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The meliorization process of urban green spaces:
Integrating landsense creation for sustainable development

GONG Gaofeng[1], *GUO Qinghai[1,2], QIU Botian[3], TANG Lina[4], MAO Qizheng[5], HE Zhichao[6]

1. School of Civil Engineering and Architecture, Zhejiang Sci-Tech University, Hangzhou 310018, China;
2. Zhejiang Academy of Ecological Civilization, Zhejiang Sci-Tech University, Hangzhou 310018, China;
3. School of Technology, Westlake University, Hangzhou 310018, China;
4. Institute of Urban Environment, CAS, Xiamen 361021, Fujian, China;
5. School of Resources and Environment, Henan University of Economics and Law, Zhengzhou 450046, China;
6. School of Architecture and Civil Engineering, Xiamen University, Xiamen 361005, Fujian, China

Abstract: Urban green spaces play a crucial role in enhancing the well-being of urban residents and promoting sustainable urban development. However, optimizing the planning and management of urban green spaces to meet residents' diverse needs and preferences poses a considerable challenge. This study addresses this challenge by employing a landsenses ecology approach, integrating residents' perspectives into the planning and design of urban green spaces. Starting from human needs, a conceptual framework for the meliorization model of urban green spaces is constructed, grounded in the principles of landsense creation and incorporating a "design-simulation-management" process. Through this model, the mechanisms driving the meliorization process are explored. This study contributes to improving the meliorization process in landsenses ecology, while expanding the theoretical framework and methodology of landscape ecology. By emphasizing the dynamic interactions between land planning, construction, and residents' experiences, this study provides valuable insights into the dynamic development of urban green spaces, facilitating the implementation of sustainable urban development strategies and practices.

Keywords: landsenses ecology; ecosystem services; digital technology; human needs; meliorization process

1 Introduction

Urban green space (UGS) plays a crucial role in enhancing the health of urban ecosystems and improving the living urban environment (Kabisch *et al*., 2015) and is considered one of the fundamental material conditions for societal survival and development (Haase *et al*., 2014; Farkas *et al*., 2023). UGS has important implications for maintaining urban ecological balance, mitigating urban environmental pollution, and enhancing the quality of life and sat-

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Author: Gong Gaofeng (1999–), Master, specialized in landscape planning and design. E-mail: q15900849817@163.com
***Corresponding author:** Guo Qinghai (1980–), PhD and Professor, specialized in landscape ecology.
E-mail: qhguo@zstu.edu.cn

isfaction of urban residents (Bolund and Hunhammar, 1999; Chiesura, 2004; Jim and Chen, 2006). With the acceleration of urbanization and the improvement of people's quality of life, there is an increasing demand for the recreation of UGS landscapes. Improving the aesthetic, ecological, social and cultural value of UGSs and strengthening their ecosystem services through planning, design, construction and management have become new challenges in the fields of urban ecology and urban sustainability.

As a component of the urban ecosystem, UGS is regarded as a means of improving urban ecosystem services. In the process of land-use planning, construction and management should include not only natural elements and socio-economic factors but also people's physical perceptions and psychological sense of the effects of land use (Zhao *et al*., 2016). Landsenses ecology is proposed as a new field of ecology based on social-economic-natural complex ecosystems (Ma and Wang, 1984; Zhao *et al*., 2020). Landsenses ecology is defined as a scientific discipline that studies land-use planning, construction, and management toward sustainable development based on ecological principles and the analysis framework of natural elements, physical senses, psychological perceptions, socio-economic perspectives, process risk, and associated aspects (Zhao *et al*., 2016). Landsenses ecology emphasizes landsense creation, which serves as a medium for expressing people's visions through landsense planning and design and aims to regulate human behavior (Zhao *et al*., 2020). Researchers have studied the landsense effect of multiple types of UGSs, such as urban three-dimensional greening (Wang *et al*., 2020b), urban parks (Liu and Tang, 2020), wetland parks (Lu *et al*., 2020), rain gardens (Ma and Shi, 2020), and community green spaces (Mao *et al*., 2021), which involves landsense creation methods, landsense assessment indicators and landsense optimization strategies. However, landsense creation, which is constrained by time, budgets and people's cognitive capacities, is a process of long-term, continuous and integrated feedback and improvement. To adapt to this change process, the study of landsense creation needs to adopt the meliorization model.

To advance the enhancement of landsense creation and to maintain urban landscapes for human well-being, scholars have explored the application and construction of the meliorization model in urban research and proposed an ideal mode of landsense creation (Lu *et al*., 2020; Wang *et al*., 2020a; Zhang *et al*., 2020; Tang *et al*., 2022; Liu *et al*., 2023). Studies have expanded the application of the meliorization model at various scales. However, most are repetitive elaborations of the meliorization model or specific applications based on conceptual elaboration, and few provide a detailed description of meliorization model or clarify the driving mechanism of the process of meliorization. Therefore, the aims of this study are (1) to propose a general conceptual framework for the meliorization model of UGS grounded in the principles of landsense creation, and (2) to investigate the driving factors and the process of meliorization.

