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Article

Study on the enhancement of ecosystem service function and sustainability planning of landscape gardening based on biomechanics

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Abstract: With the acceleration of urbanization and the impact of climate change, landscape gardening plays an increasingly important role in improving urban ecological environments, enhancing biodiversity and improving ecological service functions. Based on the principle of biomechanics, this paper discusses the strategy of enhancing the ecosystem service function of landscape gardening and proposes to optimize the sustainability of landscape gardening by means of multi-scale planning frameworks, ecological corridor construction, and microclimate regulation techniques. Through the implementation of biomechanical optimization practices in the study area, in this study, multiple technical methods were used for data collection to ensure the accuracy and reliability of the data. For monitoring plant growth, a regular sampling method was adopted to measure growth parameters (such as plant height, crown width, root depth, etc.) of plants in the study area on a monthly basis. In addition, high-precision meteorological monitoring equipment (such as temperature and humidity meters, anemometers, etc.) was used for continuous monitoring of microclimate conditions, with a data collection time span of one year, covering seasonal changes. Soil stability assessment quantifies soil stability and water management capacity through regular sampling of different soil types, using soil shear tests and water retention capacity tests. All data were processed using statistical analysis methods and combined with model simulations to validate the effectiveness of optimization strategies, ensuring the scientific and reproducible nature of research results. It was found that the optimization of vegetation configuration, soil structure and water flow management could significantly improve soil and water conservation capacity, wind speed regulation and microclimate regulation. The high density of vegetation not only enhanced the soil water retention capacity but also effectively reduced the wind speed and improved the local climate environment. In addition, the construction of ecological corridors and reasonable vegetation layout enhances the ecological connectivity and stability of the landscape. By evaluating the sustainability under different seasons, this paper further discusses how to dynamically optimize the landscape according to seasonal changes to ensure the stability of its long-term ecological service function.

Keywords: biomechanics; landscaping; ecosystem services; sustainability planning; plant growth

1. Introduction

With global climate change and the intensification of urbanization, the role of landscape gardening in enhancing urban ecological functions, improving environmental quality, and enhancing biodiversity has been increasingly emphasized. Recent studies, such as those by Ennaji et al. [1] and Ouakhir [2], have explored the application of biomechanical principles in landscape planning, demonstrating their potential in optimizing plant growth, improving soil stability, and enhancing ecological resilience under varying environmental conditions [1].

These studies highlight the increasing importance of integrating biomechanical insights into landscape design to ensure long-term ecological sustainability. The ecosystem service functions of landscape gardening include air purification, water conservation, microclimate regulation, and noise barriers, which are essential for the sustainable development of human society. However, with the rapid advance of urbanization, landscape gardening is facing problems such as soil degradation, biodiversity reduction and water stress, etc. How to effectively enhance the ecological function of landscape gardening has become an important issue in the field of ecological design at present.

Biomechanics, as a discipline that studies the interactions between organisms and the environment, provides new perspectives and methods for the ecological design of landscapes. Analyzing the interactions among plants, soil and water bodies through biomechanical models can help designers optimize landscape design and improve the stability and service function of ecosystems. Especially in landscape architecture, the growth of plants, the distribution of root systems, the water retention capacity of soil and the management of water flow are all closely related to biomechanics [2].

Therefore, the enhancement of ecosystem service function and sustainability planning of landscape gardening based on the principle of biomechanics not only has important theoretical value but also has far-reaching practical significance. This study will explore how to optimize the design of a landscape garden through biomechanics, enhance its ecosystem service function, and propose specific methods for sustainability planning [3].

2. Relationship between biomechanics and landscaping

2.1. Plant mechanics

Plant mechanics studies the mechanical interactions between plants and their growing environment, with particular attention to how plant structures are mechanically adjusted to promote their growth and stability under different environmental conditions. In landscape design, the mechanical properties of the plant’s root system, stem, leaves and other structures determine its adaptability to the environment and ecological function. The distribution of the root system in the soil not only affects the plant’s ability to absorb water and nutrients but also improves the stability and water retention of the soil. For example, deep-rooted plants can effectively reduce water evaporation by penetrating deeper into the water and nutrient layers of the soil, thus enhancing the adaptive capacity of landscaping under drought conditions. Calculating the growth depth and distribution of plant roots through mechanical modeling helps to select appropriate plant species in the design, thus enhancing the soil and water conservation capacity of the ecosystem.

Taking the effects of different soil types on plant root growth as an example, the root systems of pine, oak and wolfberry showed different growth patterns and water retention capacities in different soils. As shown in **Table 1**, the root system of a pine tree grows deeper in sandy soil, but its water retention capacity is lower, only 15%; while an oak tree grows more stably in clay soil, the root system penetrates deeper into the soil, and the water retention capacity reaches 35%, which indicates that in the area of high water demand, selecting plants with deep root systems and higher water retention capacity helps to improve the soil water conditions and enhance the ecological stability of the garden landscape.

Table 1. Comparison of mechanical properties and water retention capacity of plant roots.

Plant species	**Root depth (m)**	**Soil type**	**Moisture retention capacity (%)**
pines	2.5	sandy soil	15
oaks	3.0	loam	35
wolfberry (Lycium chinense)	1.8	sandy soil	25

In addition, the mechanical properties of plant stems and branches are critical to the stability and wind resistance of a landscape. By analyzing the changes in plant stresses under wind, designers can choose appropriate plant configurations and layouts to enhance the wind resistance of the landscape. In sandy soils, pine trees have deep and fine root systems that are adapted to arid environments, but their water retention capacity is weak, whereas oaks are able to effectively retain a higher level of water in clay soils through a more developed root structure. Through biomechanical analysis, plant configurations can be optimized to achieve the best balance between mechanical and ecological functions.

