance Testing

The study prioritized environmentally friendly materials suitable for the high-humidity conditions of wetland environments, such as modified bamboo, plant-fiber-reinforced recycled concrete, and weathering steel. To ensure scientific rigor and durability, all selected materials underwent performance testing under simulated wetland laboratory conditions:

Water resistance: In accordance with the Standard for Testing Water Absorption of Building Materials, the

volumetric water absorption after 24-hour immersion must not exceed 12% for modified bamboo and 5% for recycled concrete.

Corrosion resistance: In accordance with ISO 12944, weathering steel was subjected to accelerated salt spray corrosion tests, with an anticorrosion rating of C4-H (high-humidity industrial environments) required.

Biological resistance: Samples were exposed to microbe-rich wetland environments in accelerated testing, with quarterly biofouling growth limited to ≤30 g/m².

Mechanical performance: Tensile strength tests on plant-fiber-reinforced composites were performed per ASTM D638, with a minimum tensile strength requirement of 30 MPa.

Adjustable Structural Design

The installation adopts a modular, adjustable structural system comprising four core modules (Figure 1):

Foundation frame: Constructed from weathering steel, the frame evokes the interwoven structure of silk threads. Hydraulic adjustment systems embedded within the columns enable a height variation of 0–1.5 m to accommodate seasonal water-level fluctuations.

Cultural cladding: The exterior is enveloped in a flexible fiber membrane, featuring parametric perforated patterns inspired by silkworm cocoons and silk reels, ensuring optimal light permeability and ventilation.

Ecological modules: Detachable ecological trays at the base are planted with wetland species such as reeds. Hinged connections allow the trays to adjust their tilt automatically with changing water levels, creating a “floating silk garden” effect.

Intelligent adjustment mechanism: Integrated water-level sensors and solar-powered motors enable automatic elevation of the structure when water levels exceed safety thresholds. Visitors can also manually adjust the installation via a touchscreen interface, activating an AR (Augmented Reality) projection system that displays historical silk trade scenes on the membrane surface.