2 The process of landsense creation

2.1 Perceptual experience of UGSs

UGSs can not only alleviate the urban heat island effect (Aram *et al*., 2019), improve air quality (Selmi *et al*., 2016), prevent floods and reduce disasters (Li *et al*., 2021), and provide biological habitats (Lepczyk *et al*., 2017) and other ecosystem services, but they also provide cultural ecosystem services such as regulating emotions (Nadkarni *et al*., 2017), promoting physical activity (Brown *et al*., 2014), improving social cohesion (Jennings and Bamkole, 2019) and improving satisfaction (Kaplan, 2001). Among these services, cultural services are closely related to residents' individual needs and directly or indirectly impact their physical and psychological well-being. Residents' demand for cultural services relies greatly on their physical perception of green spaces (Mao *et al*., 2021). The quality of physical perception often determines the degree of psychological cognition, which is a basic condition for improving residents' satisfaction (He *et al*., 2022b). Ecological pollution, such as malodorous substance pollution, noise pollution, and light pollution, can directly negatively affect human physical perception, thereby affecting psychological cognition (Lü *et al*., 2021). Studies have shown that environmental stress is not a direct factor affecting mental health but plays an indirect role through physical perception. Even at lower levels of environmental stress, environmental pollution may negatively affect people's psychological cognition (Gomm and Bernauer, 2023). Visual and auditory factors are the primary contributors, accounting for 76% and 24%, respectively (Jeon and Jo, 2020). Therefore, physical perception is also a major factor affecting human judgment of ecosystem services. However, there is a threshold for physical perception. Excessive visual perception or auditory perception will negatively affect residents' perceptions (Ma *et al*., 2021; Nie *et al*., 2022). Moreover, people's physical perception, such as vision, hearing, smell, taste, and touch, is a complete system that cannot be split and in which the components often work together, which means that in the construction process of UGSs, it is necessary to fully consider people's perceptions and experiences to meet the needs of multiple human senses. Although disciplines such as landscape architecture consciously integrate residents' perceptions into planning and design, the relationships and interaction mechanisms between UGSs and residents' actual needs and perceptions are still unclear.

2.2 Changes in the perception of UGSs and their influencing factors

Urban residents are the main users and beneficiaries of UGSs, as are participants and collaborators in UGS planning and management. Human perception and evaluation of UGSs directly affect their behavior and attitudes toward the use of UGSs, which in turn affects their ability to evaluate UGSs. At present, many scholars have explored the changes in residents' perceptions of UGSs and their influencing factors. On the one hand, some researchers have paid attention to the differences in perceptions of various types of UGSs among numerous types of residents and have found that residents' perceptions are affected by their personal attributes (such as age, gender, education level and income level), social attributes (such as occupation, family structure and social relations) and environmental attributes (such as residential location and surrounding environment) (Conedera *et al*., 2015; Mao *et al*., 2020). On the other hand, considerable attention has been given to the impact of changes in UGSs on changes in residents' perceptions at multiple spatiotemporal scales, and it has been found that levels of urbanization can affect residents' well-being and landscape preferences. For example, people living in areas with higher urbanization levels are more inclined to live in natural landscapes (Xu *et al*., 2020), and cultural services continue to change with the process of urbanization (Wang *et al*., 2021).

Improving urban residents' cognitive levels and sensory experiences of UGS ecosystem services and enhancing their awareness of and participation in UGS protection are important ways to achieve sustainable urban development and ecological civilization construction (Tian *et al*., 2020). Some scholars have argued that the impact of UGSs on residents may vary with people's age, gender, life stage and health status, and it is necessary to adopt a life course approach to consider the needs and preferences of different groups (Douglas *et al*., 2017). However, the current research on UGSs is mostly static, and a dynamic perspective to effectively assess the impact and improvement of UGSs on physical and mental health is lacking (He *et al*., 2022a). Therefore, optimizing UGS planning and management to enhance the perception and satisfaction of residents across different periods and types is crucial for sustainable urban development.

2.3 The connotations of landsenses ecology

Landsenses ecology focuses on the interaction of human perception with the natural environment, aiming to optimize land use, improve human well-being and achieve sustainable development through an interdisciplinary approach (Figure 1) (Shao and Wu, 2020; Yan and Tang, 2021). Landsense creation is the core theory and method of landsenses ecology and inspires people to have positive emotional experiences and cognitive perceptions by creating and designing specific environments. A carrier with these attributes is referred to as a landsense (景感 in Chinese), and the whole process of conception and construction of the landsense is referred to as landsense creation (景感营造 in Chinese). Zhao *et al*. (2020) proposed eight principles and three pathways on the basis of landsense creation. This concept highlights the influence of the environment on human emotions and psychological states, with the aim of enhancing people's sense of well-being and quality of life by shaping the environment. For example, Zheng *et al*. (2020a) take the example of the landscape eco-industrial park on Chongming Island to construct a diverse sensory experience space based on landscape planning to meet people's sensory needs. Li *et al*. (2016) improved people's comfort with the microclimate based on planning the urban microclimate in terms of wind speed, temperature, and humidity to improve the livability and safety of the microclimate. Shao *et al*. (2020) investigated the optimal spatial scale of visual perception in land-use planning to enable people to better perceive and appreciate the aesthetics of landscapes and ecological services while avoiding confusion caused by spatial patterns and the misuse of land resources. By quantifying human perception, landsenses ecology promotes the organic integration of natural environmental factors with human physical senses and psychological perceptions, closely linking human well-being with ecosystem services and sustainable development (Zhang *et al*., 2022).

