RESEARCH ARTICLE

The role of landscape design in landscape planning under the background of big data and internet of things

Dongli Si[1, 2, *]

[1]College of Art, Jiaozuo University, Jiaozuo, Henan, China. [2]Graduate School, Emilio College, Manila, Philippines.

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The integration of big data and Internet of Things (IoT) technologies has significantly influenced the field of garden planning, presenting new opportunities for innovation in landscape design. However, current challenges such as ineffective integration of landscape elements and limited alignment with sustainable development goals hinder the optimization of urban garden planning. This study aimed to address these issues by constructing a value-added model that enhanced the green capacity and functionality of landscape design within urban planning frameworks. A comprehensive methodology was employed including the analysis of domestic and international literature, integration of diverse landscape design concepts, and investigation of key influencing factors. The results demonstrated that the proposed model effectively improved the integration of ecological balance and sustainable development principles, leading to enhanced urban planning outcomes. This research underscored the importance of incorporating advanced technologies and sustainable strategies in landscape design, providing valuable insights for future urban planning and construction efforts.

Keywords: big data; Internet of things; landscape design; garden planning; urban planning; ecological balance; sustainable development.

[*]**Corresponding author:** Dongli Si, College of Art, Jiaozuo University, Jiaozuo 454000, Henan, China. Email: si_dongli@outlook.com.

Introduction

With the continuous improvement of people's living standards, there is an increasing demand for high-quality garden design in urban planning. As a result, the integration of advanced technologies such as big data and the Internet of Things (IoT) into landscape design has become essential to meet these rising expectations. The need for enhancing the quality of life through well-designed urban green spaces is more urgent than ever. Recent studies have explored the application of contemporary concepts and technology in landscape design. Zavoleas *et al*. examined architectural gardens of the post-human era, suggesting that the diversification of landscape design could be achieved by integrating various elements [1]. Heymans *et al*. highlighted the importance of eco-city planning, where landscape design played a critical role in the monitoring and management of environmental factors [2]. Bastian *et al*. demonstrated the effectiveness of using landscape elements to promote urban development [3]. Furthermore, Shamsafar *et al*. proposed a design approach that considered human factors and leveraged big data to align with consumer and urban lifestyle needs [4]. Naveh *et al*. highlighted the importance of adopting a holistic approach to multifunctional landscapes, emphasizing that landscape planning should integrate ecological, social, and economic dimensions to achieve sustainable development. His ten major premises provided a comprehensive framework for understanding the interconnectedness of landscape functions and their contributions to urban planning [5]. Pereira *et al*. focused on the psychological benefits of integrating green vegetation and building forms [6], while Spielhofer *et al*. looked at the behavioral responses to renewable energy systems in different landscapes [7]. Babakandov *et al*. emphasized the need to integrate the requirements of diverse populations [8]. Goryacheva *et al*. discussed the trends in modern Chinese architecture and the significance of fusing different landscape design elements [9]. Kurjenoja *et al*. underlined the role of extended learning in understanding landscape perception [10]. Despite the progress, several challenges remain. There is a need to further integrate landscape design with sustainable practices, ensuring that green, low-carbon, and healthy developments are promoted. Additionally, the effective use of big data and IoT must be optimized to enhance the quality and functionality of urban green spaces, catering to the diverse needs of different cities, regions, and demographic groups. The balance between ecological integrity and aesthetic appeal also requires attention.