2.2. Soil mechanics and hydraulics

Soil mechanics and hydraulics are important factors affecting the stability of landscape ecosystems, which center on how interactions between soil particles affect water transport and soil structure stability. In landscape design, the soil's carrying capacity, water permeability and water retention ability determine the stability of plant growth, while the hydraulic characteristics affect the recycling and infiltration ability of water resources. The size of soil particles and their distribution directly determine the water permeability and water retention capacity of soil. For example, clay soils have poor water permeability but high water retention capacity due to small particle size and low porosity, while sandy soils have large porosity and high permeability but low water retention capacity (see **Table 2**). These types of soil mechanical properties have a key role in landscaping, affecting drainage design, vegetation configuration, and water management.

Table 2. Comparison of physical properties of different soil types.

Soil type	**Particle diameter (mm)**	**Porosity (%)**	**Permeability coefficient K (cm/s)**	**Cohesion$c$ (kPa)**	**Angle of internal frictionϕ (°)**
sandy soil	0.2–2.0	35	1.2×10^{-2}	5	30
loam	0.02–0.2	45	4.8×10^{-3}	10	28
loam	<0.002	50	1.1×10^{-4}	25	22

In different soil types, the water transport mechanism follows Darcy's law, which is expressed mathematically as:

$$q = -K\frac{dh}{dz} \tag{1}$$

where q is the volume of water flow per unit time, K is the soil infiltration coefficient, h is the height of the head, and z is the depth in the vertical direction. This equation shows that the infiltration capacity of soil depends on the infiltration coefficient K, while K is strongly influenced by soil porosity and particle size. For example, in sandy soils, a higher value of K results in faster water infiltration, while in clay soils, a lower value of K results in slower water infiltration. Soil permeability is critical in landscape drainage systems, especially in areas with high rainfall, where highly permeable soils are needed to reduce surface runoff and thus prevent erosion and ponding [3].

In addition to permeability, the shear strength of the soil is a key factor in landscape stability. Soil shear strength is determined by Coulomb's law:

$$\tau = c + \sigma \tan \phi \tag{2}$$

where τ is the shear strength, c is the cohesion, σ is the positive stress, and ϕ is the angle of internal friction. The shear strength of different soil types directly affects the wind resistance of vegetation and slope stability. For example, in landscaping, clay soils with higher cohesion are suitable for stabilizing steep slopes, while sandy soils with lower cohesion need to be combined with vegetation or slope protection measures to improve stability.

In addition, the movement of water in the soil is also affected by gravitational potential energy and capillary action, leading to significant differences in the distribution of water at different depths in different soil types (see **Figure 1**). In sandy soils, moisture mainly relies on gravity infiltration and is distributed more uniformly, while in clay soils, due to stronger capillary action, moisture is mostly concentrated in the surface layer, leading to dryness in the deeper layers. By reasonably planning the soil hierarchy, water distribution can be optimized and the water use efficiency of garden vegetation can be improved, thus enhancing the sustainability of the landscape [4].

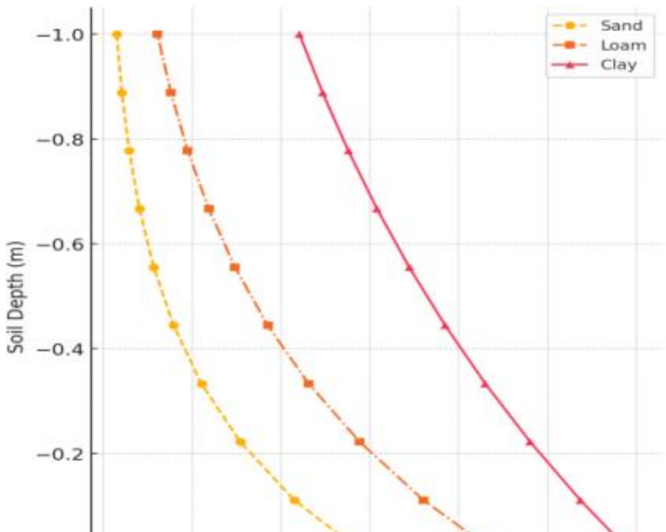

Figure 1. Schematic diagram of water distribution and infiltration paths in different soil types.

In practical application, soil mechanics and hydraulics analyses help optimize the soil structure of landscapes, improve plant survival rates, and reduce the risk of soil erosion. For example, in the design of wetland parks or rain gardens, the rational allocation of highly permeable soils can effectively reduce surface runoff, while in the design of slopes or windbreaks, priority should be given to the selection of soils with high shear strength to enhance the long-term stability of the landscape.

3. Strategies for enhancing ecosystem service function of landscape garden based on biomechanics

3.1. Optimization of plant community structure

Structural optimization of plant communities is an important strategy based on biomechanical theory, the core of which is to construct stable plant communities with reasonable mechanical distribution through the analysis of mechanical interaction and growth adaptability between individual plants. In landscape gardening, the growth pattern, root structure, branch and leaf distribution of plants and their response to wind load all affect the stability and spatial configuration of the community. Through biomechanical modeling, the competitive relationship between plants can be quantified, and the planting spacing and tier distribution of different species can be optimized to maintain the best growth condition in the natural environment [5]. The root morphology of different plants determines their ability to modify the soil structure; e.g., deep-rooted species help to enhance soil stability, while shallow-rooted plants are more suitable for covering the surface soil and reducing water evaporation.