However, people's perceptions of ecosystems are an endless process of accumulation and deepening, which affects the structure and function of complex systems and the realization of sustainable development (Zhao, 2013). To address the complexity of complex ecosystems, landsenses ecology is conducive to a meliorization model to guide the planning and design. The meliorization model is a process of advancement-feedback improvement. The aim is to facilitate the upgrading of ecosystem services, ultimately maximizing human well-being and fostering harmonious coexistence between humans and nature. Although the meliorization model and the optimization model have some common goals, that is, the pursuit of improvement, the meliorization model emphasizes the process of regulation and continuous progress toward a new goal during the running process rather than pursuing the best result (Zhao *et al*., 2016). To facilitate follow-up analysis and expression, the process of meliorization is referred to as the meliorization process. Mix-marching data plays an important role in the melioration model. This approach includes incorporating mixing data from different sources, including observational, experimental, remote sensing, statistical and other types, as well as marching data acquired during the actual implementation of the work process (Zhao *et al*., 2016). The meliorization model requires the use of mixed-marching data and scientific techniques, the construction of a superfeedback system of optimization simulation and management platform, the simulation of the ecosystem and timely and effective management of the whole process so that the ecosystem structure and function continue to converge to a better state to achieve a more comprehensive, more humane and ideal ecological restoration effect (Zhao *et al*., 2021).

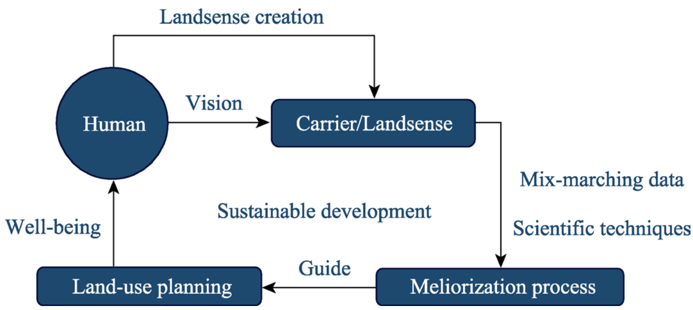

Figure 1 Conceptual framework for landsenses ecology. Landsenses ecology integrates residents' visions into carriers through landscape creation to promote the positive effects of human-ecosystem interactions. The meliorization model guides land-use planning through simulation predictions, risk assessment, and the collaborative optimization of objectives and constraints to ensure that the landsense continually approaches an "optimal" state and that well-being is enhanced.

2.4 Application of landsenses ecology in UGSs

Landsenses ecology is conducive to improving the ecosystem services of UGSs and strengthening people's perceptions, experiences, and understanding of ecosystem services in cities. Landscape planning and design through landsense creation can support people's vision and direct people to maintain, improve and increase ecosystem services for promoting sustainable development (Tang *et al*., 2020; Dong *et al*., 2022). In urban planning, landsense creation emphasizes the creation of a pleasant and livable urban environment that promotes people's sense of well-being and community cohesion through the planning and design of UGSs. Tarsitano *et al*. (2020) evaluated the physiological and psychological effects of environmental and green healing activities on participants, as well as the perception of park ecosystem services, emphasizing the importance of landscape ecology in urban planning and management. They found that adopting landscape ecology can improve people's mental-physical health while increasing their understanding of UGS ecosystem services and promoting their attitudes toward and willingness to participate in park management. Shi *et al*. (2017) believed that the method of landsenses ecology, which integrates perceptual data into the planning process, can help ecological planners understand the feelings, thoughts, and opinions of residents. This process neither reduces the artistry of the design nor affects the economic benefits of cities. At the same time, cities are human-dominated ecosystems that face the challenge of making trade-offs between human well-being and ecosystem services (Foley *et al*., 2005). The use of a meliorization model is conducive to the continuous improvement of residents' satisfaction so that we can consider human well-being from a dynamic point of view (Zhao *et al*., 2021). Taking Lisbon, Portugal, as a case study, Assunção *et al*. (2020) collected the views and opinions of different stakeholders and constructed a framework for urban sustainability modeling, assessment and optimization based on fuzzy cognitive mapping and system dynamics, which can identify complex relevant variables in the system. This methodology provides a new, integrated, participatory approach to urban sustainability decision-making and management and is also a manifestation of the meliorization model.

With the development of modern information technology and changes in people's lifestyles, especially the popularization of internet technology, UGS research has incorporated more ecological wisdom and emerging digital technology (Farkas *et al*., 2023). The development of these digital technologies provides sensors for the perception of landscapes. Landsenses ecology uses these technologies to acquire, analyze, and present data such as natural elements, physical perception, and psychological cognition, which enable the quantification and linking of residents' perceptions and ecosystem services to create and evaluate landscapes more effectively. For example, some scholars have used ecological Internet of Things (EIoT) monitoring data in the case of the Xianghe Segment of China's Grand Canal to carry out a series of specialized planning works based on landsense planning frameworks, such as soundscape planning (Dong *et al*., 2016b), environmental IoT detection (Zheng *et al*., 2015), and microclimate (Li *et al*., 2016). Zheng *et al*. (2022) established a framework for landsense assessment at the urban park scale using social media data and proposed a method for information extraction and indicator design. Zhang and Fu (2020) introduced an urban environment quantification method that combines a street view dataset and a deep learning framework and used landsense view factors as metrics to explain the urban environment from a human-oriented perspective.

