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Review article

Advancements and prospects of landsenses ecology research based on bibliometric analysis

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ABSTRACT

The integration of landsenses ecology encompasses both the ecological and perceptual effects on the ecological environment. Although the theoretical framework has gradually matured, challenges persist, including a lack of research strength, incomplete evaluation systems, and ambiguous disciplinary boundaries. Therefore, a systematic review of landsense research is necessary to analyze its characteristics and explore future research trends to ensure that landscape ecology will flourish. This study conducted a bibliometric analysis of 37 Chinese articles from China National Knowledge Infrastructure (CNKI) and 46 English articles from Web of Science (WOS). As an emerging field in ecology, landsenses has grown in recent years. However, interconnectedness among the research teams is weak. The CNKI literature tends to be concentrated, with 70.27 % of the articles appearing in the journal *Acta Ecologica Sinica*. Researchers are predominantly affiliated with the Chinese Academy of Sciences, with fewer contributions from other institutions and universities. Future directions for landsenses ecology are outlined, including (1) enhancing interdisciplinary collaboration with emerging technologies, such as VR and AI, (2) refining quantifiable landsense metrics and evaluation systems, and (3) establishing a normal model and criteria for landsense creation services. By discussing the disciplinary boundaries and application of landsenses ecology, this study contributes a theoretical reference value for its development. This study proposes the concepts and associated contents of landsenses ecology and mixed marching data and explains the role of the meliorization model and Internet of Things (IoT) in landsenses ecology-based land-use planning, construction, and management. Utilizing the results of bibliometric research, this study proposes recommendations for the future application and theoretical development of landsenses ecology. These suggestions aim to bolster landsenses ecology application practices and theoretical foundations, enabling a more significant contribution to ecosystem services and facilitating sustainable development strategies.

1. Introduction

The demand for improved environmental quality has been progressively increasing, prominently manifesting in continuous improvement and a growing emphasis on its ability to provide solace and enjoyment to individuals [1]. There is heightened concern regarding everyday environmental health issues, with a desire to reconnect with nature, breathe fresh air, and an ongoing increase in

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the demand for a green living environment. As urbanization advances in China, people's expectations of urban ecological environmental quality are gradually increasing [2]. Simultaneously, urban environmental quality is increasingly being recognized as contributing to human health and well-being [3]. Ecologist Jingzhu Zhao proposed the theory of "landsenses ecology", asserting that urban ecological construction necessitates a comprehensive consideration of factors such as natural elements, physical perception, and psychological cognition. In urban planning, design, and management, attention should be devoted not only to spatial patterns but also to the perceptions of urban residents. This approach advocates the gradual achievement of sustainable development goals [4]. Grounded in modern ecological principles, landsenses ecology emphasizes traditional Chinese ecological thinking, representing an innovative development in China's traditional ecological culture [5].

Landsenses ecology involves interdisciplinary research across various domains. Zhang et al. (2017) explored the connection between classical Chinese gardens and landsenses ecology, focusing on aspects such as garden landscape construction, landsense operations, and ecological aesthetics [1]. Lu et al. (2020) integrated the theoretical framework of landsenses ecology with landscape design and conducted research on the planning and design of wetland parks using landsenses ecology [6]. Landsenses ecology has also been applied to the conservation and restoration of river ecosystems by incorporating landsense creation into ecological protection and restoration projects and evaluating their ecological benefits [7]. In the context of urban parks, researchers have combined landsenses ecology methods with landscaping elements in the study of urban ecosystem services [8].

A quantitative indicator system that characterizes the perceptual effects is gradually being developed. Zhao et al. (2020) proposed use of the green visibility ratio to reflect the perception of pedestrians to the surrounding green environment and developed a method for representing perceptual effects using this ratio [9]. Zhang et al. (2020) constructed the landsenses visibility ratio to characterize perceptual effects [10]. Dong et al. (2022) summarized landsenses ecology indicators encompassing sensory diversity, perceptual coherence, interactivity, susceptibility, stimulation frequency, aftertaste, surprise, distance perception, overlap, and coverage. Collectively, these indicators contribute to an accurate understanding of perceptual effects [5].

While cultivating ecological landscapes, landsenses ecology concurrently reinforces human physical perceptions and psychological cognition, enhancing and expanding the functionality of ecosystem services. Current research predominantly focuses on the dimensions of physical senses, with Shao et al. (2020) proposing optimal visual perception theory as an approach to landsense creation [11]. Considering the visual, auditory, tactile, and olfactory senses, Zheng et al. (2020) established a perceptual indicator system to investigate the relationship between tourist perceptions and the types of ecosystem services provided by urban parks from a landsenses perspective [12]. However, research addressing people's psychological perceptions is limited. Zhang et al. (2021) analyzed the psychological cognitive mechanisms and factors within the framework of landsenses ecology, concluding that the causal chain of "ecological self—visual resonance—self-realization needs—behavior" constituted the perceptual mechanism from psychology to behavior [13].

The connotation and extension of landsenses ecology have expanded through more effective integration with ecosystem services and sustainable development. Despite its rapid development as a novel direction in ecological research, landsenses ecology lacks distinctive theoretical exploration. The differentiation between landsenses ecology and other disciplines, including landscape architecture, landscape ecology, and urban ecology, remains indistinct, and is accompanied by a lack of systematic analysis of an evaluation system for landsenses ecology. This study employed a bibliometric approach, selecting the latest databases from the China National Knowledge Infrastructure (CNKI) and Web of Science (WOS) to analyze research trends in Chinese and international literature. Through a visual analysis of publication quantities, years, authors, institutions, keywords, topics, and research methods, this study explored the research hotspots, advancements, and methodologies in landsenses ecology. This study delved into the uniqueness of landsenses ecology theory; in particular, the differences between landsenses ecology and landscape architecture or landscape design are suggested. This study proposes future research issues, including perspectives on both theoretical and methods of quantification