In recent years, the application of IoT and big data technologies in garden planning and management has significantly improved the technical level of the field. IoT technology uses sensor networks to achieve real-time monitoring and data collection of environmental parameters, providing a basis for the dynamic management of garden ecosystems. Big data technology analyzes massive amounts of data to identify key trends and potential problems in garden planning, optimize resource allocation and ecological design strategies [10]. IoT sensors have been widely used in monitoring plant growth, soil moisture, and air quality, providing data support for the construction of smart gardens [11]. Big data analysis has also played an important role in predicting ecosystem changes and formulating sustainable development strategies [12]. The combination of these technologies is driving garden planning from a traditional model to an intelligent, data-driven direction. Under the background of big data and IoT technology, the development of garden planning not only depends on people's planning concept for the overall living environment but also depends on the important technical guarantee provided by modern information technology. Using advanced data management and classification analysis and processing system, the overall control of garden planning is realized. The intelligent big data storage technology provides important data support for the establishment, management, and monitoring of the garden database and can effectively carry out intelligent management and maintenance. On the basis of improving the management level of garden service, it saves a lot of manpower and plays an important role in improving the technical level of landscape design in the whole garden planning. The landscape design concept built on the big data platform plays an important role in monitoring and managing the ecological balance and ecological restoration in garden planning. In the past decade, with the widespread application of big data and IoT technologies, significant progress in market size and research and development has been made. The use of these technologies has effectively improved the overall management efficiency of garden planning, monitoring, and maintenance, and has led to a steady increase in the planning and construction of ecosystems year by year [13]. Urban garden planning and design not only need to integrate the important elements of green vegetation and ecological construction but also should pay attention to the concept of sustainable development in landscape design, which plays an important role in promoting and improving the overall planning of the city. In garden planning, the concept of sustainable development reflects in the use of big data technology for the overall planning of garden design and the needs to base on the balance of the ecosystem and effectively grasp the actual situation of garden development. Meanwhile, the deficiencies in the development of the whole plan can be effectively avoided and constantly integrated towards the direction of green and sustainable development. The new landscape design concept is more in line with people's life and leisure. The concept of sustainable development plays an important role in landscape design and points out the development direction for garden planning and construction. Through the timely analysis of big data and the data of the IoT platform, strengthen the monitoring and management of garden planning and design, and timely put forward the scheme of garden planning and construction, the sustainable development of garden planning can be promoted, and the ecological balance of the whole garden construction and development can be maintained.

Garden planning should be built based on the overall layout of the city, and an intelligent garden management system should be established through the effective integration of elements in landscape design. Based on the big data analysis platform, the overall management efficiency of the garden is improved. Through different technology applications such as internet mobile, network cloud computing, remote sensing image technology, *etc*., the efficiency of landscape design and management can be greatly improved. In the process of intelligent green garden management, a lot of human resources can be optimized, so that the management quality of garden construction can be improved, and the overall efficiency of urban garden planning and engineering construction can be improved greatly. Through the construction of an intelligent garden management system, the use of multi-directional technology can achieve better management and efficiency improvement, while, through the application of sensor intelligent technologies such as intelligent watering, mobile terminals, remote sensing technology, robots, unmanned aerial vehicle (UAV), *etc*., the management efficiency of landscape design elements in garden planning can be greatly improved [14]. At the present stage, in the city, the management mode of garden planning is regional. Through the big data platform, it can effectively provide important guidance and management for landscape design in gardens to build a three-level management and maintenance platform based on the garden management department, garden maintenance workers, and garden consumer groups. Based on this data platform and by integrating new technologies into the landscape design process, the effective integration and maintenance of different landscape design elements can be realized, which not only improves the maintenance efficiency of landscape maintenance personnel but also improves the living standard and overall quality of modern people and greatly improves people's care degree for the whole environment. In addition, a unified and authoritative garden planning information platform can be built, so that the landscape elements can be better protected in the garden design to greatly improve the operation efficiency of the garden management platform in the overall planning [15]. The different elements of landscape design have different investments in management methods and management groups. Through the investigation of input cost, operation cost, maintenance time, and operation difficulty, the higher the quality of people, the better the management and operation system, and the stronger the guiding role for the whole garden planning.

In the process of garden project construction and planning, many cities realized the effective sharing of information in the overall landscape design process using big data and IoT. By building a shared platform, the government departments can better understand the real needs of people and make the information degree of landscape design higher. In the whole process of project construction supervision and management, continuous information feedback can get the maximum play in the garden design and the application of landscape elements. The comprehensive supervision and management of the visualization of urban landscape design can be achieved using satellite remote sensing technology. Based on different geographic information systems (GIS), a balanced ecosystem is built to promote the comprehensive application of the whole garden planning space. In the overall urban planning and management work, the use of visual management system can better realize the comprehensive monitoring of urban garden engineering projects in the first time and plays an important role for people to timely understand and feedback the deficiencies in the planning process [16]. Under the background of big data and IoT technology, the database management system can realize the information feedback of people to the garden planning. Through the comprehensive application of IoT and multimedia information technology, the urban spatial database can be given comprehensive play, and the government departments and talents at all levels can widely participate in the overall planning and construction of the city, so that the whole landscape design can realize information and visualization. In terms of space design, time collocation, and application attributes, different landscape elements can be better integrated. Through the establishment of visual virtual reality garden, the comprehensive monitoring of garden engineering construction can be better realized.