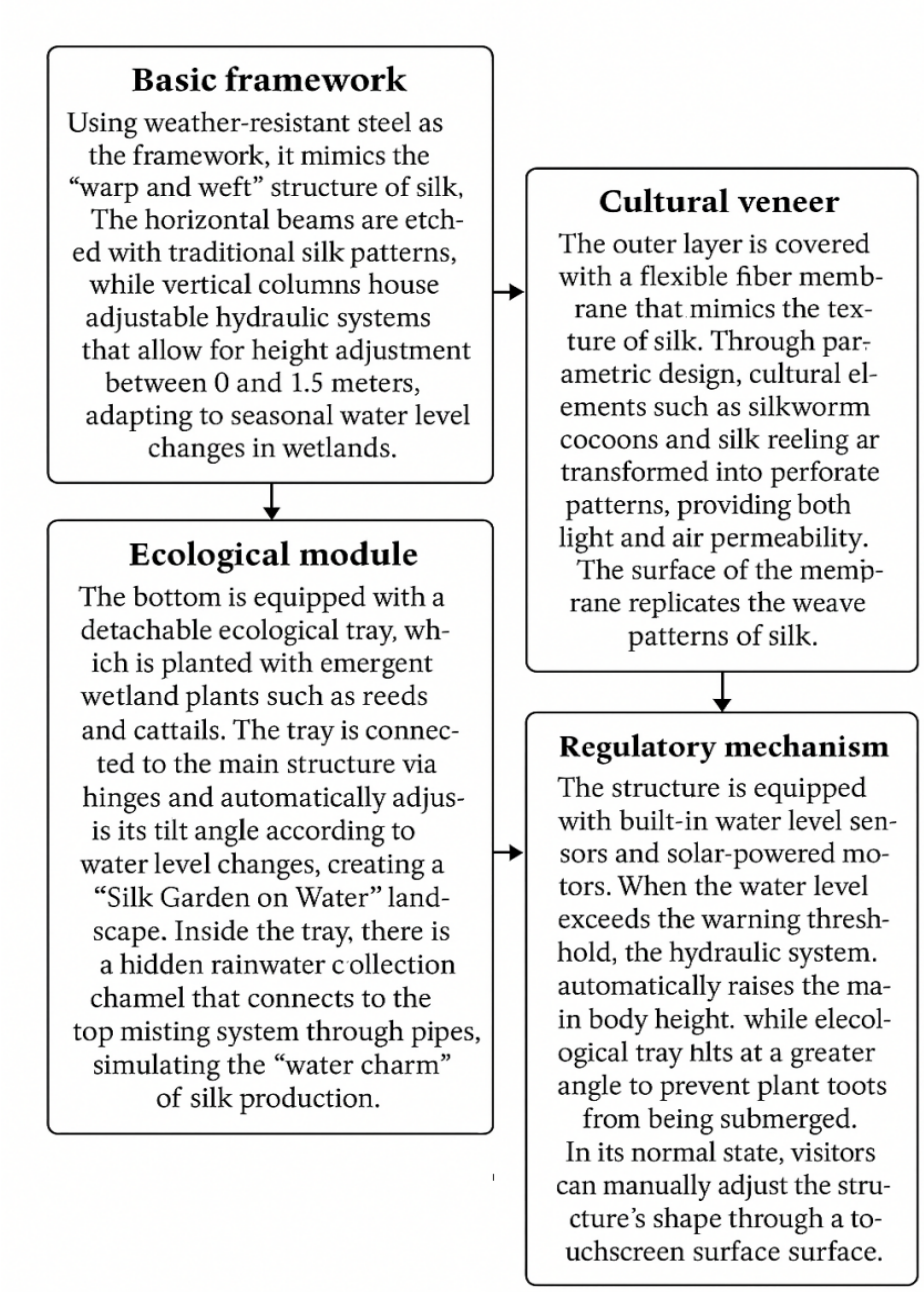

Figure 1. Schematic of the design of adjustable structure of wetland landscape integrating silk culture

Experimental Evaluation Methods

To quantitatively assess the overall performance of the design scheme, established an experimental group (featuring installations integrating silk culture) and a control group (featuring conventional installations of equivalent volume and layout without cultural themes). Comparative testing was conducted in a simulated wetland laboratory environment and in designated areas of the park.

Evaluation Framework and Quantitative Metrics

A comprehensive evaluation framework comprising six primary indicators was developed. The specific measurement criteria are presented in Table 1.

Table 1. Comprehensive Evaluation Framework for Landscape Installations

Evaluation Dimension	Measurement Method	Scoring Criteria
Expression of Cultural Imagery	Cultural-theme alignment	A panel of experts evaluates the correlation between the installation's external form and design concept with the silk culture theme of Chaohu.
Ecological Adaptability	Impact on flora and fauna	Plant community coverage in the wetland is quantified through aerial photography and ground plot surveys. Infrared monitoring tracks animal movement paths, and disturbance rates are compared before and after installation.
Device Functionality	Comfort of rest spaces	In accordance with *Park Design Code* (GB 51192-2016) ergonomic standards for seating, parameters such as seat height and tilt are measured and evaluated. Scores are calculated across five dimensions: perceived comfort of seat materials, seating support comfort, appropriateness of spacing between units, integration of equipment with the landscape, and overall practicality, based on feedback from visitors and experts.
Aesthetic Artistry	Color harmony	A 20-member evaluation panel of landscape designers, artists, and environmental aesthetics experts rates the proportionality and formal resonance of the installations within the wetland landscape; the average score is recorded as the final rating.
Cultural Transmission Effect	Popular science impact	A sample of 150 visitors in the installation area completes a knowledge test on silk culture before and after their visit; the percentage improvement in cultural knowledge is calculated.
Economic Viability	Material costs	Installation material costs are compared with those of conventional materials, accounting for overall expenditure.

Statistical Analysis

All quantitative data were analyzed using SPSS version 26.0. Independent-sample t-tests were applied to compare the scores of each indicator between the experimental and control groups. Differences were considered statistically significant at $p < 0.05$.