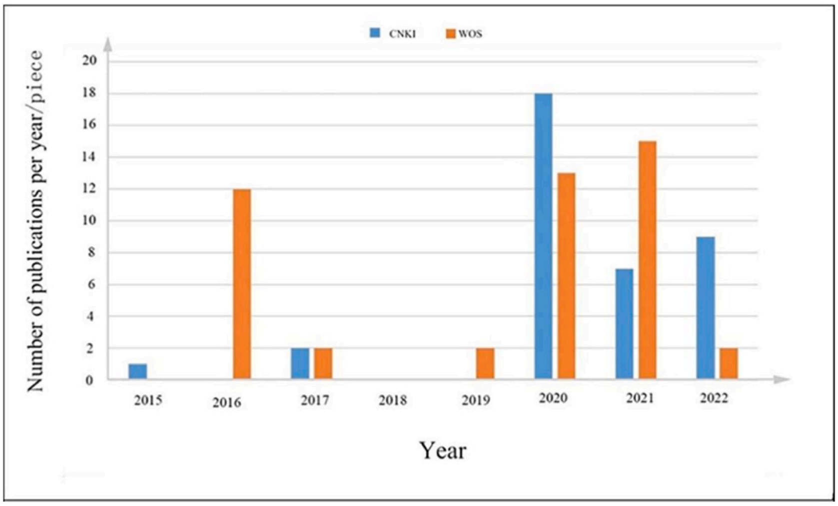


Fig. 1. Published articles on landsenses ecology (2015–2022).

research, and provides a theoretical reference value for the development of landsenses ecology.

2. Data sources and research methods

2.1. Data collection

This study conducted a search of the CNKI database using the keywords landsense, landsense creation, and landsenses ecology. The search scope for CNKI included Peking University Core Journals, the Chinese Social Sciences Citation Index, and Chinese Science Citation Database. Additionally, on the WOS website, an advanced search was performed with the theme subject set as landsenses ecology or landsense for the years 2015–2022. By filtering the titles, abstracts, and keywords of the retrieved articles and excluding those not relevant to the topic, 37 Chinese and 46 English articles were identified, resulting in a compilation of 83 articles (Fig. 1).

Analysis of publication timelines of the 83 articles indicates a comparatively lower number of publications before 2016, with earlier studies predominantly employing terms such as landscape perception and landsense experiences. Notably, in 2020, there was a substantial increase in the publication of English articles (18), whereas in China, the years 2020–2021 saw higher numbers, with 13 and 15 publications, respectively. By 2022, however, there was a decrease in the total number of published articles in both Chinese and English, with only two Chinese articles. The cumulative volume of research studies in landsenses ecology (<100), signifies an insufficient overall quantity, which is indicative of the field's nascent stages with ongoing gradual enhancements in theoretical research.

2.2. Research methods

This study focuses on the literature related to landsenses ecology as its primary research subject. First, a statistical analysis of the literature was conducted using CiteSpace and Excel to obtain foundational data, including article themes, authors, institutions, abstracts, and content. Primarily grounded in co-citation analysis theory and pathFinder algorithms, CiteSpace facilitates the generation and examination of co-occurrence networks for keywords and subject categories, as well as co-citation networks for authors, articles, and journals. Importantly, the tool contributes to the analysis of temporal patterns within a knowledge domain, including identifying rapidly growing thematic areas and citation hotspots as well as discovering points of knowledge inflection [14]. In this investigation, the primary analytical technique employed, bibliometric evaluation, has been demonstrated to be replicable and capable of surmounting biases arising from the knowledge systems and preferences of reviewers, thus offering an advantage over conventional evaluation methodologies. Nonetheless, it is acknowledged that bibliometric approaches may neglect the nuanced authorial insights embedded within the full texts of scholarly articles. A body of research has illuminated the fact that a qualitative examination and interpretation of seminal works, predicated upon the foundation of bibliometric analysis, can serve to ameliorate the inherent limitations of such quantitative methods [15]. This integrated approach ensures a more comprehensive appraisal of the literature,

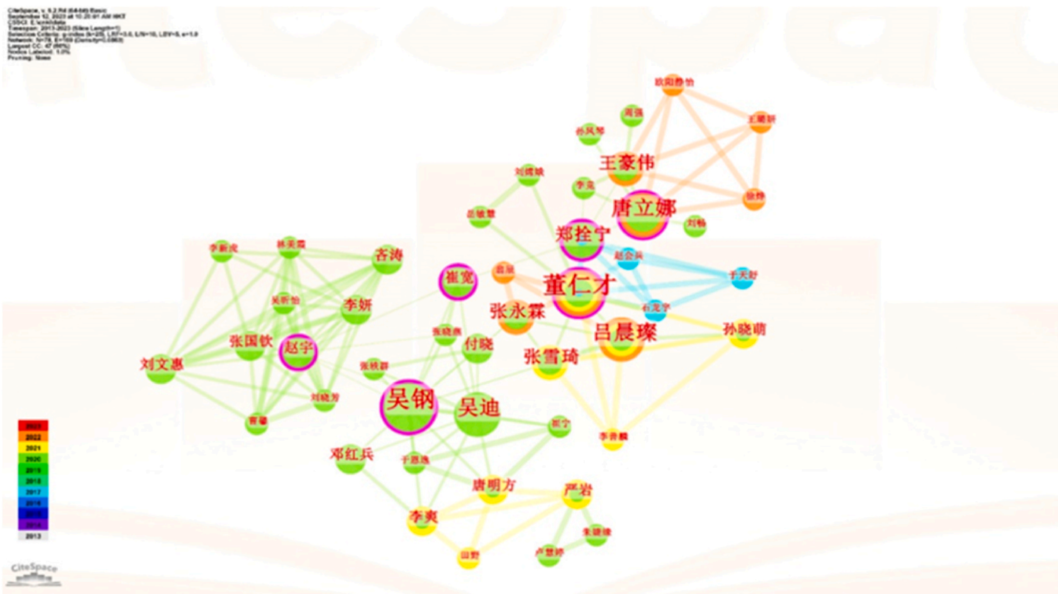


Fig. 2. Network diagram of CNKI published author relationships. In collaboration with the team led by Rencai Dong, the authors who have engaged in the most extensive collaboration are Shuangning Zheng and Yonglin Zhang. Similarly, in association with the team led by Gang Wu, predominant collaborators include Wudi Wu and Hongbing Deng. Furthermore, working closely with the team led by Lina Tang, primary collaborators include Ting Xu's team and Lu Wang's research group.

balancing the breadth of bibliometric data with the depth of qualitative insights. In this research, a comprehensive examination and categorization of the pertinent literature in both English and Chinese have been conducted. Furthermore, an in-depth analysis of the methodologies and perspectives presented by the authors has been undertaken to address the limitations inherent in bibliometric approaches. Subsequently, an analysis was conducted on the focal points of landsenses ecology, encompassing related disciplines, technological keys, and research methodologies, with the aim of elucidating current theoretical deficiencies. Finally future directions for landsenses ecology development are discussed.

