

Enhancing Sustainable Urban Landscapes through AI-Driven Low-Carbon Plant Selection: A Novel Approach

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Abstract. In the face of global environmental challenges, sustainable urban landscapes play a pivotal role in mitigating carbon emissions and fostering healthier cities. This paper presents a groundbreaking approach to low-carbon plant selection for landscape architecture, leveraging AI technology to address the limitations of existing language models in the field. Through the integration of professional databases, the introduction of judgment modules, low-carbon plant landscape recommendation modules, general dialogue modules, the use of prompt engineering technology, fine-tuning technology, our system offers precise, ecologically sound recommendations for low-carbon landscape designs.

Keywords: Low carbon; Carbon neutral; Plant landscape design; Natural language processing Deep learning.

1. Introduction

Urbanization is an accelerating global phenomenon [1], with more than half of the world's population now residing in cities. This rapid urban growth brings about numerous challenges [2], including increased carbon emissions, reduced green spaces, and the degradation of urban ecosystems [3]. In the face of these challenges, sustainable urban landscapes have emerged as a critical component of addressing environmental concerns and enhancing the quality of urban life. Among the crucial elements of sustainable urban landscapes is the thoughtful selection and integration of plant species that promote carbon sequestration and biodiversity.

Low-carbon plant selection in landscape architecture has become a focal point in this endeavor, where the goal is to not only enhance the aesthetic appeal of urban spaces but also to reduce their carbon footprint. However, achieving this balance between aesthetics and environmental sustainability has been a complex task [4]. Existing solutions often rely on language models with limited domain knowledge, resulting in recommendations that lack precision and ecological considerations. To address this challenge, our research introduces a pioneering AI-driven approach to low-carbon plant selection in landscape design. We have developed a comprehensive platform that integrates data on plant characteristics, carbon sequestration potential, and ecological adaptability [5, 6]. This platform enhances the quality of urban landscapes while simultaneously reducing their carbon footprint, making it a valuable asset for landscape architects and urban planners. In this paper, we present the step-by-step development of our AI-driven low-carbon plant selection platform, highlighting the data collection and cleansing process, redefined user interactions, task modules, and testing phases. We also address the limitations of existing language models in the field and demonstrate how our approach offers precise, ecologically sound recommendations for low-carbon landscape designs. This innovative platform paves the way for environmentally responsible urban development [7] and showcases the potential of AI in revolutionizing sustainable landscape architecture.

As urbanization continues to reshape the world's landscapes, our approach offers a significant step towards harmonizing urban development with ecological sustainability. It is our hope that this research will inspire a new era of environmentally conscious landscape architecture [8] and further foster the synergy between AI technology and sustainable urban design.

2. Methodology

2.1 Data collection and integration

2.1.1. Data collection and preprocessing

In this study, the primary task is to collect data relevant to low-carbon plant landscape design in order to construct a comprehensive plant database [9]. This step involves obtaining plant information from various sources, including data on plant ecological characteristics, carbon sequestration potential, growth rates, and maturity periods. The accuracy and completeness of this data are crucial for recommending suitable low-carbon plants [10]. During the data collection process, natural language processing (NLP) techniques are employed to extract information about plants from text data from various sources [11]. This encompasses botanical literature, ecological databases, and plant-related websites. Following data collection, we perform data preprocessing to eliminate potential errors, redundancies, and inconsistencies [12]. This includes using machine learning for data cleaning, NLP techniques for entity recognition, and data standardization to identify and rectify issues, ensuring that data from different sources can seamlessly integrate into the system.