RESULTS AND DISCUSSION

Expression of Cultural Imagery

To assess the installations' effectiveness in conveying the imagery of silk culture, 30 experts evaluated both groups using a seven-point Likert scale. The results (Figure 2) showed that the experimental group scored an average of 6.21 ± 0.53 on "symbol recognizability," "thematic relevance," and "cultural innovativeness," significantly higher than the control group's 3.45 ± 0.68 ($t(58) = 17.5$, $p < 0.001$). These findings confirm that the experimental design effectively communicates its cultural theme. Expert feedback emphasized that the experimental group successfully transformed the abstract concept of silk culture into clearly perceptible landscape forms by incorporating shape language mimicking the smoothness of silk threads and woven textile structures, along with figurative symbols such as cocoons. By contrast, the control group, lacking a cultural theme, scored close to the scale's midpoint, indicating no meaningful cultural associations were evoked.

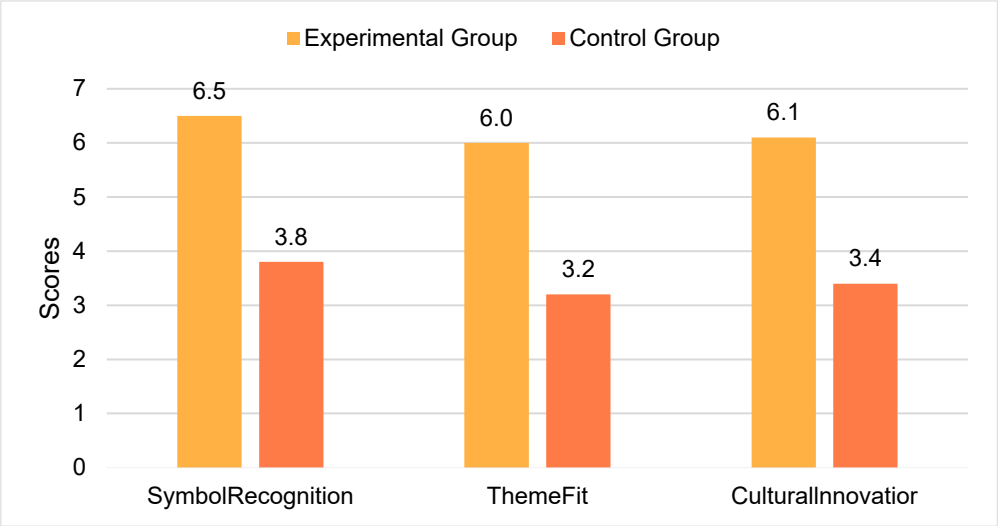

Figure 2. Comparison of evaluation dimensions

Ecological Adaptability

Ecological monitoring conducted over one quarter following installation (Figures 3 and 4) revealed initial impacts on the surrounding environment for both groups. Plant community coverage in the experimental group plots declined by 3.2%, while that in the control group fell by 5.8%. Regarding animal activity, one effective activity path disappeared in the experimental group, compared with two in the control group. Although the experimental group's ecological impact was numerically less severe, statistical testing indicated that the difference in vegetation coverage changes between groups was not significant ($p = 0.08$). This result suggests that the introduction of any large-scale installation inevitably disturbs wetland ecosystems in the short term. Nevertheless, the experimental design prioritized low-ecotoxicity materials, such as plant-fiber composites, and incorporated ecological corridors to minimize barriers to wildlife movement. The long-term benefits of these measures will require continued monitoring beyond the timeframe of this study to be fully validated.