Wind loading effect is a key factor in the process of plant community optimization. The stability of plants under wind pressure can be calculated by the mechanical formula, which takes into account factors like plant morphology and soil characteristics. In practical applications, such as urban parks or coastal landscapes, plants with low wind resistance, such as shallow-rooted shrubs, should be selected to reduce the risk of plant uprooting during high winds. Additionally, vegetation arrangement strategies can optimize the distribution of wind forces across the landscape, further enhancing the wind resistance of plant communities, which is mainly affected by the parameters of wind speed V, canopy area A and air density ρ. According to the wind force formula [6]:

$$F_w = \frac{1}{2}\rho C_d A V^2 \tag{3}$$

where F_w is the wind loading force and C_d is the resistance coefficient, and plants with different morphologies have different resistance coefficients. In high wind speed areas, tree species with low resistance coefficients should be selected when optimizing the community to reduce the wind shear force effect and improve the overall wind stability (see **Table 3**).

Table 3. Comparison of resistance coefficients for different plant root types and wind loads.

Plant species	Root system type	primary role	wind resistance factor C_d
various trees of genus Populus	deep-rooted (e.g., plant)	Improved soil stability	0.32
elm	shallow rooted	Reduced evaporation of surface water	0.41
camphor	composite root system	Balancing soil stabilization and water regulation	0.36

In addition, the branch and leaf distribution of plants also affects the overall wind resistance. While a dense leaf structure can enhance microclimate regulation, excessive wind resistance may lead to tilting or even collapse of the tree. Therefore, in the optimization process, by adjusting the spatial spacing between trees, hierarchical distribution and tree species matching, the impact of wind load can be balanced so that the overall force of the community is uniform.

In addition to wind load optimization, the height gradient distribution of plant communities is also a key factor influencing ecosystem stability. Tall trees can reduce surface wind speed while providing a suitable microclimate environment for the lower vegetation, while mid-level shrubs and groundcovers can optimize water use efficiency and reduce soil loss [7]. **Figure 2** shows an optimized gradient distribution strategy, which is mainly adjusted by hierarchical structuring to improve the mechanical stability of the community and ensure the growing space for different levels of vegetation (**Figure 2**).

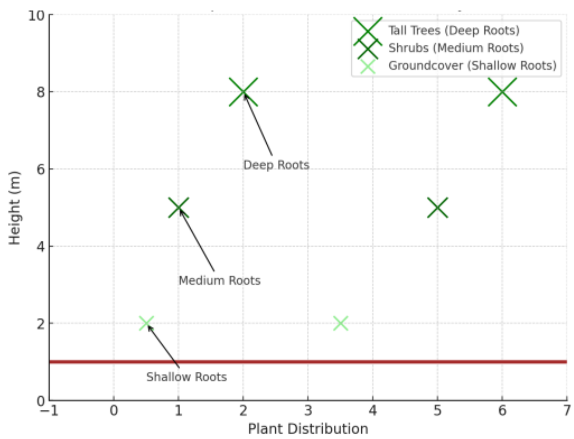

Figure 2. Schematic diagram of plant community gradient distribution based on biomechanical optimization.

Through the analysis method of biomechanics, the spacing, layer distribution and wind load adaptability of plant communities can be reasonably adjusted to ensure the stability and growth coordination among plants.

3.2. Improved spatial layout of the landscape

The optimization of landscape spatial layout involves the application of biomechanical principles at different scales, the core of which is to regulate the spatial structure through mechanical analysis so as to make the landscape reach the optimal state in terms of stability, aerodynamic characteristics and water flow management. The biomechanical perspective emphasizes the mechanical interactions between plant communities and the environment, such as wind field optimization, topographic influence, soil carrying capacity, and water flow path design, which determine the overall spatial layout of the landscape. In high wind speed areas, the configuration of trees, shrubs and terrain should follow the aerodynamic laws to reduce wind shear and vortex effects so that the airflow within the landscape is evenly distributed [8]. Based on the hydrodynamic equations, the attenuation of wind speed V behind an obstacle can be expressed by the following equation:

$$V_d = V_0 e^{-\alpha d} \tag{4}$$

where V_d is the wind speed in the downwind direction at a distance of d, V_0 is the initial wind speed in the upwind direction, and α is the attenuation coefficient related to vegetation density (see **Table 4**). In landscape design, the model can be used to adjust the arrangement of trees and terrain to make the wind field more stable and reduce unnecessary wind erosion.

Table 4. Physical parameters of different vegetation densities and surface materials.

Parameter type	variable symbol	high density vegetation area	low density vegetation area	non-vegetated area
Wind speed attenuation factor	α	0.7	0.4	0.1
roughness coefficient of water flow	n	0.025	0.035	0.012

Water flow management is an equally important aspect of landscape layout optimization. Hydraulic models can be used to optimize stormwater runoff paths through the landscape, thereby reducing erosion and increasing water use. Based on Manning's formula, the surface water flow rate v is influenced by slope S and roughness n and can be calculated by the following equation:

$$v = \frac{1}{n} R^{2/3} S^{1/2} \tag{5}$$

where R is the hydraulic radius and n depends on the surface material. In landscape design, rational selection of surface materials and adjustment of slopes can optimize water flow paths for both effective drainage and reduced erosion impacts. **Figure 3** demonstrates the effect of different surface materials on water flow velocities, where the lowest water flow velocities were observed on vegetation-covered surfaces and the highest on bare surfaces, indicating the critical role of vegetation in mitigating water scour.