2.1.2. Calculation of plant carbon sink module

This study aims to provide carbon data support for the design of low-carbon plants by constructing a plant carbon sink data module in a database. The carbon sink module primarily evaluates the carbon sequestration performance of plants through the calculation of their carbon sink capacity. The methods employed include the photosynthetic rate method, leaf area index method, and model-based estimation method [13]. The photosynthetic rate method involves measuring the instantaneous photosynthetic rate of plants using instruments and calculating the daily carbon sequestration performance of plants through appropriate formulas. The leaf area index method uses the leaf area index of individual plants to estimate their daily carbon fixation. The model-based estimation method refers to the development of carbon fixation models based on field inventory data. In this study, we primarily utilized the National Tree Benefit Calculator model, CITYgreen model, and i-Tree model [14].

The research calculates the carbon sequestration capacity of commonly used horticultural plants using the photosynthetic rate and leaf area index methods. The model-based estimation method is used to validate and complement the calculated carbon sequestration capacity. Through the statistical analysis of common plant growth parameters such as leaf surface, tree canopy width, and tree height, this study determined the carbon sequestration performance levels of these horticultural plants. The integrated carbon sink data, linked with the plant database, was incorporated into the comprehensive database of this research.

2.1.3. Integration of comprehensive database

To achieve the objectives of low-carbon plant landscape design, this study integrates data from diverse sources to build a comprehensive plant database. The database encompasses basic plant information and data related to carbon sequestration, such as the carbon dioxide absorption capacity of different plant species. This study utilizes MySQL to store and maintain extensive plant information [15]. Additionally, we have developed custom data integration tools to process data in various formats and structures, ensuring that it can be accessed and queried consistently within a unified framework, as shown in Figure 1. The result of this step is a highly specialized plant database, providing a robust data foundation for low-carbon plant landscape design platform. This database will be a critical component in subsequent steps, particularly in the low-carbon plant recommendation module, helping users clarify design criteria and achieve sustainable urban landscape design.

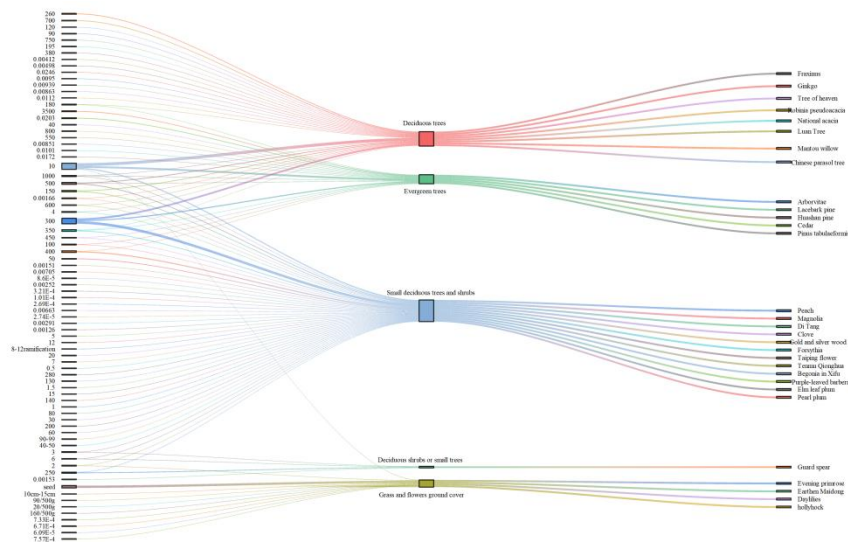


Fig. 1 Low-carbon plant landscape database. Source: Author

2.2 Redefining User Interaction and Task Logic

2.2.1. User Interaction

This section focuses on redefining how users interact with our low-carbon plant landscape design platform. This study designed the user interface to display the factory database and design tools. This study combines natural language processing and machine learning techniques to expand and enhance user requirements [16, 17]. For instance, users can specify specific conditions for plant planning, and the platform will respond with advanced task logic to assist users in designing precise low-carbon plant landscapes.