3. Results

3.1. *Literature publication characteristics*

3.1.1. *Analysis of authors*

Statistical analysis was performed for authors retrieved from the CNKI and WOS websites using the CiteSpace software to generate author collaboration networks. The generated networks reflect the primary researchers, research teams, and interconnectivity among various research teams. Each circle in Fig. 2 represents a distinct author in the literature, with connecting lines symbolizing collaborative relationships between authors. Different colors represent the year of publication. Among all the first authors, Lina Tang appeared twice, whereas the remaining first authors appeared only once. Notably, the teams of Lina Tang, Rencai Dong, and Gang Wu collaborated seven times with other authors' teams, a relatively high frequency, followed closely by Chencan Lv (five times) and Shuanning Zheng (five times). Teams with fewer than five instances of collaboration with other teams were categorized as having lower collaboration frequencies. The majority of first authors in the English literature originate from China, with Lan Zhang publishing four articles and Rencai Dong and Jingzhu Zhao contributing two. The remaining first authors have published one article (Fig. 3). Considering the collaboration frequencies among author teams, the teams of Gang Wu, Lina Tang, Rencai Dong, Ye Tian, and Yan exhibited relatively high collaboration frequencies (7–9 times), whereas other author's teams had collaboration frequencies <7. These teams collectively constitute the primary research force in landsenses ecology.

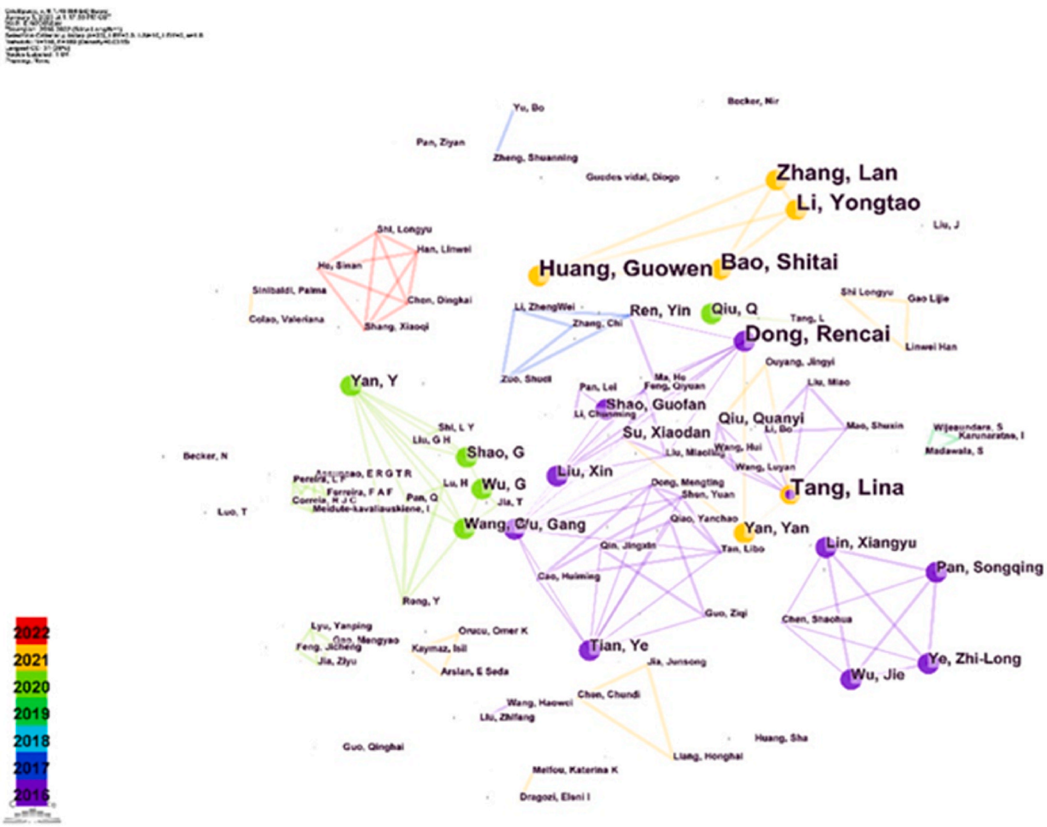


Fig. 3. Network diagram of WOS published author relationships. The authors who have collaborated most extensively with the research team led by Lina Tang include Miao Liu and Shuxin Mao. Likewise, those who have engaged in the highest degree of collaboration with the team led by Yan include Rencai Dong and Xiaodan Su. The researchers who have collaborated most frequently with the team led by Yongtao Li include Guowen Huang and Shitai Bao. Additionally, the authors who have collaborated most extensively with the team led by Lan Zhang include Yongtao Li and Guowen Huang, among others.

3.1.2. Research statistics from CNKI

An analysis of Chinese journals revealed that, among the 37 files examined, 26 originated from *Acta Ecologica Sinica*, (70.27 %). Publications from other journals were scattered, with only one article each, indicating that the current focus of research in landsenses ecology is predominantly within *Acta Ecologica Sinica*, which primarily disseminates original and innovative scientific research results in fundamental ecological theory and applied research. However, future studies on landsenses ecology should consider broadening the scope of journal publications to include a variety of journals. This would increase awareness of landsenses ecology among a wider audience of scholars, allowing for a more effective application of landsense ecological theories.

3.1.3. Research statistics from WOS

The WOS literature is notably concentrated. Specifically, 42 articles were published in the *International Journal of Sustainable Development and World Ecology*, whereas the remaining articles were distributed among the *International Journal of Environmental Research and Public Health* (two articles), *Journal of Cleaner Production* (one article), and *Sustainability* (one article). Compared to the distribution of documents from the CNKI, source journals were more concentrated. Within the Chinese literature, 74.36 % was sourced from *Acta Ecologica Sinica*, whereas a substantial majority of English literature was heavily concentrated in the *International Journal of Sustainable Development and World Ecology* (91.3 %).