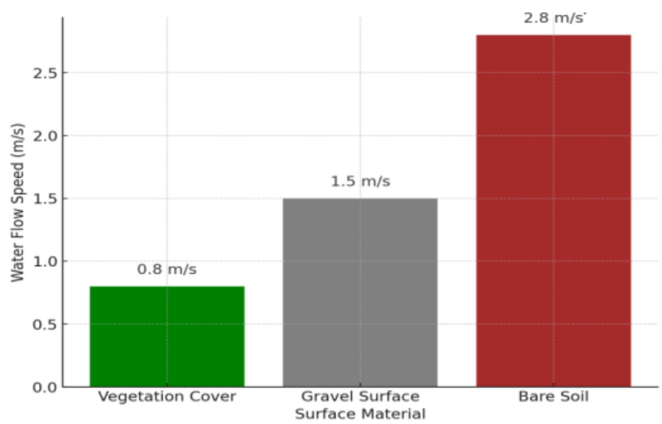

Figure 3. Effect of different surface materials on water flow rate.

In specific landscape spatial layout design, optimization methods based on biomechanics can effectively improve the stability of the wind environment and reduce the impact of surface runoff on the ecosystem. By adjusting the density of vegetation and topographic patterns, airflow patterns can be optimized at different scales, while reducing the erosive effects of wind and water flow on the surface.

3.3. Ecological corridor construction methods

The role of ecological corridors in landscape systems is similar to that of mechanical support structures, and their core function is to form a stable circulation network for biological populations, air flow and hydrological circulation through optimized vegetation configuration, terrain adjustment and wind field control. The optimization of the corridor structure involves hydrodynamics, terrain mechanics and vegetation structure stability, in which the support of the plant root system directly affects the durability and stability of the corridor. The contribution of the plant root system to soil shear strength can be calculated by the following equation:

$$S_t = S_0 + kR_d \quad (6)$$

where S_t indicates the soil shear strength after root enhancement, S_0 is the base shear strength without roots, R_d is the root density, and$k$is the soil-root binding coefficient (see **Table 5**). The high density of deep-rooted plants can significantly improve the stability of corridor soil; therefore, when constructing ecological corridors, deep-rooted plants should be reasonably allocated to improve the shear strength [9].

Table 5. Relationship between root density and soil shear strength in different vegetation types.

Plant species	**Root density R_d (kg/m³)**	**Soil-root binding coefficient$k$ (kPa-m³/kg)**	**Shear strength increment S_t-S_0 (kPa)**
pines	45	0.8	36
willow tree	30	1.2	36
elm	20	0.9	18

From the perspective of fluid dynamics, optimization of wind speed and airflow is the key to corridor function enhancement. Landscape optimization methods based on fluid dynamics can reduce the turbulence effect through vegetation configuration and make the airflow inside the corridor more uniform. The distribution of wind speed in the ecological corridor follows the fluid continuity equation:

$$A_1V_1 = A_2V_2 \quad (7)$$

Among them, A_1 and A_2 represent the cross-section area of the entrance and exit of the corridor respectively, and V_1 and V_2 represent the corresponding wind speed. In order to optimize the wind environment of the ecological corridor, a suitable cross-section ratio should be ensured so that the wind speed is evenly distributed to avoid the formation of strong or dead wind areas.

Hydrological characteristics are also important factors in the optimal design of ecological corridors. The movement of water in the corridor is influenced by the slope of the terrain and vegetation, and its velocity can be calculated by the slope influence equation:

$$v = CS^{0.5} \tag{8}$$

where v is the water flow velocity, S is the slope, and C is the flow coefficient (depending on the vegetation density and surface roughness). In the design of ecological corridors, it is necessary to adjust the topography and vegetation configuration so that the water flow is evenly distributed in the corridor to prevent excessive scouring of the soil while maintaining the stability of the water supply [10]. Reasonable corridor slope and vegetation cover can effectively control the rate of water flow and ensure the efficient circulation of water resources in the landscape system.

Through biomechanics-based optimization methods for ecological corridors, the connectivity and functionality of the corridors in the landscape system can be improved by ensuring the stability of the vegetation structure while improving air circulation and water management. The structural design of ecological corridors needs to incorporate soil mechanics, fluid dynamics and vegetation growth mechanics simultaneously to ensure long-term stability and efficiency.

3.4. Microclimate control technologies

The core of microclimate control technology lies in the use of biomechanical principles to optimize the spatial layout of landscape elements so that environmental parameters such as wind speed, temperature and humidity, and radiation transmission can reach a stable state, thus realizing the active regulation of local climate. The microclimate characteristics of the landscape are mainly affected by aerodynamics, thermodynamics and water vapor transmission mechanisms, in which the spatial distribution of vegetation, canopy structure and the choice of surface materials are crucial to the regulation of the microclimate. For example, wind speed control is a key factor in microclimate optimization, and the wind-blocking effect of vegetation can be described by the Darcy-Forkheimer equation:

$$V = V_0 e^{-\beta x} \tag{9}$$

where V is wind speed, V_0 is initial wind speed, x is vegetation blocking distance, and β is vegetation density influence factor. Reasonable configuration of trees, shrubs and ground cover plants can effectively reduce the wind speed, optimize the heat exchange process, and form a stable wind environment inside the landscape.