2.2.2. Logical Optimization and Fine-tuning of Tasks

This study focuses on improving the task logic and optimizing the model parameters to ensure that the platform can handle the user's plant-landscape planning and design needs in a highly professional manner. The study includes the introduction of three modules, the judging system module, the Low-carbon plant recommendation module and the general dialogue module. In this study, prompt engineering was introduced into three modules to insert standard answers and data, and the parameters of the large model were fine-tuned to ensure that users got accurate answers to the questions.

2.2.3. Low-Carbon Plant Recommendation Module

The Low-Carbon Plant Recommendation Subsystem is a core component of platform, integrating data from a professional plant database. This subsystem encompasses the following tasks:

Information Completeness Assessment: The system evaluates the design conditions provided by users to ensure completeness. If more information is required, the system interacts with the user to gather necessary details. Plant Retrieval: The system retrieves plants from the database that meet the user's specified conditions. This step combines domain expertise to ensure that the selected plants are suitable for the specific design task. Answer Generation: The system generates low-carbon plant landscape design specifications, including plant material lists, carbon sequestration performance assessments, and a summary of relevant information. This ensures that users receive comprehensive design proposals. These task modules work in synergy to provide users with professional plant

planning and design solutions, thereby promoting the development of sustainable urban landscape design.

3. Discussion

3.1 Application and effect

We have developed the Low-Carbon Plant Landscape Design Platform (LCLA CHAT) to ensure the natural aesthetics and ecological equilibrium of landscapes, as depicted in Figures 2 and 3. This study integrates AI technology with landscape architecture design to provide comprehensive recommendations for eco-friendly landscape design solutions for landscape architects. Designers can input their requirements on a web platform, such as park size, type, current project phase, and the selection of low-carbon plants. LCLA CHAT will then analyze these requirements and identify cost-effective, energy-efficient plant combinations while offering comprehensive design instructions. This synergy ensures that ecological and design principles are harmoniously integrated into the landscape planning process, ultimately benefiting sustainable landscape design.

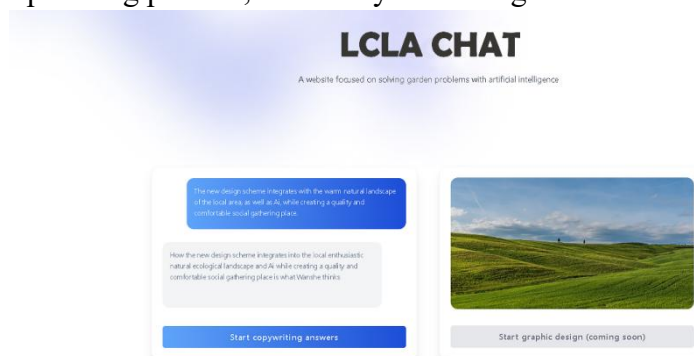


Fig. 2 Platform interactive interface. Source: Author

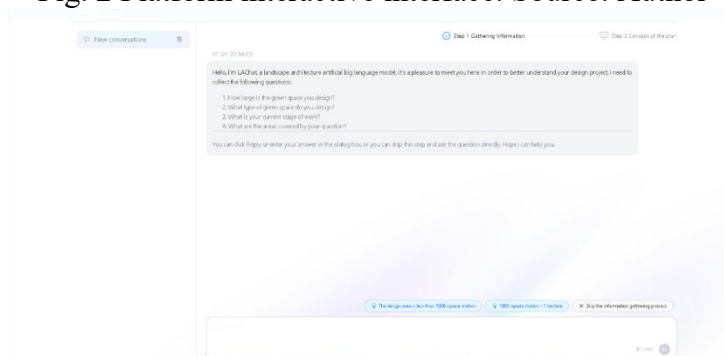


Fig. 3 Platform text interactive interface. Source: Author

3.2 Large-scale language model comparison

In order to promote the development of sustainable landscapes and maximize user satisfaction, we conducted a comparative analysis of responses from GPT and LCLA CHAT to various queries, as shown in Figure 4. Furthermore, we conducted a more in-depth analysis of their recommendations for plant arrangement and combinations. The results indicate that LCLA CHAT not only provides specific plant material lists but also offers more comprehensive suggestions. The plants chosen by LCLA CHAT align with high carbon sequestration efficiency and economic viability, further adhering to the low-carbon theme.