3.2. Analysis of research hotspots

By conducting a co-occurrence network analysis of keywords from landsenses ecology articles in the CNKI database, a visualization of frequently occurring keywords was generated (Fig. 4). Larger nodes in the graph represent a higher frequency of occurrence, whereas the lines connecting keywords denote associations. Increased interconnections signify wider relationships with other keywords, with line colors indicating the respective years. A higher frequency of occurrence of a particular keyword or category of keywords within published literature signifies its relevance as an industry hotspot. Centrality, a commonly used concept in network analysis, measures the degree to which a vertex or node in a network serves as a "bridge" within the entire network.

In the Chinese literature, landsense creation appeared 14 times, being the most frequently occurring keyword, with a centrality of 0.24. Following were ecological restoration (thrice), landscape design (twice), the Internet of Things (twice), landsenses ecology (twice), and urban parks (twice) (Table 1). The remaining keywords appeared once only. This trend reflects the current focus in landsenses ecology, centered on landscape sensing and ecological restoration, emphasizing the design of habitable environments conducive to residents' lifestyles while prioritizing ecological conservation.

Visualizing keyword frequency and connections in the English-language literature from the WOS website revealed that landsenses ecology appeared 33 times (Fig. 5). Following were "ecosystem services" (eight times), sustainable development (six times), and ecological planning (six times), all ranking high in frequency (Table 1). Calculations using CiteSpace indicated a centrality value of 1.22 for landsenses ecology, 0.32 for ecosystem services, and 0.11 for grand canal, whereas other keywords had centrality values below 0.1, which signified the current research hotspots in landsenses ecology revolve around ecosystem services, green spaces, and urban settings, correlating to landscape sensing, encompassing studies in human habitats and advancements in ecosystem services.

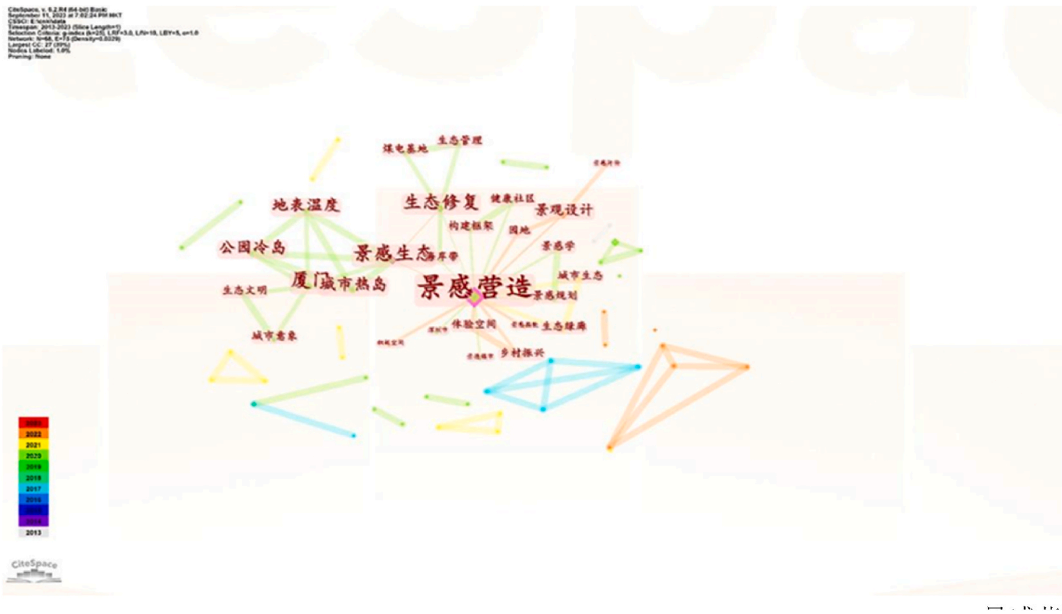


Fig. 4. Correlation network diagram of high-frequency keywords in the CNKI. In here, 景感营造means landsense creation, 生态修复means ecological restoration, 景感生态means landsenses ecology, 景观设计means landscape design, and 城市公园means urban parks.

Table 1
Frequency and concentration of keywords in the CNKI and WOS literatures.

CNKI database			WOS database		
Keyword name	Frequency	Concentration rate	Keyword	Frequency	Concentration rate
landsense creation	14	0.24	landsenses ecology	33	1.22
ecological restoration	3	0.03	ecosystem services	14	0.32
landscape design	2	0.02	sustainable development	8	0.03
Internet of Things (IoT)	2	0.00	ecological planning	6	0.00
landsenses ecology	2	0.11	landsense creation	6	0.02
city park	2	0.00			

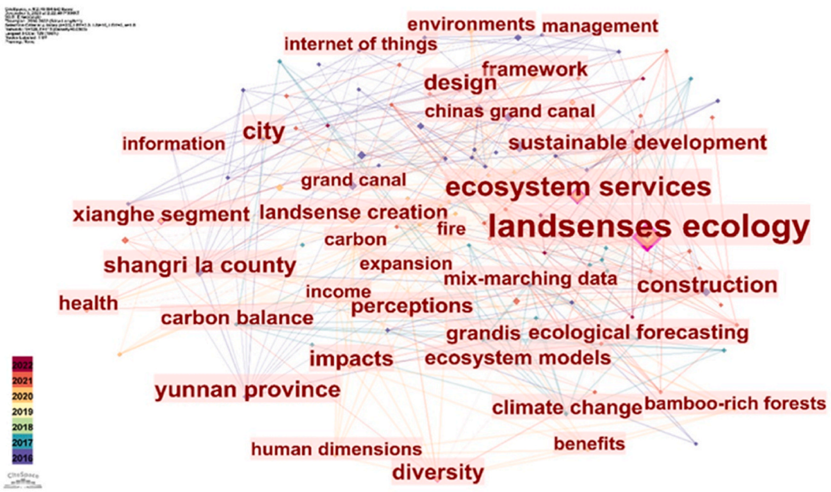


Fig. 5. Correlation network diagram of high frequency keywords in the WOS.