In addition to wind field regulation, thermodynamic optimization plays a decisive role in microclimate regulation. Surface heat transport is influenced by the heat capacity and thermal conductivity of materials, and the absorption and reflectivity of short- and long-wave radiation by different materials determines the surface temperature. The surface temperature can be calculated by the Stefan Boltzmann law T_s:

$$Q = \sigma \varepsilon T_s^4 \tag{10}$$

where Q is the surface radiant heat flux, σ is the Stephen Boltzmann constant, and ε is the material emissivity (see **Table 6**). High emissivity materials can effectively absorb heat, while low emissivity materials reduce heat accumulation, so in landscaping, high reflectivity paving and low emissivity vegetation can be combined to form a thermal equalization system to reduce extreme temperature fluctuations.

Table 6. Comparison of physical parameters of different vegetation types and surface materials.

Parameter type	variable symbol	high density vegetation area	low density vegetation area	Non-vegetated areas (hard surfaces)
Wind speed attenuation factor	β	0.8	0.5	0.1
surface emissivity	ε	0.95	0.85	0.30
Heat capacity (J/kg-K)	C_p	1800	1500	900

In addition, water vapor transport and transpiration are equally important aspects of microclimate optimization. The transpiration cooling effect of vegetation can be estimated by the transpiration cooling equation:

$$E = \frac{\lambda \times \Delta e}{r_a + r_s} \tag{11}$$

where E is the transpiration rate, λ is the latent heat of evaporation, Δe is the water vapor pressure difference between inside and outside the stomata, and r_a and r_s represent the aerodynamic resistance and stomatal resistance, respectively. The formula indicates that high leaf area index (LAI) vegetation can enhance the transpiration cooling effect, so trees and shrubs with higher LAI should be selected in the microclimate optimization design to improve the transpiration cooling effect (see **Figure 4**).

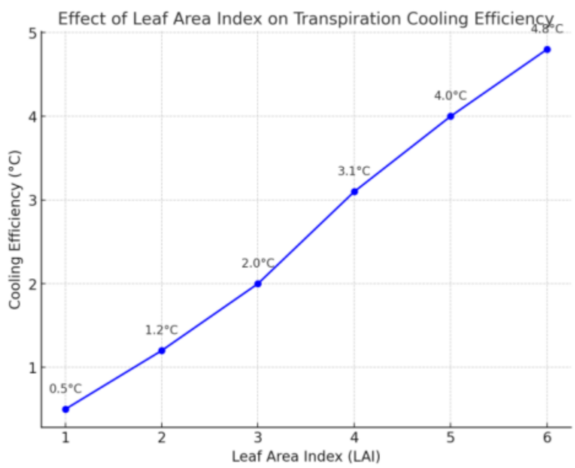

Figure 4. Comparison of transpiration cooling efficiency of different vegetation types.

By integrating wind speed regulation, thermal regulation and transpiration optimization strategies, the biomechanics-based microclimate regulation method can effectively improve the local environmental stability of the landscape so that it can maintain ecosystem balance under different climatic conditions and improve the environmental adaptability of the landscape.

4. A biomechanics-based approach to sustainability planning

4.1. Multi-scale planning framework

The biomechanics-based approach to sustainability planning emphasizes integrated planning at different scales to optimize the ecological functions of the landscape and ensure its long-term sustainability. Multi-scale planning frameworks typically include macro-regional, meso-landscape and micro-site scales, each of which involves the application of specific biomechanical principles. At the macro-regional scale, planning focuses on the stability of the overall ecosystem, including the ecological connectivity of the landscape, the rational allocation of green space systems, and the optimal use of natural resources [11]. At this scale, biomechanical models can be used to assess the wind field, water flow and temperature regulation effects in different regions to determine the optimal green space layout and vegetation types to ensure the sustainability of large-scale ecosystems.

At the mesoscopic landscape scale, the planning focuses on the functional configuration of landscape units, including the rational layout and interconnection of landscape elements. At this time, biomechanics is mainly applied to the regulation of wind power, soil improvement, and the hydrological cycle, and the contribution of plant roots to soil stability and water retention capacity is analyzed through the mechanical model so as to optimize the vegetation configuration of different landscape units in order to enhance the wind resistance, the resistance to the scouring capacity of the water flow, and the efficiency of water resources utilization in the landscape.

At the micro-site scale, the planning focus shifts to the design of specific garden facilities and local microclimate regulation. At this time, the layout of plants, the relationship between vegetation and water bodies, and the stability of soil structure are optimized through careful biomechanical analysis [12]. Based on the principle of microclimate regulation, the canopy morphology, plant community configuration, and ground materials can be adjusted to improve the local distribution of temperature, humidity, and wind speed so as to improve the appropriateness of the plant growth environment and ecological service function.

4.2. Ecosystem services assessment and optimization

Assessing the interactions of various ecological elements in a landscape through biomechanical modeling can quantify how factors such as vegetation, soil, wind speed, and water flow work together to provide important ecological services such as hydrologic regulation, climate regulation, soil conservation, and biodiversity protection. For example, the root systems of plants are mechanically important for soil stability and water retention, factors that are directly related to the soil and water conservation capacity and wind resistance of a landscape. Therefore, understanding and assessing these biomechanical properties is fundamental to optimizing ecological service functions in landscape planning.