Regarding seasonality, in order to ensure that the park features attractive landscapes throughout all four seasons, LCLA CHAT selects plants that bloom in spring, flourish in summer, exhibit vibrant autumn foliage, and remain appealing in winter. These plants not only introduce a touch of spring to the park, attracting visitors, but also provide shade and attract butterflies and other insects.

The autumn selections, including trees like maples, ginkgos, and persimmons, infuse the park with an autumnal palette. Redwoods, hollies, and cypresses, on the other hand, retain their greenery in winter, infusing the park with a touch of vitality. LCLA CHAT offers more detailed recommendations for plant selection and combinations in intricate park design. For example, considering the seasonal characteristics of the recommended plants enhances their decorative effect in the park throughout the year. However, GPT's responses do not incorporate the seasonal attributes of plants into the design instructions.

In terms of landscape functionality and layout, to further compare the differences in plant recommendations between GPT and LCLA CHAT, we examined their responses in the context of landscape functionality and layout. Under various landscape functions and layouts, LCLA CHAT demonstrated a more detailed and thoughtful approach. For instance, in recreational areas, LCLA CHAT suggested planting large deciduous trees such as plane trees and magnolias to provide shade for visitors. In educational areas, it proposed displaying plants relevant to the industrial era, like cotton and flax, along with explanatory signs detailing their industrial applications. Importantly, due to the park's industrial theme, LCLA CHAT intricately integrated plants with industrial artifacts and structures. For example, it incorporated elements mimicking industrial-era railroad tracks, using old rails as design features and planting low shrubs or ground cover plants such as golden privet and cotoneaster on either side of the pathways. In contrast, GPT's plant combination recommendations deviated significantly from the industrial theme due to a lack of consideration for landscape functionality and layout. Therefore, LCLA CHAT's plant recommendations proved superior to GPT's. These results also demonstrate that LCLA CHAT not only considers the characteristics of the plants themselves but successfully integrates plants with the landscape functionality and layout of the park, maximizing the expression of the park's industrial theme.

Regarding carbon sequestration performance, to explore the plant combinations selected by LCLA CHAT, we conducted a comparative analysis of carbon sequestration values for the plant species chosen by GPT and LCLA CHAT. For instance, from the perspective of carbon sequestration performance, the platform introduced the basics of carbon sequestration, and LCLA CHAT's recommended plants exhibited a characteristic of high carbon sequestration. Specific data were presented in scientific notation. LCLA CHAT's plant combinations not only inherently yielded a low-carbon effect but also displayed lower carbon considerations on a spatial scale and within the park's theme. For instance, LCLA CHAT leaned towards selecting native and drought-tolerant plants, reducing energy consumption for irrigation and fertilization while promoting organic carbon storage in the soil. Furthermore, LCLA CHAT favored large deciduous trees like plane trees and magnolias, which can absorb and store significant amounts of carbon throughout their lifecycle, thus enhancing the park's carbon storage capacity. In contrast, GPT did not consider the carbon sequestration performance of the selected plants, resulting in noticeably lower carbon sequestration values compared to those chosen by LCLA CHAT.