Comparing the keyword concentrations in these studies, high-frequency keywords exhibited disparities. The CNKI literature demonstrated a more dispersed focus, with a lower concentration of high-frequency keywords compared to that of the WOS literature; for example, landsenses ecology occurred 33 times, with a concentration of 1.22. Content-wise, the WOS literature emphasizes ecological design and sustainable development, whereas the CNKI literature predominantly focuses on landscape sensing.

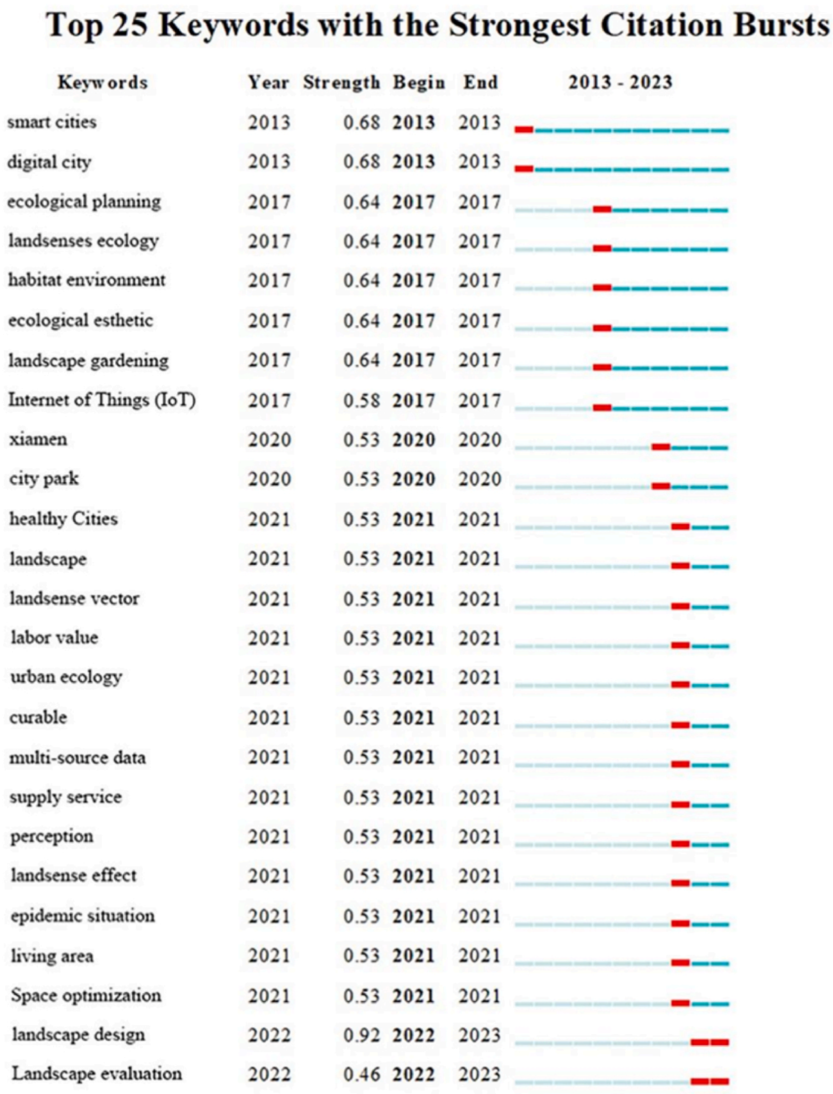
3.3. Research trends

Burst terms refer to terms that emerge suddenly and undergo significant frequency changes within a relatively short period. Burst terms comprehensively and dynamically reflect evolutionary trends and cutting-edge developments in a research field, thereby effectively exploring future research avenues. Analyzing burst strength (BS) using the Burstness module in the CiteSpace software facilitated a comprehensive exploration of the evolving research landscape by highlighting pivotal terms.

A timeline analysis of burst terms in Chinese literature derived from the CNKI and WOS databases revealed that before 2017, Chinese literature on landsenses ecology predominantly focused on research in smart (BS 0.68) and digital cities (BS 0.68) (Fig. 6). Smart cities leverage information and communication technologies to sense, analyze, and integrate critical information from the core systems of urban operations (Yao et al., 2023). Functionally, the smart city framework includes a perceptual layer aimed at guiding new forms of urban interaction through deeper perception. Landsenses ecology is aligned with physical perceptions, psychological cognition, and the concept of smart cities. During 2017–2020, research emphasized residential environments (BS 0.64) and urban parks (BS 0.53), with a concentration at the city level. Post-2021, the research shifted focus to perception (BS 0.53), landsense effects (BS 0.53), and supply services (BS 0.53), with a transition from the city–regional scale to the residential area scale. Examining burst terms in conjunction with the literature revealed that landsenses ecology has increasingly been applied to enhance landsense effects at the urban scale, with recent studies concentrating on the individual perceptions of urban residents, considering landsenses ecology as a method for studying how landscapes provide perceptual services to city dwellers.

Analysis of burst terms and the occurrence timeline in the WOS indicated that from 2016 to 2017, research predominantly focused on ecological planning (BS 2.59), ecological restoration (BS 1.27), and the carbon–oxygen balance (BS 0.62), covering larger scales, such as watershed and provincial regions (Fig. 7). During this period, attempts were made to integrate landsenses ecology with sustainable development studies. During 2020–2021, the focus shifted toward visual perception (BS 0.9) and psychological cognition (BS 0.85), gradually shifting attention to the individual use of landscape facilities and perceptions within the landscape environment.