In the process of ecosystem service optimization, the application of biomechanics can effectively enhance various functions of the landscape. For example, appropriate plant configurations can not only increase the shear strength of soil, but also improve the permeability of water flow. The root systems of plant communities provide stronger hydrological regulation of the landscape by reducing soil erosion and increasing water retention capacity [13]. As shown in **Table 7**, with the increase of vegetation density, the water retention capacity and wind resistance significantly increased, indicating that the rational layout of vegetation can effectively improve the stability of the landscape under the influence of wind and water flow.

Table 7. Effect of different vegetation densities on water retention capacity and wind resistance.

vegetation density	Moisture retention capacity (%)	Wind resistance (m/s)
lower (one's head)	20	5
center	35	3.5
your (honorific)	50	2

In the specific optimization method, using the analysis of biomechanics, the landscape design can be adjusted at different scales, from the structure of vegetation layers to the selection of soil types to the design of water flow paths, to comprehensively improve the ecological service function. Especially in microclimate regulation, by adjusting the canopy morphology, root depth, and surface cover materials, the local climate can be effectively controlled, the temperature and humidity distribution can be optimized, and the vegetation growth environment can be improved (see **Figure 5**).

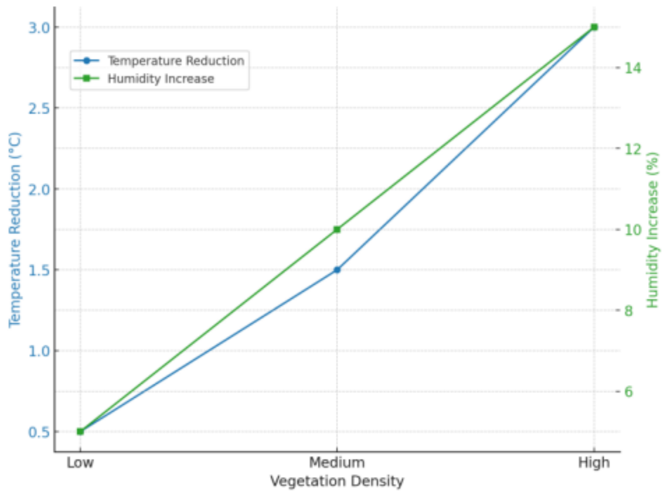

Figure 5. Effect of different vegetation configurations on local climate regulation.

5. Practical application and effectiveness evaluation

5.1. Implementation of biomechanical optimization practices in the study area

In order to verify the effectiveness of the biomechanics-based landscape optimization strategy, a representative urban park located in the central area of the city was selected for the case study. The research methodology involved systematic data collection through a combination of remote sensing analysis and field surveys.

Vegetation configurations, soil properties, and microclimate conditions were monitored over a 12-month period, covering seasonal variations. The data collected were analyzed using statistical methods to assess changes in soil stability, water retention capacity, and plant growth rates. Additionally, plant survival rates under different biomechanical optimization configurations were compared, with a focus on the impact of vegetation density and root system depth on ecosystem service functions [14].

First, the vegetation configuration of the entire park was analyzed at the macro-regional scale by means of a biomechanical model, focusing on optimizing the vegetation cover and landscape structure. Through the calculation of wind speed, water flow paths and temperature and humidity distribution, the areas in the park that need to be covered with more greenery were identified in order to improve the overall hydrological regulation ability and wind resistance, and to reduce the local heat island effect. In addition, at the mesoscopic landscape scale, the focus was on optimizing the vegetation community structure within the park, with deep-rooted plants and high-density vegetation configurations to improve water retention capacity and soil stability, and to reduce soil erosion and wind erosion.

At the micro-site scale, the plant layout of the specific area has been adjusted through biomechanical optimization, and plant species with a high leaf area index have been added to enhance the transpiration cooling effect. The design of the area also pays special attention to the interaction between canopy morphology and wind speed to ensure that the vegetation configuration can both effectively control wind speed and improve local climatic conditions without affecting ventilation.

The selection of the study area and the design of specific implementation strategies fully consider the multifunctionality of the park landscape to ensure the enhancement and optimization of all ecological service functions. Through this practice, the contribution of biomechanics-based optimization methods to the ecosystem service functions of parks at different scales can be comprehensively assessed, providing a theoretical and practical basis for the design of future landscapes.

5.2. Evaluation of the effectiveness of the practice

5.2.1. Plant growth and stability

The assessment of plant growth and stability is one of the most important indicators of the effectiveness of optimization strategies in the practice of the study area. By regularly monitoring plant growth, we assessed the adaptability and stability of vegetation under varied environmental conditions, ensuring that the results contributed to understanding plant resilience in diverse landscapes. To achieve this assessment, we selected several typical plants, namely trees, shrubs and ground covers, and recorded and analyzed their growth parameters (e.g., height, crown width, root distribution, etc.) [15]. By incorporating biomechanical modeling, we focused on analyzing the effect of vegetation root system stability on plant growth.

By regularly measuring plant growth in the experimental area (shown in **Table 8**), we found that the growth rate of plants in the optimized area was generally faster, especially in the area where soil stability was significantly improved, and the root growth of plants was more robust, thus increasing overall plant stability [16]. The improved shear strength of the soil significantly reduced the interference of wind and water currents on the plants, and increased the ability of the vegetation to grow and resist toppling under extreme climatic conditions. Especially in the configuration area of deep-rooted plants, the root growth depth showed a positive correlation with vegetation stability, further verifying the positive effect of biomechanical optimization on plant growth.