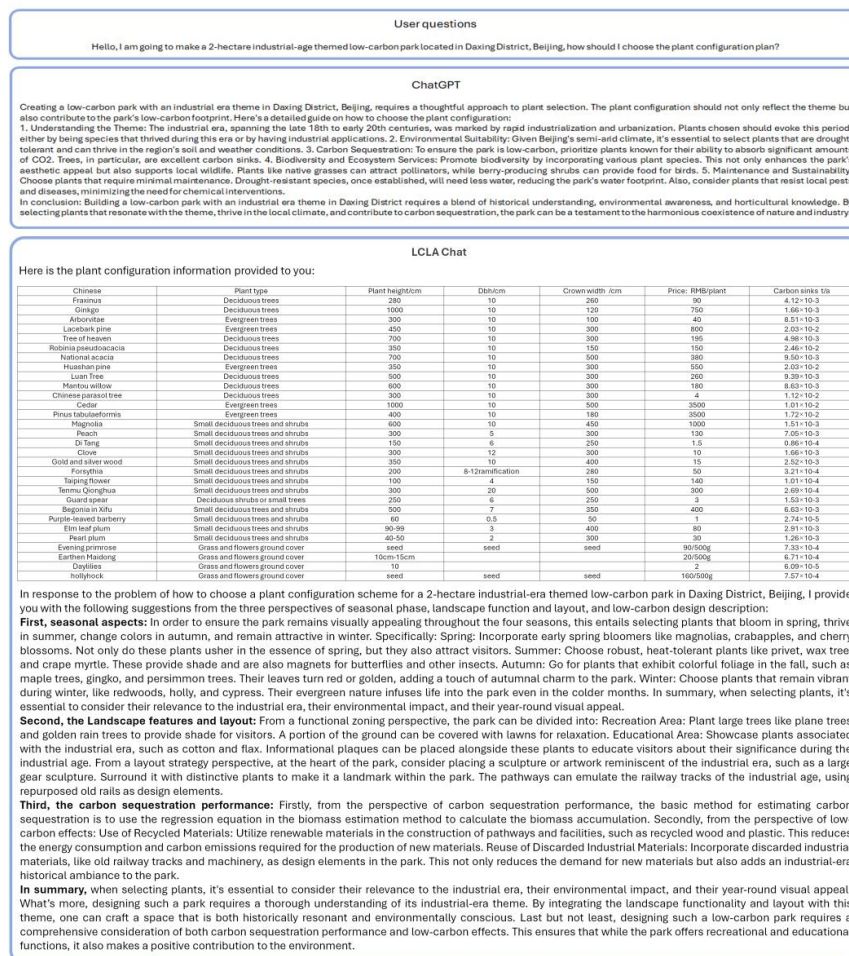


Fig. 4 Entity relationship diagram of landscape platform database. Source: Author

4. Conclusion

A comparison between GPT and LCLA CHAT in providing plant pairing choices for industrial-themed parks revealed that LCLA CHAT offers more detailed and comprehensive plant suggestions. This includes plant names, plant types, Latin names, growth habits, suitable habitats, ornamental features, plant height, canopy width, price, and carbon sequestration performance. LCLA CHAT has built an accurate and comprehensive low-carbon plant database, and the carbon sequestration performance of its plant pairings significantly outperforms those provided by GPT. Even while ensuring a low-carbon sustainable landscape, LCLA CHAT achieves a breakthrough in combining plant landscaping with the park's theme. The conventional plant suggestions from GPT struggle to meet the objectives of a green, low-carbon park. With the advent of LCLA CHAT, this vision becomes more attainable. LCLA CHAT is an AI system more conducive to sustainable landscape development that is low in carbon and environmentally friendly, dedicated to maintaining a balance between park construction and the ecological environment.

The main innovation of this study is our invention, which integrates professional knowledge and databases in the field of landscape and garden plant design into the system. At the same time, through the dialogue function of the large language model, it conducts precise searches in the database based on user information. The retrieved plants are provided to the large model to standardize the generation of its solutions, thereby offering accurate answers. Through deep learning technology and fine-tuning of the large language model, we added a judgment system to assist users in clarifying task requirements. We redesigned the task logic for all garden plant

planning and design issues, ultimately presenting users with a highly professional "low-carbon plant material list + design plan description." Our system will be of significant guidance in constructing green, low-carbon modern parks, becoming a design basis for the selection and pairing of high carbon sequestration plants in park construction, filling the gap in GPT's high carbon sequestration plant choices. Therefore, the plant choices provided by LCLA CHAT maximize both the low-carbon objective and park features. The application of LCLA CHAT will become the mainstream direction and trend for future park construction.