3 Conceptual framework of the meliorization process

Based on the eight principles and three approaches to landsense creation proposed by Zhao *et al*. (2020), a conceptual framework of the meliorization process (Figure 2) is constructed from the aspects of design, simulation, and management, with the complex ecosystem as the core. During the process of landsense creation, different groups of people will have diverse landsense experiences in various stages of the natural and social environment, which will affect the setting and selection of sustainable development goals and paths. People have an increasing demand for ecosystem services and sustainable development. On the other hand, people have new demands and visions for UGSs in the process of urban development, driving the continuous development of landscape functions and ecosystem services to a greater extent.

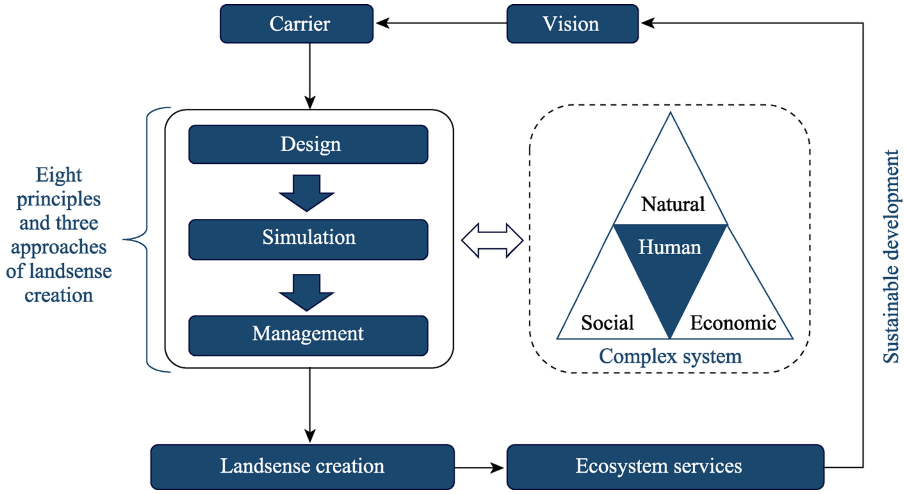

Figure 2 The framework of the human needs-based meliorization process. Grounded in the eight principles and three approaches of landsense creation and with the complex ecosystem at the core, the vision is incorporated into the medium through design, simulation, and management. Through landsense creation, ecosystem services are improved, thereby realizing sustainable development. This new vision will continue to propel the development of higher-level ecosystem services.

In the meliorization process, landsense creation is the most important means for landscape planning and design to practice landsenses ecology, and it is also an effective way for urban managers to maintain, improve and increase ecosystem services and achieve sustainable development (Tang *et al*., 2020). Landscape planning and design are the processes by which scientists and practitioners work together to consciously change landscapes for the sustainable provision of ecosystem services (Nassauer and Opdam, 2008). It is common for scientists and practitioners to incorporate scientific knowledge into decisions about landscape change. Landscape planning and design play important roles in determining the composition and configuration of regional landscapes (Gilman and Wu, 2023). Both the quantitative area, accessibility, and equity (Ekkel and de Vries, 2017; Ayala-Azcárraga *et al*., 2019; Zhu *et al*., 2021) and the quality enhancement of UGSs, such as landscape compositional structure, plant configurations, and biodiversity, have impact on UGS sustainable development (Guo *et al*., 2024). The meliorization model provides a framework for continuous optimization and refinement of the process of landsense creation to ensure that sustainable development goals and residents' visions are achieved and that the landscape is continually being improved. The implementation framework of the meliorization model may include three sections: (1) design: obtaining basic regional information and public perception information, analyzing the data, combining the regional landscape characteristics and residents' perceptual experience, and formulating a regional optimization strategy matching residents' visions; (2) simulation: simulating and assessing the ecological landscape design and searching for the ecological design that has optimal ecological functions and ecosystem services; and (3) management: applying IoT technology to enhance the overall landscape experience and ecological environment quality of the green space through an intelligent monitoring system (Figure 3).