Table 8. Comparison of plant growth parameters in different vegetation zones.

vegetation area	Plant height increase (cm)	Root depth (cm)	Increase in soil shear strength (%)	Reduction of wind speed effect (%)
Optimized areas (high density vegetation)	30	50	40	30
Non-optimized areas (low density vegetation)	20	35	10	15

In addition, **Figure 6** demonstrates the relationship between the distribution of plant roots and the growth condition. By comparing the depth of the root system with the height of the plant, it can be seen that the more developed the root system is, the more stable the growth condition is; especially in the area of high wind speed, the deep-rooted plants show stronger wind resistance and growth resilience [17].

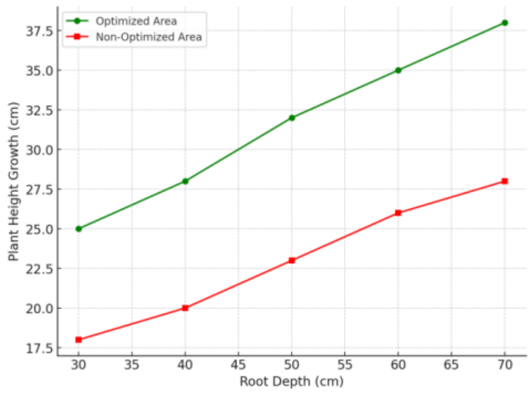

Figure 6. Relationship between plant root depth and plant height.

5.2.2. Soil and water management

The effectiveness of soil and water management practices in the selected study area is an important indicator for assessing the sustainability of the ecological landscape. To ensure the stability of plant growth and enhance ecosystem services, we conducted a detailed analysis of soil water retention capacity, infiltration and water flow distribution [18]. By measuring soil moisture, infiltration rates, and water flow paths in different vegetation zones, we were able to assess the water management capacity of the soil more comprehensively. In particular, by monitoring soil moisture after rainfall, we analyzed the effects of different soil types on water retention and combined them with biomechanical optimization measures to regulate water flow paths and thus reduce soil erosion.

In practice, two typical soil types, sandy and loamy soils, were selected to study their water retention capacity under different vegetation configurations. As shown in

Table 9, by comparing the water permeability of different areas, it was found that sandy soils had higher water permeability but poorer water retention capacity, while loamy soils could significantly improve water retention capacity under higher vegetation density. By optimizing the soil structure and vegetation configuration, the water management effect of the landscape was improved.

Table 9. Water retention capacity of different soil types under different vegetation cover.

Soil type	vegetation density	Moisture retention capacity (%)	Permeation rate (cm/h)
sandy soil	lower (one's head)	10	4.5
	your (honorific)	20	8.2
loam	lower (one's head)	25	3.2
	your (honorific)	45	5.6

In addition, **Figure 7** shows the water distribution of different soil types when water flows through different vegetation cover areas. It can be seen that soil type is closely related to the density of vegetation cover, and areas with dense vegetation can effectively slow down water flow and promote water infiltration and retention, thus enhancing the soil's water management capacity.

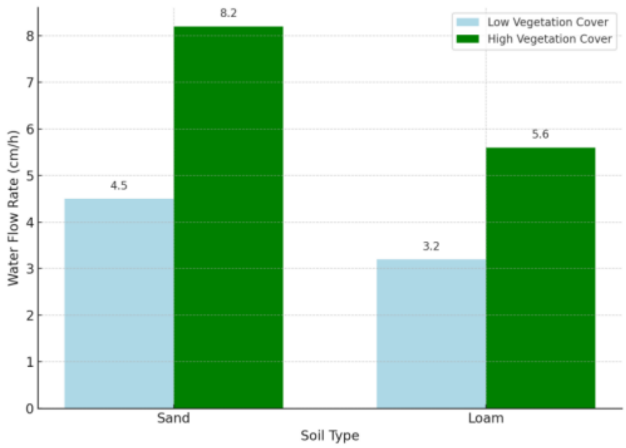

Figure 7. Distribution of water flow under different soil types and vegetation cover.

Through the comprehensive assessment of soil and water management, we found that biomechanical optimization not only helps to enhance the water retention capacity of soil but also effectively regulates water flow paths, reduces soil erosion, and improves the efficiency of water resource utilization. This optimization process demonstrates significant ecological benefits in practical applications and provides strong support for further landscape sustainability planning.

5.2.3. Increased ecosystem service functioning

To assess the impact of biomechanical optimization measures on ecosystem function, we focused on improvements in plant growth, soil moisture retention, wind speed regulation and hydrological cycle. Through long-term monitoring in different areas, we collected data on vegetation growth rate, soil moisture, and wind resistance, which provided quantitative support for ecosystem service enhancement.

Firstly, the assessment of plant growth and stability aspects showed that plants in the optimized areas grew faster, especially in the areas optimized for high vegetation density and root depth. By comparing the growth parameters of different vegetation areas (see **Table 10**), we found that plants in areas with high vegetation densities grew healthier and had better root development, which effectively improved the stability and wind resistance of the vegetation. In addition, soil moisture and wind resistance were also significantly improved. Through the application of biomechanical optimization measures, the soil shear strength is improved, the fixation of the vegetation root system on the soil is enhanced, the impact of wind on plants is reduced, and the overall stability of the landscape is enhanced.