References

- [1] Triantakou, D. and D. Stathakis, Examining urban sprawl in Europe using spatial metrics. *Geocarto International*, 2015. 30(10): p. 1092-1112.
- [2] Li, W. and K.-S. Hong, A study on the Urban linear Park to which the Concept of Sustainable Design has been Applied. *Journal of Basic Design & Art*, 2022. 23(2): p. 339-357.
- [3] Yang, Z.F., et al., Limiting factor analysis and regulation for urban ecosystems-A case study of Ningbo, China. *Communications in Nonlinear Science and Numerical Simulation*, 2010. 15(9): p. 2701-2709.
- [4] 김승현, A Study on Sustainable Urban Landscape Design - Focused on the American Society of Landscape Architects Sustainable Landscape Designs. *Journal of The Urban Design Institute of Korea*, 2013. 14(1): p. 97-108.
- [5] Li, J. and J.L. Gan, The Importance of Low-Carbon Landscape Design in Rural Tourism Landscape. *Ecological Chemistry and Engineering S-Chemia I Inzynieria Ekologiczna S*, 2022. 29(3): p. 319-332.
- [6] He, G., et al., Estimating Carbon Sequestration Potential of Forest and Its Influencing Factors at Fine Spatial-Scales: A Case Study of Lushan City in Southern China. *International Journal of Environmental Research and Public Health*, 2022. 19(15).
- [7] Zhou, K.H. and R.H. Tan, More Than Thirty Years of Environmentally Sensitive Area Loss in Wuhan: What Lessons Have We Learned from Urban Containment Policy? *Land*, 2022. 11(8).
- [8] Ling, T.Y. and Y.C. Chiang, Well-being, health and urban coherence-advancing vertical greening approach toward resilience: A design practice consideration. *Journal of Cleaner Production*, 2018. 182: p. 187-197.
- [9] Yang, L. and W. Ye, Landscape design of garden plants based on green and low-carbon energy under the background of big data. *Energy Reports*, 2022. 8: p. 13399-13408.
- [10] Misni, A., et al., Applying low carbon landscapes at the Premier Polytechnic of Sultan Salahuddin Abdul Aziz Shah, Shah Alam, Malaysia. *International Journal of Environment and Sustainable Development*, 2020. 19(3): p. 284-294.
- [11] Chen, Z., et al., Exploring Text Mining for Recent Consumer and Sensory Studies about Alternative Proteins. *Foods*, 2021. 10(11).
- [12] Liu, Y., et al., WT-2DCNN: A convolutional neural network traffic flow prediction model based on wavelet reconstruction. *Physica a-Statistical Mechanics and Its Applications*, 2022. 603.
- [13] Shi, T., et al., Research progress on calculation method and impact factors of carbon sequestration capacity in urban ecosystems. *Ying yong sheng tai xue bao = The journal of applied ecology*, 2023. 34(2): p. 555-565.
- [14] Raum, S., et al., Achieving impact from ecosystem assessment and valuation of urban greenspace: The case of i-Tree Eco in Great Britain. *Landscape and Urban Planning*, 2019. 190.
- [15] Syed, A.H. and T. Khan, SHPIS: A Database of Medicinal Plants from Saudi Arabia. *International Journal of Advanced Computer Science and Applications*, 2017. 8(5): p. 49-53.
- [16] Song, J., et al., Deep learning-based extraction of predicate-argument structure (PAS) in building design rule sentences. *Journal of Computational Design and Engineering*, 2020. 7(5): p. 563-576.
- [17] Cai, M., Natural language processing for urban research: A systematic review. *Heliyon*, 2021. 7(3).