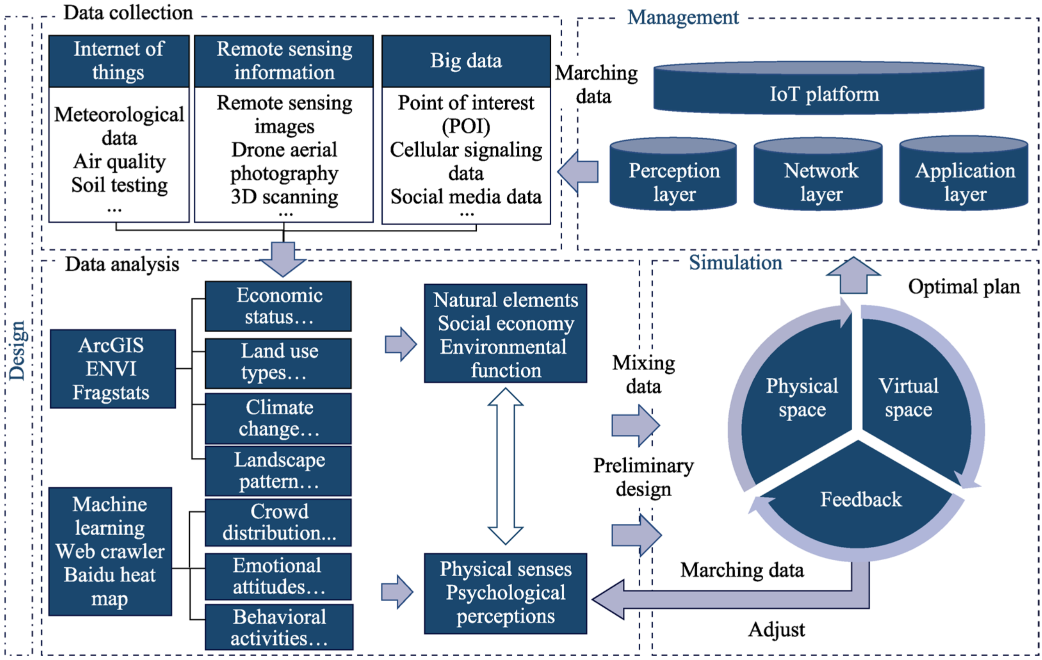

Figure 3 The implementation framework of the meliorization model. Digital technology is employed to gather essential regional data and insights into public perception. These data are then systematically analyzed to identify key regional challenges and understand residents' visions and aspirations. Simulation software evaluates designs, rectifies deficiencies, and finds optimal solutions. The IoT enables real-time monitoring and provides continuous and accurate feedback that can help to further enhance the landscape experience and environmental quality.

3.1 Design

Data collection within the study region is a critical initial step in research. It is necessary to apply new technological methods, such as the IoT, big data, and remote sensing information, to obtain useful materials such as remote sensing images, climate data, vegetation coverage, soil characteristics, and biodiversity. However, during the process of UGS construction, attention must be given not only to the natural benefits of UGSs but also to residents' attitudes and regional vision. To this end, big data such as cellular signaling data, points of interests (POIs), and social media data are utilized (Yang *et al*., 2019; Ullah *et al*., 2020; Cao *et al*., 2021). By considering human physical and psychological perceptions, it is possible to further quantify the rules of human behavior and clarify the actual needs of residents.

Digital technology and statistical methods were used to analyze the attributes and properties of the collected regions and public perceptions, to reveal the landscape characteristics of the regions and the perceptions of residents, and to provide help for landscape design. Specifically, artificial intelligence (AI) algorithms such as regression trees and random forests accurately interpret plant types, vegetation growth, and land use types in remote sensing satellite images (Latifi *et al*., 2012; Yigitcanlar *et al*., 2020) and combine a series of digital software platforms such as GIS, ENVI, and Fragstats to carry out geological geomorphological analysis, land use evaluation, ecological pattern construction and other large-scale landscape planning analyses to assess spatiotemporal changes in landscapes at the natural physical level and social and cultural levels (Tsoka *et al*., 2018; Brown *et al*., 2020). By combining machine learning to quantify the physiological and psychological perceptions of residents in urban scenes for different data types, the results revealed the perceptions and demands of residents (Zhang *et al*., 2021). Generalized linear models (GLMs), factor analyses, structural equation models and other statistical methods were used to quantify the perceptions of natural elements, economic elements and social elements, the current situation and potential of the region, and the vision and demands of residents to provide a scientific basis and guidance for landscape design (Ha *et al*., 2022; Lin *et al*., 2023; Wei *et al*., 2023).

Finally, through the feedback of the data analysis results, the current situation of the region and the perception effect of residents were clarified, and reasonable planning and design were carried out. The goal is to enhance the spatial experience and perception of the participating subjects while improving the quality of UGSs, thereby causing emotional resonance.

3.2 Simulation

For specific issues related to UGS landscapes, the adoption of spatial optimization strategies includes both physical and virtual spaces, allowing real-time feedback and adaptive adjustment. In the physical space, computer software and AI are used to generate and evaluate automated and intelligent solutions. A combination of simulation and actual measurement methods is adopted. Using ENVI-met, computational fluid dynamics software, and Sound Plan software, the thermal environment, wind environment and sound environment in a city can be simulated over a full range (Zhu and Zhang, 2020; Liu *et al*., 2021). Machine learning and deep learning techniques can be used to train computers to generate urban landscape design and planning systems through data training (Fan, 2022; Jiang *et al*., 2024). This allows for the analysis and simulation of spatial forms and natural processes, the assessment of the feasibility of the plan, and the verification and provision of feedback on multiple plans during the plan selection phase to derive a reasonable plan.

Technologies such as virtual reality (VR), augmented reality, and mixed reality are combined to achieve three-dimensional and immersive plan display and simulation. In the interaction between virtual reality and reality, by immersing oneself in the virtual environment created by the region, unreasonable aspects of the design plan can be quickly and accurately identified, improving the intuitiveness and experience of planning and design (Lee and Lu, 2016). Physiological detection technologies, such as electroencephalograms (Zhang *et al*., 2023), eye trackers (Yin *et al*., 2020), and electrocardiograms (Qin *et al*., 2013), are usually used in combination with questionnaire interviews to collect physiological signals and subjective perceptions from a perceptual perspective. The collected data can help planners better measure the physiological and psychological responses of observers in region creation, promoting the maximization of regional landsense effects. Through the simulation of physical and virtual space levels, reasonable plans are formulated and adjusted in the implementation phase, creating designs and intervention measures that can produce benign expected structures and continuously improving the plan.