The trends observed for landsenses ecology in the WOS aligned with those observed in the CNKI. Studies published in both domestic



Top 25 Keywords with the Strongest Citation Bursts

Keywords	Year	Strength	Begin	End
smart cities	2013	0.68	2013	2013
digital city	2013	0.68	2013	2013
ecological planning	2017	0.64	2017	2017
landsenses ecology	2017	0.64	2017	2017
habitat environment	2017	0.64	2017	2017
ecological esthetic	2017	0.64	2017	2017
landscape gardening	2017	0.64	2017	2017
Internet of Things (IoT)	2017	0.58	2017	2017
xiamen	2020	0.53	2020	2020
city park	2020	0.53	2020	2020
healthy Cities	2021	0.53	2021	2021
landscape	2021	0.53	2021	2021
landsense vector	2021	0.53	2021	2021
labor value	2021	0.53	2021	2021
urban ecology	2021	0.53	2021	2021
curable	2021	0.53	2021	2021
multi-source data	2021	0.53	2021	2021
supply service	2021	0.53	2021	2021
perception	2021	0.53	2021	2021
landsense effect	2021	0.53	2021	2021
epidemic situation	2021	0.53	2021	2021
living area	2021	0.53	2021	2021
Space optimization	2021	0.53	2021	2021
landscape design	2022	0.92	2022	2023
Landscape evaluation	2022	0.46	2022	2023

Fig. 6. Keyword emergence chart of the CNKI articles. Year represents the initial appearance year of the keyword, whereas Begin and End signify the commencement and conclusion years when the keyword serves as a frontier. The red lines delineate the specific chronological phases during which the keyword evolves into an academic research hotspot. Light blue indicates nodes that have not yet emerged, whereas dark blue signifies the initiation of node appearance. BS denotes the degree to which the keyword's frequency of occurrence during a specific period deviates from its average frequency.

Chinese journals and international English journals collectively reflected the developmental process of landsenses ecology from initial concentrated large-scale theoretical application studies to recent studies, particularly post-2020, which emphasized research on how landscapes provide perceptual services to individuals.

3.4. Literature theme analysis in the CNKI

A statistical analysis of themes in the sample literature revealed that the subject of landsenses ecology was the primary focus in most of the 35 articles, with no more than five articles dedicated to any other theme. Notably, themes such as ecological perspective (five), urban parks (four), ecosystem services (four), ecological concepts (three), and ecology (three) displayed the highest frequencies. Examining the distribution of secondary themes, landsense creation emerged as the predominant theme in 24 articles, followed by nine articles related to ecosystem services. Secondary themes included the melioration model, ecological civilization, ecological theory, mountains, waters, forests, fields, lakes, grass, noise pollution, and water purification, all of which are intricately linked to research revolving around landsense creation.

There has been limited research on assessment methods for landsense creation. Liu et al. (2020) proposed the concept of landsense

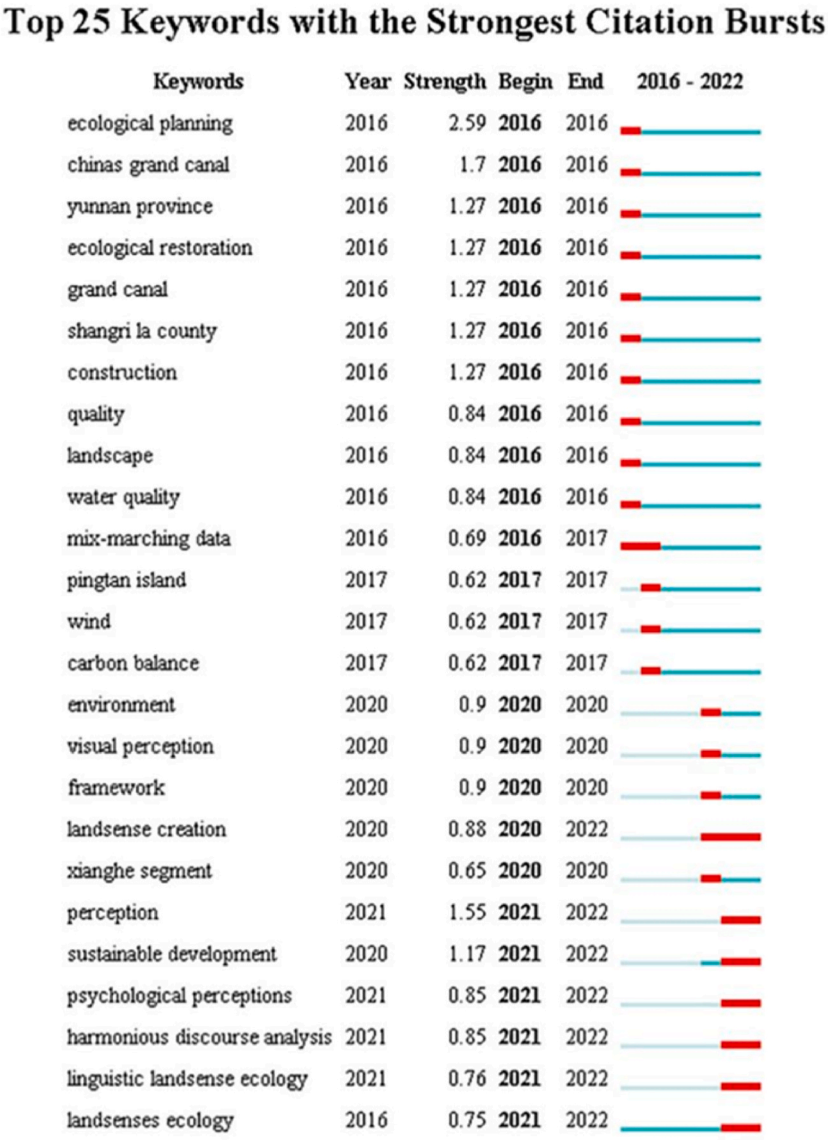


Fig. 7. Keyword emergence chart of WOS studies.

creation value to characterize its effectiveness [16]. The researchers employed five different quantitative assessment methods based on the characteristics of landsense elements. The distribution of secondary themes reflected distinctive research approaches and methods in landsenses ecology, encompassing the melioration model, analysis of landsense aspects from the perspectives of ecosystem services and psychological cognition, and the application of IoT. The core concept of the melioration model is that "there is no best result, only a better method,"embodying continuous regulation and improvement during the operational process. The ultimate goal is not the optimization of a singular phase but the synchronous intersection, mutual coordination, and regulation of goals and constraints, leading to the continuous improvement of comprehensive objectives [17].