This research comprehensively analyzed existing literature, case studies, and the synthesis of data from big data platforms and developed a methodological framework to evaluate the impact of incorporating various landscape design elements, considering both the technical and social aspects of urban planning. By advancing the current knowledge and methodologies in landscape design, this study provided a robust foundation for future research and practical applications by promoting the idea of smart, sustainable, and aesthetically pleasing urban spaces that were responsive to the evolving urban spaces needs of society. The results of this study would serve as a valuable resource for urban planners, designers, and policymakers, guiding them toward the development of more livable and resilient cities.

Materials and methods

Study subjects and data resources

In the field of garden design, data storage and management are crucial. Two databases including MySQL (https://www.mysql.com/) mainly used to store and manage various data in garden design such as vegetation coverage, environmental monitoring data, *etc*. and PostgreSQL (https://www.postgresql.org/) provided advanced data processing capabilities and supported complex queries to meet the needs of accurate data analysis in garden planning were employed in this study. Apache Hadoop (https://hadoop.apache.org/) was used for distributed storage and processing of large-scale datasets for efficient big data analysis. Quantum GIS (QGIS) (https://qgis.org/en/site/) was used for map production, spatial data analysis, and visualization in garden planning. Python 3.8 (https://www.python.org/) was applied for data cleaning, analysis, and modeling. R Studio (https://www.rstudio.com/) was used as a statistical analysis and graphic display tool in garden planning. This study investigated the investment in garden planning in eight representative cities in China at different economic development levels, which included Beijing, Shanghai, Guangzhou, Shenzhen, Chengdu, Wuhan, Harbin, and Xi'an. All data for the eight cities were obtained from authoritative databases and publicly available platforms to ensure accuracy and reliability. Green coverage rates were sourced from the National Environmental Monitoring Center (www.neemc.org.cn), while landscape diversity indices were derived from reports provided by the Urban Ecology Planning Institute. Economic development data were collected from the China Statistical Yearbook (www.stats.gov.cn), and infrastructure quality information was purchased from UrbanInfo (www.urbaninfo.cn). All data acquisitions were authorized by the respective databases, and cross-validation was performed to ensure consistency and reliability. The data processing followed international standards and included essential geographical information such as city, province, and country to ensure the representativeness and generalizability of the research findings.

Model construction

For a garden planning community, the greening rate was an important indicator factor and was expressed as follows.

$$l = \frac{c_1 + c_2 + c_3 + c_4\Lambda - p_1 - p_2 - \Lambda}{D} \quad (1)$$

where l was the landscaping rate. $c_1, c_2, c_3, c_4\Lambda$ were the floor areas of all types of green vegetation. $p_1, p_2\ \Lambda$ were all kinds of roads and buildings covering floor areas in landscaping. D was the total building area of the garden. In the garden planning and design, the degree of reasonable collocation of landscape elements could be expressed by the floor area ratio. Based on the basic idea of landscape design in green garden planning, this research constructed the calculation model of green capacity rate planning below.

$$L = [\sum(q_1 \times Q \times k) + G \times 3 + C \times 1] \div c \quad (2)$$

where L was the green capacity rate in the garden planning, which combined with the arbor leaf area index q_1, projection area of trees Q, number of trees k, the shrub covering area G, the grass covering area C, and proportional to the site area. In the study of the plot ratio of the urban garden planning, in order to better realize the value appreciation of the landscape elements, the value evaluation of each element was evaluated by constructing the value-added model of the garden landscape elements as follows.

$$Z = [J \times (1 - S) - F_1 - F_2 - F_3 - F_4 - F_5 - F_6] \times L - F_7 \quad (3)$$

where Z was the value-added value of garden landscape elements. J was the total value of the garden investment. S was the landscape business tax and related expenses. $F_1, F_2, F_3, F_4, F_5, F_6, F_7$ were the preliminary costs, construction costs, marketing costs, unpredictable costs, interest costs, and land costs, respectively. L was the green capacity rate. To better maximize the value-added landscape design, the maximization model was constructed as below.

$$Z_{\max} = (\sum F_i \times X_i) \times D \quad (4)$$

$$0 \le X_i \le 1 \quad (5)$$

$$\sum X_i \le 1 \quad (6)$$

where Z_{max} was the maximum appreciation of landscape design elements. F_i was a series of related costs. X_i was the total investment ratio. D was the total garden area. Through the model construction of the landscaping rate, green capacity rate, and the value-added situation of landscape design, the relationship between various factors could be better evaluated, which was conductive to improving the comprehensive effect of landscape design.