3.3 Management

With the use of modern digital technology to construct an IoT detection platform, real-time collection, transmission, and processing of multidimensional data within the carrier, including natural elements, physical senses and psychological perception, can be achieved, providing a scientific basis for landscape evaluation and optimization (Zhao *et al*., 2016). The construction of the IoT includes the perception layer for data collection, the network layer for data transmission, and the application layer for data processing and analysis (Talavera *et al*., 2017). Enhancing the collection of environmental characteristic information in the research area resolution of these problems for real-time perception, data transmission, comprehensive analysis and deep mining of environmental problems has become possible. This process results in year-round, all-weather, multidimensional remote real-time monitoring and intelligent early warning of the ecological environment and forms environmental behavior information through quantification and interactive feedback (Zheng *et al*., 2020b).

Through the IoT detection platform, real-time ecological environment conditions within the region, as well as human use of the region, can be obtained. These data can assist in evaluating the landscape ecological value and landscape perception value with respect to aesthetics, comfort, and preference (Dong *et al*., 2016a; Li *et al*., 2016; Yu *et al*., 2020). Simultaneously, AI can be used to analyze data through models to predict the trend of landscape changes, to identify potential problems and risks, and to propose improvement and optimization suggestions and measures (Saheer *et al*., 2022; Yu *et al*., 2022). AI can also promote relevant stakeholders through visualization, voice, and text to realize interactive feedback on the environment and behavior.

4 Driving mechanisms of the meliorization process

4.1 Technological driver of the meliorization model

In the context of the rapid development of digital technology, the application of digital technology to urban ecosystems has driven the transformation of landsense creation and implementation paths for the meliorization process. Traditional planning and design often rely on subjective experience and lack objective feedback evaluation methods (Cheng *et al*., 2021; Reyes-Riveros *et al*., 2021). The application of digital technology realizes intelligent operation and real-time feedback under the full life cycle of the carrier (Figure 4). At the physical space level, the assistance of digital technology has enabled the quantification and intelligent analysis of regional information, enabling more objective solutions for the current problems of the region (Cui *et al*., 2020; Liang *et al*., 2023; Wu, 2023). AI and simulation applications can simulate the possible operation results in the process of landsense creation and compare feedback with the stage goals (vision), make necessary and timely adjustments, derive the optimal plan, and form the process of improvement of the plan (Liu *et al*., 2021; Tang and Long, 2022; Leng *et al*., 2023). With landscape information data, the IoT and cloud computing technology can provide accurate real-time data, improve landscape design and management, and pave the way for future improvements (Yusoff *et al*., 2015; Zheng *et al*., 2015). At the social perception level, VR, big data, and various biological sensors provide methods for quantitatively measuring public emotional cognition and provide an objective basis for the landsense creation of residents' vision (Li *et al*., 2020; Chandler *et al*., 2022). Digital technology not only realizes the transition from subjective design to objective response but also establishes a connection between the public and the carrier, realizing the