3.5. Disciplinary analysis of literature

In the statistical analysis of disciplines covered in the WOS articles, 46 English articles spanned 29 disciplines, as classified according to the categories in the "2020 Web of Science Core Collection Help." Notably, more than five articles were found in 10 disciplines, all intersecting with the field of *Environmental Science and Ecology*, with 44 articles spanning the realm of *Science and Technology*. Within this corpus, 28 articles delved into *Biodiversity Conservation*, 23 explored *Anthropology*, 15 delved into *Economics*, and 11 pertained to *Psychology*. Additionally, a smaller number of articles addressed topics such as *Agriculture, Meteorology and Atmospheric Science*, *Public Environmental and Occupational Health*, and *Sociology*. Statistical analysis of the disciplinary orientation of

English articles on the WOS revealed a predominant focus on *Environmental Science and Biodiversity Conservation*, with a noticeable emphasis on the study of human perception in the landscape from the perspectives of *Behavioral Science and Sociology*.

Simultaneously, a classification of disciplines for articles published in the CNKI revealed that *Architecture* dominated with 25 articles, followed by 13 articles on *Environmental Science*. Other disciplines such as P*hysical Geography* encompassed only seven articles, whereas the quantity of articles in fields such as *Forestry* and *Meteorology* was limited, with only one article each.

3.6. Landsense evaluation methodology

Landsenses ecology emphasizes enhancing urban living environments and fostering subjective well-being. Consequently, in establishing an evaluation framework, the discipline often selects indicators from two key perspectives, encompassing both the objective physical environment and the subjective perceptual realm. Indicators of the objective physical environment included ambient temperature, humidity, noise levels, and landscape element types. The subjective perceptual aspects involved quantitative assessments of visual perception and psychological cognition. Through a statistical analysis of 30 Chinese- and English-language articles containing methods for landscape perception assessment, six categories of landsense evaluation methods were identified, including online data semantic segmentation methods, psychological experimental methods (eye tracking, electroencephalogram signals, and electrocardiograms), physical monitoring and analysis methods, subjective perception methods, image semantic segmentation, and geographic information system (GIS) visual analysis (Table 2).

3.6.1. Semantic segmentation evaluation

As a form of deep learning methodology, semantic segmentation was integrated into the landsenses ecological evaluation model. Semantic segmentation is a classification technique in computer vision technology that autonomously partitions landscape elements along their respective boundaries within an image [46,47]. Researchers have endeavored to extract semantic information from texts and images to represent tourists' psychological perceptions of landscapes. Zheng et al. (2022) employed semantic segmentation to discern and quantify semantic data from visitors' comments on urban parks, subsequently establishing a landsense evaluation model based on quantified data [18]. Yan et al. (2023) used the DeepSentiBank model to extract psychological perception data from visual semantics of location photos posted by tourists [19]. Through deep learning methods, they modeled and analyzed human perceptions of urban landscapes using probabilities to characterize the indicators of subjective human perception. These approaches primarily involve the use of web scraping tools to acquire online textual or image data, thereby offering the advantage of a large dataset to mitigate issues associated with excessive data subjectivity. Additionally, these methods yield geographically referenced datasets, enabling the visualization of spatial landsense experience patterns.

3.6.2. Subjective perception evaluation

Landsenses ecology emphasizes the subjective perception of individuals within landscape spaces, records people's subjective experiences through questionnaires, and analyzes the collected data to evaluate individuals' subjective perceptions of these spaces. Researchers have employed diverse approaches to questionnaire design, demographic requirements for respondents, and questionnaire data analysis methods. Kalivoda et al. (2014) used kernel density analysis to conduct hotspot analysis of preferred locations while studying cultural landscape perception in ecosystem services research [29]. Chen et al. (2021) incorporated photographs into questionnaires and acquired tourists' subjective perception data regarding landscape spaces through the perceptual ratings of these images [37]. Most studies analyzed questionnaire data using methods such as correlation and multiple regression analyses, and structural equation modeling to derive evaluations of people's subjective landscape perceptions. Direct questionnaire analysis yielded data on individuals' landscape perceptions, yet often entailed a high degree of subjectivity. Furthermore, evaluations provided by different demographic groups may have diverged. In the future, the integration of subjective indicators with objective measures could establish a landsense evaluation framework while mitigating the impact of demographic variations on evaluation outcomes.

3.6.3. Physical monitoring assessment

Individual perceptions of the external environment stem from landsense reactions to their physical surroundings. In an effort to incorporate physical environmental indicators into landsense evaluation frameworks, some studies have employed electronic instruments to measure changes in the physical environment. Li et al. (2022) selected temperature, sound pressure level, and brightness as comprehensive evaluation factors, whereas Hedblom et al. (2019) opted for spatial landsense evaluation indicators such as vegetation type, terrain height, and water coverage [26,27]. These methods prioritize landsense experience objectivity and offer the advantage of mitigating the risk of weak perceptual universality resulting from the autonomy inherent in subjective perception surveys. However, the current indicator systems remain deficient.

3.6.4. Computerized interpretation assessment

Researchers have employed computer software programming methods to digitally interpret landscape images and assess individuals' perceptual feedback within specific spaces. Xu et al. (2020) used Photoshop to establish selections for natural elements and subsequently evaluated spatial perception by determining the proportions of these elements in a scene based on the ratio of pixel count to photo pixels [42]. He et al. (2021) analyzed the visual elements of onsite photos captured by surveyors during field investigations using computer programs [32]. Through application of the Cat's Eye Quadrant program, the researchers quantified the number of people, amount of vehicular traffic, and area ratio within the photos to develop a landsense evaluation system based on photographic data. This approach circumvents the measurement inaccuracies and excessive subjectivity of questionnaire surveys. However, to

Table 2
A review of landscape perception evaluation methods.