Results and discussion

The impact of economic factors on landscape design in garden planning

The differences in garden planning investments between cities with stronger economic conditions such as Beijing and Shanghai and those with relatively weaker conditions such as Harbin and Xi'an were assessed in terms of their influence on the quality and diversity of landscape design to reveal the correlation between higher investments and more sophisticated, diverse designs. The resulting data underscored how economic capacity shaped urban planning and ecological strategies with wealthier cities prioritizing more innovative and sustainable approaches. The differences in garden planning investments between cities with varied economic conditions showed that there was a clear positive correlation between the annual GDP of a city and its investment in garden

Table 1. Comparison of urban garden planning investment under different economic conditions.

City	Average annual GDP (¥100 million)	Annual investment in garden planning (¥10,000)	New green area per year (Hectares)
A	5,000	2,000	150
B	3,000	1,500	100
C	8,000	3,000	200
D	2,000	1,000	50

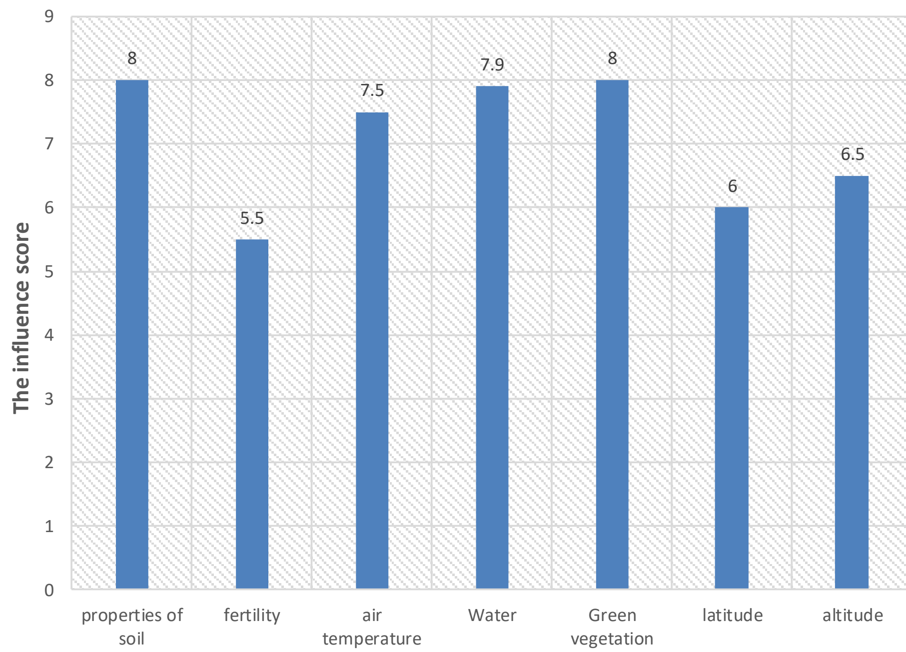

Figure 1. Impact degree of the influence factors of landscape elements in different garden planning.

planning, as well as the annual increase in green areas (Table 1). Cities with better economic conditions could allocate more funds toward garden planning, leading to enhanced landscape quality and larger green spaces. This finding highlighted that economic prosperity directly influenced the scope and quality of urban landscape design, offering cities with better financial resources the opportunity to implement more sophisticated and expansive planning strategies. However, for cities with limited economic resources, alternative approaches such as public-private partnerships (PPP) and low-cost, efficient design strategies such as using native plant species to reduce maintenance costs could be explored. These methods could help ensure high-quality green spaces even in economically constrained environments. The analysis of the influencing factors of different landscape elements in garden planning showed that soil properties, air temperature, and green vegetation had a high degree of influence, reaching scores of 8, 7.5, and 7.9, respectively. The influences of fertility and latitude were relatively low at 5.5 and 6.0, respectively (Figure 1). The higher the value, the greater the influence of the factor on garden planning.

The roles of big data and IoT platforms

In this study, the use of big data technology enabled the analysis of changes in green vegetation coverage over the past decade in a large city. The results showed that the growth trend of green vegetation coverage showed a

Table 2. Changes in green vegetation coverage in a large city in the past decade.