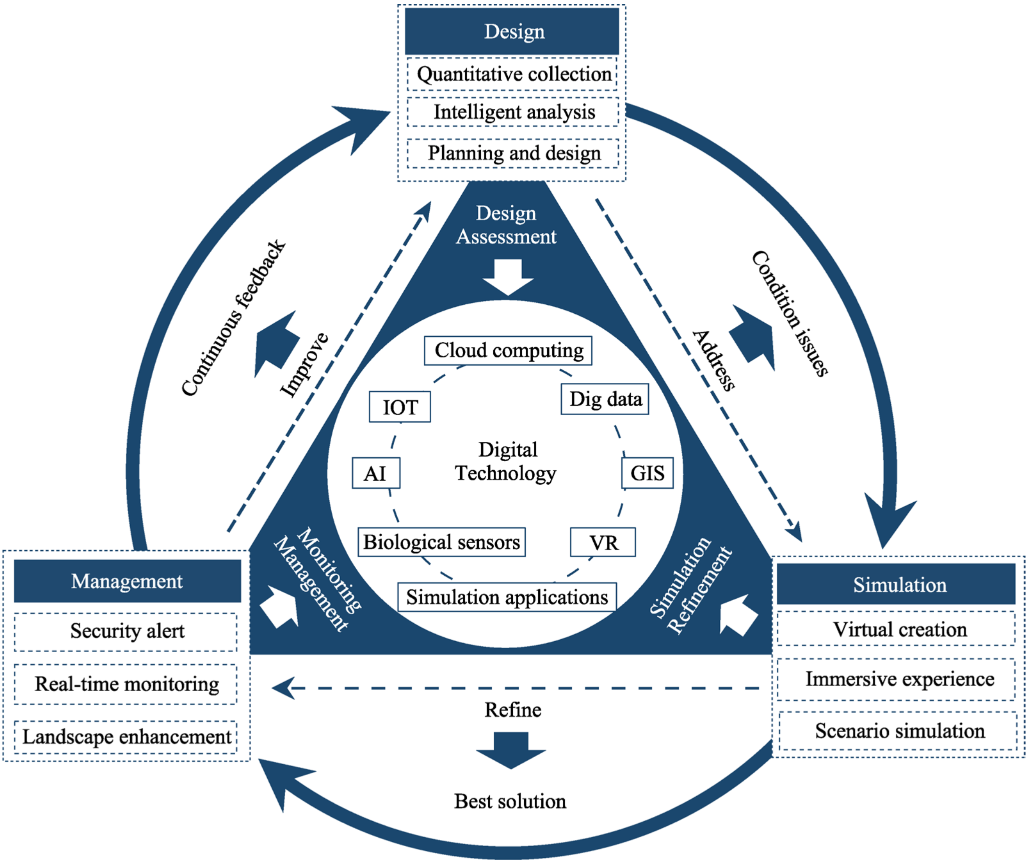

Figure 4 Flowchart of the digital technology-driven meliorization model. Digital technologies, including big data, AI and the IoT, provide efficient tools for the optimization process. These technologies enable quantitative regional information collection, intelligent analysis, scenario simulation, and monitoring management, leading to a more objective representation of the carrier's current state.

meliorization process in a short time. At the same time, digital technology enhances the dynamic interaction between people and landscapes and improves the feasibility of landsense creation.

The value of digital technology as a driver of improvement lies not only in changing traditional planning and design methods and processes but also in the quantification and real-time updating of feedback data. The meliorization process requires a massive amount of diverse data to support the dynamic process of planning and designing (Dong *et al*., 2022). The comprehensive penetration of digital networks into daily life has led to an explosive growth of data in various fields, allowing people to obtain massive amounts of data and providing new ideas for solving problems (Figure 5). In particular, the emergence of mobile positioning data, such as cellular signaling data, social media data, Baidu heatmaps, POIs and street view images, provides a very effective tool for studying the dynamic changes in urban crowds and the interaction of urban spatial structures (Yang and Cao, 2017; Tao *et al*., 2020; Yang *et al*., 2024). The use of physiological data monitoring instruments such as eye trackers, skin conductance meters, and electroencephalographs transforms residents' physical senses and psychological cognition into objective perceptual information through reception and translation, resulting in the quantification of psychological perception and physical perception in the process of landsense creation (Bazrafshan *et al*., 2023). The connection between natural environmental factors and human physical senses and psychological perception can be used to effectively evaluate the impact of the ecological environment on human well-being. These multidimensional, multiscale, dynamically updated data provide information for the meliorization process, provide continuous feedback, and provide effective data for the next update.

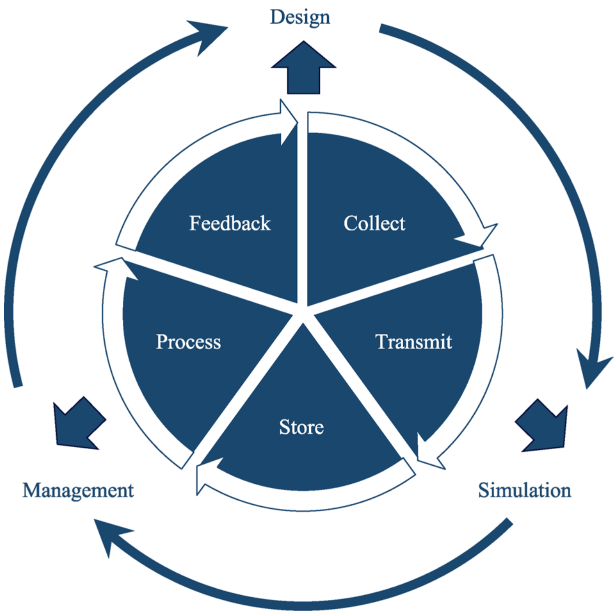

Figure 5 Flowchart of digital information as a driver of the regional meliorization model. Throughout the stages of design, simulation, and maintenance, a substantial volume of real-time data are produced. The continuous updating of this real-time dynamic information provides information for enhancement, the establishment of a continuous feedback mechanism, and the provision of valuable data for future updates.

4.2 Demand-driven meliorization model

The implementation of a digitally driven meliorization model is an indirect factor. Human needs are the most direct and important factor that affects the meliorization process. Human needs determine the goals, motivations, strategies and effects in the process of landsense creation and are an important indicator for evaluating the effect of the meliorization model. Human needs are directional and progressive. According to Maslow's hierarchy of needs (Maslow, 1943), people's needs can be divided from low to high into physiological needs, safety needs, love needs, esteem needs, and self-actualization needs. The pursuit and improvement of human well-being in the development of human society follow Maslow's hierarchy of needs. Different levels of needs have various demand intensities and preferences for numerous types of ecosystem services (Qi *et al*., 2020). Haida *et al*. (2016) found that people's emphasis on ecosystem services is consistent with their hierarchy of needs. The support and supply services corresponding to physiological needs are the most important, followed by the regulation services corresponding to safety needs, and cultural services are the least important. Han *et al*. (2021) further pointed out that as human needs increase, the difficulty of meeting residents' needs increases. These studies have proven the correlation between Maslow's hierarchy of needs and ecosystem services.