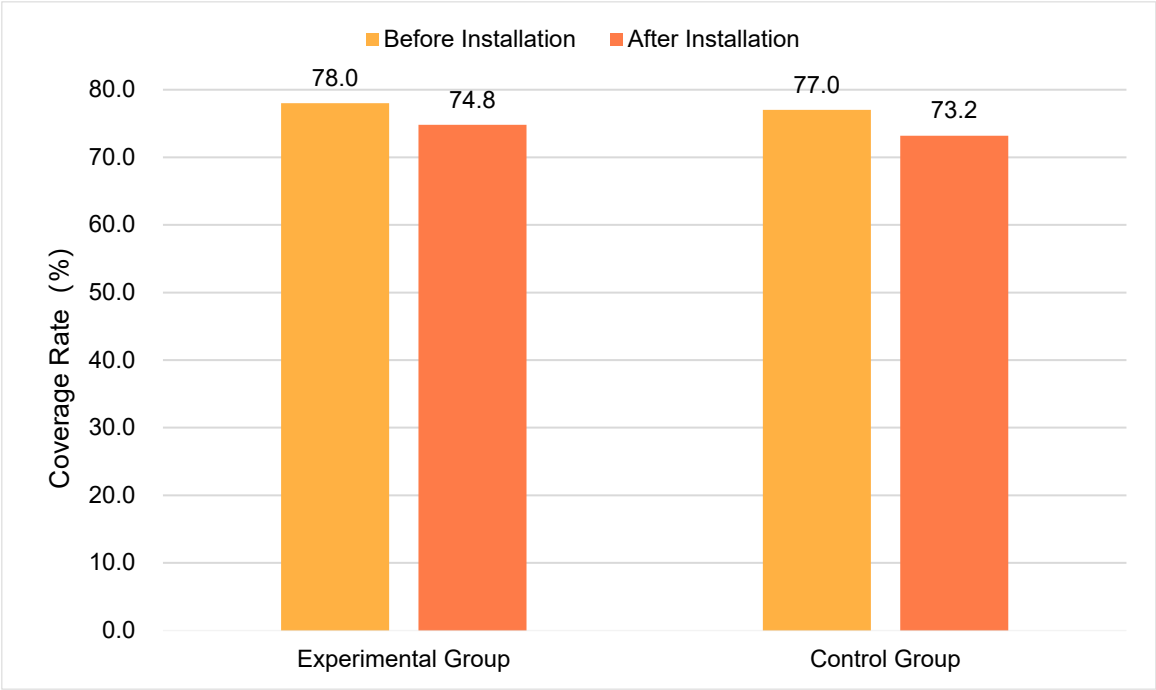

Figure 3. Changes in plant community coverage

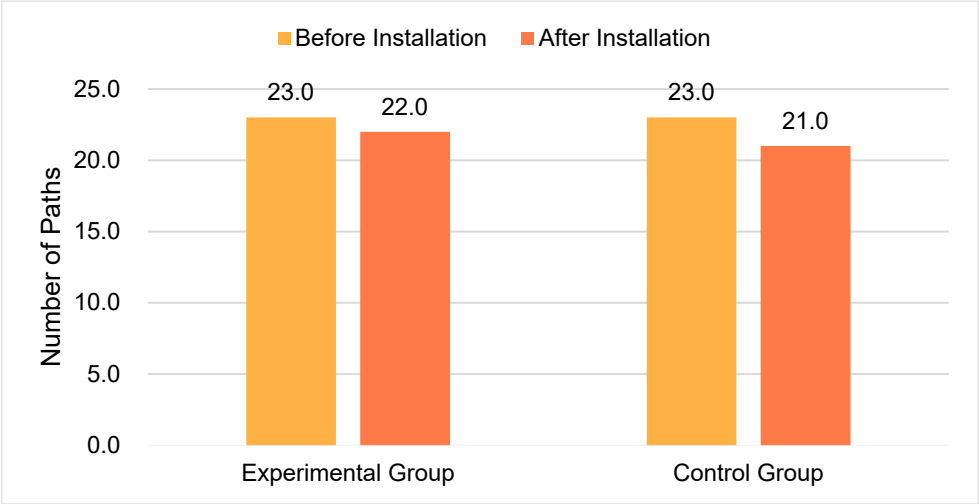

Figure 4. Changes in the number of animal activity paths

Device Functionality and Comfort

Objective measurements demonstrated remarkable advantages of the experimental group in functionality and comfort. Seat pressure distribution tests indicated that the experimental group's average peak seating pressure was 15.2 kPa, significantly lower than the control group's 24.8 kPa ($p < 0.01$). Additionally, visitors' average dwell time in the experimental group area was 12.5 minutes, markedly longer than the control group's 7.2 minutes ($p < 0.05$).