Years	Green vegetation coverage rate (%)	Year-on-year growth (%)
2013	25.4	-
2014	26.3	+0.9
2015	27.1	+0.8
2016	28.2	+1.1
2017	29.3	+1.1
2018	30.5	+1.2
2019	31.7	+1.2
2020	32.9	+1.2
2021	34.1	+1.2
2022	35.3	+1.2
2023	36.5	+1.2

Table 3. Preference for urban landscape elements in different climate zones.

Climate zone	City	Temperature range	Average humidity	Main soil types	Preferred plant species
Subtropical humid zone	E	15 - 28°C	70 – 85%	Clay	Lawn grass, bushes
Cold and dry areas	F	-10 - 15°C	30 – 50%	Sandy loam	Pine, coniferous forest
Temperate maritime climate	G	5 - 20°C	60 – 70%	Loam	English Oak, European Beech
Tropical monsoon climate	H	20 - 30°C	80 – 90%	Red soil	Coconut trees, tropical flowers

consistent upward trajectory, which indicated that the application of big data for monitoring and management facilitated the effective execution of garden planning (Table 2). The results suggested that continuous data-driven monitoring significantly contributed to urban greening efforts, helping ensure that garden designs were not only sustainable but also adaptable to evolving environmental conditions. Developing advanced algorithm models to predict the long-term ecological impacts of garden planning and establishing open data platforms to involve the public in greening efforts were recommended as future directions. These advancements could further enhance urban sustainability and public engagement.

The influence of ecological factors on landscape design in garden planning

Ecological factors such as temperature, humidity, and soil type play a critical role in landscape design decisions. Table 3 illustrated how cities in different climate zones prioritized certain ecological factors in plant species selection for landscape projects. The results showed that cities with warmer climates focused more on water-efficient plants, while cooler cities might prioritize frost-resistant species. These regional differences emphasized the need for designers to adapt their strategies to local ecological conditions to ensure plant survival and overall landscape health. Beyond selecting appropriate plant species, integrating these plants into a cohesive ecosystem could maximize biodiversity and enhance resilience. Establishing wildlife corridors and implementing water restoration projects were additional strategies to strengthen ecosystem services in urban gardens.

Landscape planning and development strategies under the background of big data and IoT

To optimize garden maintenance plans, a comprehensive big data analysis system was developed, which incorporated user feedback to adjust maintenance strategies based on actual usage and environmental changes. Table 4 presented examples of maintenance adjustments made through this feedback loop.

Table 4. The garden maintenance plan adjusted based on user feedback.

Maintenance Activities	Original frequency	User feedback suggestions	Adjusted frequency	Adjustment basis
Lawn mowing	Monthly	More frequently	Once every two weeks	Users want their lawns to be kept neat and tidy
Tree pruning	Once a quarter	No change	Once a quarter	The current frequency meets user needs
Watering	Twice a week	Reduce the number of times	Once a week	Users reported excessive watering leading to water accumulation
Fertilization	Once every six months	Increase the number of times	Once a quarter	Users believe that the current amount of fertilizer is insufficient to support growth

Table 5. Quantitative results of optimizing garden maintenance plans based on big data and IoT.

City	Water usage reduction (%)	Plant survival rate increase (%)	Public satisfaction improvement (%)	Biodiversity index increase (%)	Maintenance efficiency improvement (%)	Energy consumption reduction (%)
Beijing	18	12	N/A	N/A	25	N/A
Shanghai	15	25	N/A	N/A	N/A	N/A
Guangzhou	N/A	N/A	22	10	20	N/A
Shenzhen	N/A	N/A	15	N/A	30	N/A
Hangzhou	N/A	N/A	N/A	15	N/A	N/A
Chengdu	20	N/A	N/A	N/A	18	N/A
Nanjing	N/A	N/A	18	N/A	N/A	35
Wuhan	N/A	N/A	N/A	N/A	40	N/A

Additionally, the quantitative effects of the optimized maintenance plans across various cities were demonstrated in Table 5. The results showed that Beijing had an 18% reduction in water resource use and a 25% increase in maintenance efficiency, while Guangzhou experienced a 22% rise in public satisfaction and a 10% increase in the biodiversity index. These improvements validated the effectiveness of integrating big data and IoT technologies into garden planning and maintenance, resulting in better resource conservation, ecological benefits, and enhanced public experiences. These findings underscored the significance of advanced technology in creating smarter urban green spaces. Involving the public in planning processes through feedback mechanisms not only enhanced the relevance of garden designs but also fostered a sense of community ownership and satisfaction. Future research can explore further optimization of IoT-based systems to address resource challenges and enhance the ecological and social impact of urban gardens.

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