This study posited that the hierarchical progression of human needs and interactions formed by the succession of ecosystems drive the changes in the structure, process, function, and services of UGSs (Figure 6). All signals from the outside world can only be understood and accepted by humans, further influence human decision-making and behavior, and produce feedback to the ecosystem by becoming transformed into human perceptual information. People's perceptions and evaluations of UGSs directly affect their behaviors and attitudes toward UGSs and subsequently affect the complex social-economic-ecological functions of UGSs (Davenport and Anderson, 2005; Cobbinah *et al*., 2021). The landscape elements of UGSs have undergone substantial changes, leading to changes in residents' perceptions and well-being. These changes may affect residents' satisfaction and preferences for UGSs and thus affect their use and protection (Ning and Ou, 2021). That is, through feedback and adjustment mechanisms, the environment is brought more into line with expectations and preferences, thereby protecting UGSs.

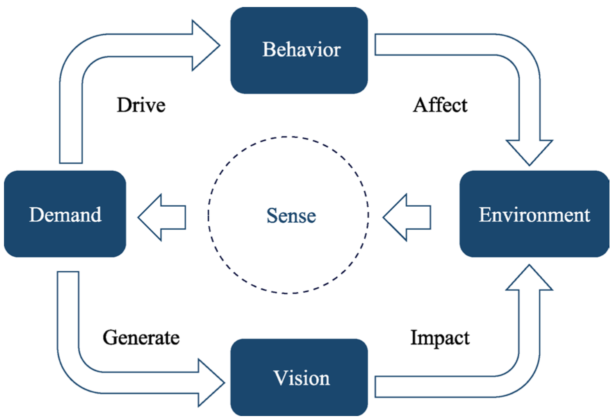

Figure 6 Interaction chart between UGSs and human needs. Residents' sense of UGSs shapes human needs and influences their behaviors and vision toward these spaces. These demands and behaviors, in turn, impact the use and sense of UGSs through feedback and regulatory mechanisms, forming a reciprocal cycle.

The level of human well-being depends on the distribution of benefits at various levels of human needs or the degree of satisfaction of needs (Li *et al*., 2013). Trade-offs exist not only among ecosystem services but also among different beneficiaries of ecosystem services, and even more so for ecosystem services and human well-being. Leviston *et al*. (2018) explored the connection between ecosystem services and human well-being from the perspective of social psychology and argued that the relationship between ecosystem health and human well-being is not linear but, rather, mutually influential. From an aesthetic perspective, Gobster *et al*. (2007) argued that human perception of the eco-landscape produced aesthetic experiences. Human aesthetic experiences not only cause changes in the landscape but also affect the aesthetic experience. Some studies adopt an ecological perspective and argue that ecosystem services and human well-being present a cyclical relationship, forming a dynamic process (Zhang and Fu, 2014; Xu *et al*., 2019; Niu *et al*., 2023). In the dynamic process of ecosystem services and human well-being, ecosystem services directly or indirectly match human consumption patterns to maintain human well-being. If ecosystem services are consumed within an appropriate range, residents' well-being can be continuously improved, and the improvement of well-being will in turn increase the protection of the ecosystem. In contrast, overconsumption may cause the degradation of ecosystem functions. The degradation of the ecosystem limits the improvement of human well-being, forming a feedback mechanism that affects human well-being (Wang *et al*., 2013). Therefore, clarifying the trade-offs and synergistic effects of ecosystem services is crucial for achieving sustainable ecosystem management (Rodríguez *et al*., 2005; Xu *et al*., 2023).

5 Conclusions

This study took human needs as the starting point and constructed a conceptual framework for the meliorization model of UGS grounded in the principles of landsense creation, integrating the "design-simulation-management" process. In terms of the driving factors of the improvement of UGSs, it is proposed that the development of digital technology is an indirect driving force for the meliorization process of UGSs, not only by advancing landsense creation methods and providing efficient tools and implementation paths for meliorization process but also by providing quantification and updating of real-time data and continuous feedback. This study revealed that the hierarchical progression of human needs and interactions formed by the succession of ecosystems drive changes in the structure, process, function, and services of UGSs and proposed that human needs are the direct driving force for the meliorization process of UGSs.

Landscape research involves understanding not only biology and physics but also the influence of many human factors, as landscapes are systems in which the environment and humans interact with each other (Wu, 2013). Compared with landscape ecology, landsenses ecology emphasizes the role of humans in the pattern and process of ecological landscapes, especially the role of humans in transforming landscape structure and function and their perceptions of the landscape. The introduction of these methods has not only improved the process of landsense creation and the meliorization process but also expanded the theory, methods, and content of landscape ecology. The meliorization model continuously monitors land planning, construction, and residents' perceptions from a dynamic perspective to achieve sustainable UGS development. With the development of digital technology, the mechanisms of human action, behavior and objects and the implementation path of landsense creation and improvement will further change and improve. The driving force of digital technology became more apparent in this study, providing important support for creating a more humanized and intelligent urban landscape environment. Moreover, planners, designers, builders, managers, and other major formulators and implementers of urban landscapes need to conduct scientific and reasonable analyses and make reasonable decisions based on the needs and expectations of users, as well as the conditions and restrictions of environmental factors, to ensure the feasibility, adaptability, and sustainability of urban landscapes.

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