The pressure data highlight the superior ergonomic performance of the experimental design, offering enhanced physical comfort. Extended dwell time further reflects the installation's overall appeal, attributed not only to physical comfort but also to the immersive artistic atmosphere created by the silk culture theme and interactive AR experiences, which collectively enhanced visitor engagement and willingness to participate.

Aesthetic Artistry

In the aesthetic evaluation, 20 artists and designers rated both groups on a five-point scale. As shown in Figure 5, the experimental group achieved a mean composite score of 4.42 ± 0.41, significantly outperforming the control group's 2.78 ± 0.59 ($p < 0.001$) across the dimensions of "morphological coherence," "color harmony," and "material integration."

The experimental group's superior scores were attributed to the design's deep integration of culture and environment. The installations echoed the natural forms of wetland flora through silk-inspired contours,

employed traditional silk color palettes harmonized with wetland tones, and utilized eco-friendly materials to replicate the unique texture of silk. This systematic aesthetic approach enabled the installations to merge seamlessly with the natural landscape, achieving a unity of cultural symbolism and ecological aesthetics.

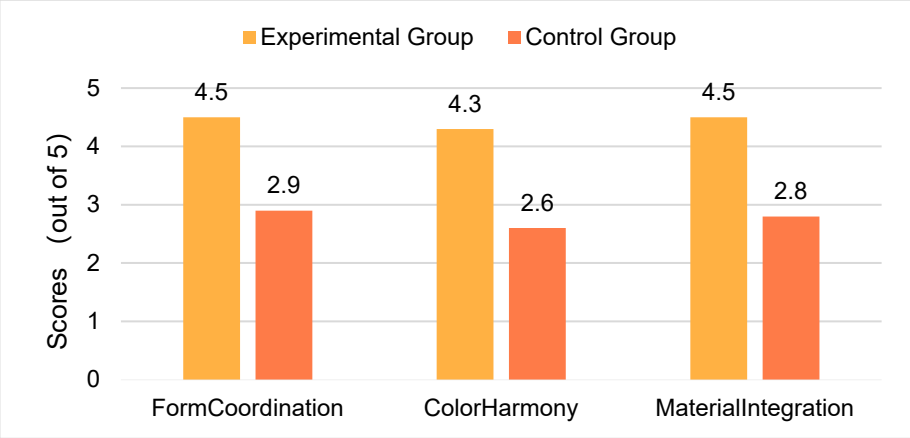

Figure 5. Expert ratings of aesthetic artistry

Cultural Transmission Effect

A knowledge survey of 150 visitors revealed that following their experience, visitors who engaged with the experimental installations improved their correct response rate on silk culture–related knowledge by an average of 45 percentage points, compared with a 10-point improvement among control group visitors, a difference that was highly significant ($p < 0.001$).

These findings provide strong evidence of the cultural transmission effectiveness of the experimental design. Beyond functioning as rest facilities, the installations served as “cultural carriers.” Visitors absorbed cultural knowledge implicitly through observation of form, reading interpretive materials, and interacting with AR features, confirming that embedding cultural narratives into landscape design is an effective strategy for enhancing public cultural literacy while achieving educational engagement.

Economic Viability–Life Cycle Cost Analysis

A life cycle cost analysis (LCCA) was performed to assess the total economic costs of the installations over a 10-year operational period. As shown in Table 2, while the experimental group required higher initial investment, its total life cycle cost was significantly lower than that of the control group, overcoming the limitations of traditional cost analysis. The experimental design’s use of premium weathering steel, intelligent adjustment systems, and customized cultural cladding resulted in increased upfront costs; however, these

high-quality materials and innovative processes (e.g., plant-fiber composites) offer superior durability and reduced maintenance requirements, substantially lowering long-term operational expenditures. By contrast, the control group's conventional materials, despite their lower initial costs, required more frequent repair and replacement. From a sustainable development perspective, the experimental design, which integrates cultural and technological innovations, demonstrates superior long-term economic efficiency.