Table 10. Relationship between different vegetation densities and soil and water conservation capacity.

vegetation density	Moisture retention capacity (%)	Root depth (cm)	Increase in soil shear strength (%)
low vegetation cover	15	25	12
Medium vegetation cover	35	40	30
High vegetation cover	50	55	45

The above data show that the soil and water conservation capacity of high-density vegetation areas is significantly enhanced. Especially in the soil moisture monitoring after precipitation, the area with higher vegetation cover can effectively reduce water evaporation and increase the depth of water penetration, which is conducive to the management of water resources and plant growth. With the implementation of biomechanical optimization measures, the ecosystem service function of the landscape was significantly improved.

5.3. Continuity assessment and optimization

In the process of continuity assessment and optimization, mainly through long-term ecological monitoring of the optimized area, we collected several data, including soil moisture, vegetation growth, wind speed change and microclimate effect, etc. Based on these data, we assessed, identified and optimized potential problem areas. To ensure the stability of the landscape and the long-term effectiveness of the ecological service functions, the ongoing assessment of biomechanical optimization relies not only on regular data monitoring, but also on adjusting the landscape structure to cope with changing environmental conditions.

The relationship between soil moisture and vegetation growth is what we focus on during the assessment process. By continuously monitoring soil moisture and vegetation growth (see **Table 11**), we can effectively assess the effectiveness of water management strategies to ensure that water retention capacity remains stable between seasons. In addition, the effect of wind speed changes on vegetation stability is also included in the continuity assessment. By analyzing the effects of wind speed on plant root depth, branch and leaf distribution through biomechanical models, we can predict the growth performance of plants under extreme climatic conditions and provide theoretical support for subsequent optimization.

Table 11. Relationship between soil moisture and plant growth under different seasons.

pneumococcal	Soil moisture (%)	Plant height increase (cm)	Impact of wind speed (%)
springtime	30	15	20
summertime	40	20	25
fall	35	18	15
winner	33	10	10

The data in **Figure 8** indicate that water retention capacity is more stable during the fall and winter seasons, but during the spring and summer seasons, high temperatures and precipitation uncertainty have a greater impact on soil moisture and plant growth, suggesting the need for better soil and water management and plant configuration adjustments during these seasons.

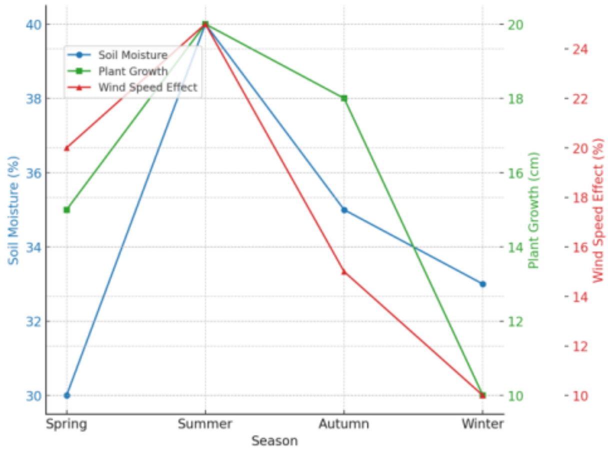

Figure 8. Effectiveness of soil and water conservation and wind speed regulation under different seasons.

Through continuous ecological monitoring and the application of biomechanical modeling, potential ecological problems are identified and the landscape design is adjusted according to seasonal changes. This data-driven, continuous assessment and optimization methodology improves the ecological service function of the landscape, as well as its ability to adapt to environmental changes, ensuring the long-term stability and sustainability of the landscape.

6. Conclusion

The application of biomechanical optimization in landscape design demonstrates its significant potential in enhancing ecosystem services. By integrating biomechanical principles into the design process, this study has shown that plant growth, soil stability, and water management can be effectively improved, contributing to more resilient and sustainable urban landscapes. The use of biomechanical models to optimize plant configurations and root systems has proven to be especially beneficial in improving soil-water retention and reducing erosion, particularly in urban parks and coastal regions.

However, the scalability of biomechanical strategies across different landscape settings remains an area for further exploration. While the strategies demonstrated substantial success in urban environments, their adaptability in diverse climates, such as arid or tropical regions, requires further validation. Future research should focus on refining biomechanical models for various plant species and soil types, with a particular emphasis on extreme climatic conditions, to ensure their broader applicability. Furthermore, the integration of advanced technologies like artificial intelligence into biomechanical optimization models holds great promise for enhancing predictive accuracy and landscape planning efficiency.

In addition, the long-term ecological impacts of biomechanical optimization on various landscape types, including wetlands, agricultural lands, and coastal zones, need to be studied in greater detail. By exploring these areas, researchers can establish a comprehensive understanding of the benefits and limitations of biomechanical approaches in diverse environmental contexts.

For policymakers and urban planners, the findings from this study offer valuable insights into creating sustainable urban green spaces. Policymakers can incorporate biomechanical principles into planning regulations, such as incentivizing the use of deep-rooted, native plant species to enhance soil stability and water retention. Urban planners can utilize these insights to optimize plant species selection, improve spatial arrangement, and design multifunctional green spaces that address urban heat islands, stormwater management, and biodiversity preservation.

Ultimately, while biomechanical optimization has shown promise in enhancing ecosystem services, continued research is essential to refine these strategies and adapt them to varying environmental and climatic conditions. The successful application of biomechanical principles to landscape design represents an innovative approach that can significantly contribute to the sustainability of urban and rural landscapes, helping to create environments that are both ecologically resilient and beneficial to human well-being.

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