Table 2. Ten-year Life Cycle Cost Comparison of the Two Installation Groups (Unit: 10,000 CNY)

Cost Item	Experimental Group	Control Group
Initial Material and Manufacturing Cost	55	50.5
Cumulative Maintenance Cost (10 years)	5	20
Residual Material Value after 10 Years (recovery)	−10.0	−2.0
Total Life Cycle Cost	50	68.5

CONCLUSION

This study, set in Chaohu Wetland Park, successfully explored and established an innovative framework that deeply integrates silk cultural imagery with wetland landscape installation design. Through systematic design, experimentation, and evaluation, the research not only confirmed the feasibility of this integration strategy but also provided a new paradigm and empirical evidence for the synergistic development of regional cultural heritage and ecological landscape construction.

Findings demonstrated that through systematic deconstruction and reconfiguration of silk cultural symbols, landscape installations can serve as effective new carriers of regional cultural transmission. The experimental group scored significantly higher than the control group in the dimension of cultural imagery expression, indicating that culturally integrated designs with clear thematic intent can effectively enhance the uniqueness and cultural connotation of landscapes, thereby strengthening public cultural identity [12,13]. Regarding ecological adaptability, the study confirmed that any form of construction inevitably causes short-term disturbance to wetland ecosystems. Although short-term impacts between the experimental and control groups did not differ considerably, this result underscores the long-term value of prioritizing eco-friendly materials and preserving ecological corridors at the design stage. The study thus verified the feasibility of

reconciling cultural expression and ecological conservation in landscape design, offering a valuable reference for sustainable wetland development.

Furthermore, the research highlighted that exemplary design can unify functionality, aesthetic value, and visitor experience. The experimental installations not only excelled in aesthetic artistry but also significantly enhanced visitors' physical comfort and dwell time through ergonomic design. This result demonstrates that embedding cultural narratives can empower functional design, creating more engaging and participatory public spaces [14,15]. By conducting LCCA, this study challenged traditional perceptions, showing that although culturally and technologically innovative designs may require high initial investments, their use of durable, low-maintenance materials can markedly reduce long-term operational costs, yielding superior economic benefits over the full life cycle.

Despite its positive outcomes, this study has several limitations. First, it focused primarily on the Chaohu Wetland Park, and its conclusions require contextual adaptation for wetlands with differing climatic and geographic conditions. Second, ecological monitoring was short-term and did not fully capture the installations' long-term ecological effects. Finally, the depth of cultural expression and richness of interactive experiences still leave room for improvement. Looking ahead, we recommend further research in the following areas: employing technologies such as virtual reality and digital twins to create immersive interactive scenes of silk culture, thereby expanding the depth and reach of cultural communication; establishing long-term ecological monitoring systems to investigate the co-evolution of landscape installations and wetland ecosystems; developing biocompatible materials that are degradable or promote plant growth; exploring modular and detachable structural designs to facilitate maintenance and upgrading; and integrating advanced technologies such as 3D printing and parametric design to achieve customized, precision-manufactured installations with improved efficiency and quality.

In summary, this study provides a clear conceptual framework and scientifically grounded evaluation methods for creatively revitalizing and transmitting regional culture while respecting natural ecosystems. It holds remarkable theoretical and practical implications for guiding future cultural landscape design toward greater depth and sustainability.

Author Contributions

Dexin Huang and Ying Yang designed the study; all authors conducted the study; Dexin Huang and Ting Wang collected and analyzed the data. Ting Wang and Ying Yang participated in drafting the manuscript, and all

authors contributed to critical revision of the manuscript for important intellectual content. All authors gave final approval of the version to be published. All authors participated fully in the work, took public responsibility for appropriate portions of the content, and agreed to be accountable for all aspects of the work in ensuring that questions related to the accuracy or completeness of any part of the work were appropriately investigated and resolved.

Conflict of Interest

The authors declare no conflict of interest.

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Availability of Data and Materials

The datasets used and/or analysed during the current study were available from the corresponding author on reasonable request.

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Not applicable.

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