Landsense evaluation methodology	Description of evaluation methodology	Literature source
Online text semantic segmentation	1. "Microblog comments" were used as the data source and the sensory and design element thesauri as the basis for discriminating high-frequency words.	Zheng et al., 2022 [18]
	2. "2BULU" website location photo data were used as the data source and the DeepSentiBank model was used to extract visual semantic results from location photos.	Yan et al., 2023 [19]
	3. "Ctrip" review data were used as the data source and the ROSTCM6 software was used for vocabulary segmentation.	Zhou et al., 2023 [20]
	4. "Ctrip/Where to go/Popular Dianping (snapshot)" online review data were used as the data source, and Baidu API sentiment analysis technology was used to categorize the data.	Liao et al., 2023 [21]
Experimental methods; eye-tracking, EEG signals, ECG.	1. The Tobii Pro on-screen eye-tracking device, gaze duration, first gaze duration, total gaze duration, and the proportion of gaze duration in each region were used as indicators.	Ding et al., 2023 [22]
	2. Brain activity signals were captured using five landscape videos via 32 channels of Brain Products (LiveAmp).	Wang et al., 2022 [23]
	3. A Tobii Fusion 250 Hz telemetric eye-tracker with binocular infrared tracking technology), electroencephalographic (EEG) signal activity, skin conductive (EDA) signal activity, electrocardiographic (ECG) signal activity, was used.	Qin et al., 2023 [24]
	4. An SMI mobile eye-tracker was used to evaluate human perception of three types of landscapes via a dataset of gaze counts and times.	Guo et al., 2021 [25]
	5. A Toppy "broad-spectrum" professional eye-tracker considered average gaze duration, gaze frequency, and average eye-roll amplitude as quantitative indices to evaluate landscape perception.	Wu et al., 2022 [26]
Physical monitoring, measurement data	1. Angular resolution (for visual ability or acuity to distinguish minute details of objects), visual acuity, optimal visual distance.	Shao et al., 2020 [11]
	2. Temperature, sound pressure level and luminance value were selected as comprehensive evaluation factors	Li et al., 2022 [27]
	3. The relationship between landscape perception and physical inspection data (vegetation type, terrain height, water cover) was explored.	Hedblom et al., 2019 [28]
Subjective perception evaluation – questionnaire	1. Self-administered questionnaire for 400 hikers: the questionnaire was represented by illustrations and hikers were asked to assess the visual aesthetic quality of each scene.	Kalivoda et al., 2014 [29]
	2. Questionnaire regarding participants' perceptions of the distribution of LULC (ground cover), including the degree of cover and fragmentation.	Saldias et al., 2021 [30]
	3. Mail surveys were collected and 630 were returned with relevant data, including information on residents' perceptions, evaluation, identification and use of the landscape.	Soini et al., 2012 [31]
	4. Information was collected through random questionnaires, including basic socio-economic attributes of cyclists, and greenway use characteristics, particularly cycling activity during specific time periods (weekdays and non-weekdays).	He et al., 2021 [32]
	5.858 valid questionnaires were collected from 58 cities. Participants were asked to assess their perception of the local landscape quality and sense of belonging to a local place.	Wartmann et al., 2022 [33]
	6. Pictures of different types of landscapes were viewed and different types of sounds were simultaneously listened to, recording the sound parameters. A questionnaire was completed to evaluate various aspects of the landscape, including aesthetics, comfort, naturalness, etc.	Duan et al., 2022 [34]
	7. Questionnaire design; three aspects: environmental design, cultural image perception and place perception; and image-building indicators, such as visibility, image, brand value, etc. Indicators of place perception: cognition, satisfaction, loyalty, etc. Indicators of cultural landscape design: integration of cultural elements, degree of humanized design, environmental protection, etc.	Zhang et al., 2023 [35]
	8.180 university students studying different disciplines were recruited as participants and divided into a professional group studying landscape architecture and a non-professional group studying other disciplines. The participants were randomly divided into nine groups, and each participant in a group was asked to experience one type of urban green space using one method. Data were obtained by completing a questionnaire.	Gao et al., 2019 [36]
	9. The method used was an online survey, taking photos of the natural vegetation in major parks and designing a questionnaire to be collected on a specialized website to investigate the views of Shanghai residents on natural vegetation.	Chen et al., 2021 [37]
	10. The questionnaire was established with photos of different degrees of nature for different urban research subjects to select from, and the research subjects were analyzed using demographics.	Kaymaz et al., 2021 [38]
	11. The questionnaire consisted of 18 observational variables, including: physical perception, aesthetic perception, psychological perception, and perception of public facilities. 399 community residents were surveyed with an effective rate of 89.26 %.	He et al., 2022 [39]
	12. Average scores on all viewpoints were computed to compare the difference between virtual and actual scenes.	Shi et al., 2020 [40]
	13. Information was collected on the influence of three-dimensional transportation on landscape preference through a questionnaire survey (containing two aspects: basic information of the participant, and preference and influence of landscape quality on the participant).	Li et al., 2012 [41]
Image semantic segmentation (computer software)	1. A selection of natural elements was created using Photoshop (trees, grass, bodies of water), after which the number of pixel sources was adjusted depending on the pixel ratio of the photograph.	Xu et al., 2020 [42]
	2. A computer program was used to analyze and calculate the visual elements of the site photographs (nodes) taken by the investigators during the field survey. The number of people and motor vehicles and the area ratio in the photographs were quantified using the application program "Cat's Eye Quadrant".	He et al., 2021 [32]

(*continued on next page*)

Table 2 (*continued*)

Landsense evaluation methodology	Description of evaluation methodology	Literature source
	3. Features of the real-time pictures were extracted, where all the important attributes of the studied area were attached or assigned to the surface, point or line elements, and quantified according to the indicators: skyline curvature, landmark distribution, number of layers on the surface of the buildings, distribution of the opposite view, sky area, landform area and the fractal dimension.	Jin et al., 2021 [43]
	4. The MIT Place Pulse Google Street View (PP-GSV) dataset was used as a sample to train the model, after which the panoramic images of the Beijing Tencent Street View (BJ-TSV) dataset were used as a data source, parameterized by crowdsourced evaluation using an online platform to determine perceived intensity.	Zhang et al., 2021 [44]
Geographic information system (GIS) visual analytics	1. By coding the feature points (core viewpoints), landscape perception was assessed by the number of feature points in the area.	Guo et al., 2022 [45]
	2. Using the GIS 9.3 desktop version to construct a 3D model, the ecological perception value of the entire space was obtained by calculating the pixel value, buffer superposition, and direction calculation after weighting the ecological sense of each location.	Li et al., 2012 [41]

ensure its viability, a comprehensive elucidation of the foundation and rationale of this method is crucial before its implementation.

3.6.5. GIS visual analysis

GIS is extensively employed in the field of spatial analysis, wherein ecological aesthetics encompass not only an individual's landsense perception of a small-scale scene but also broader spatial awareness or macroscopic spatial perception. Guo et al. (2022) encoded the key features of scenic areas using GIS and evaluated the landsense of these regions through visibility analysis, based on the number of characteristic points [45]. Such methods are well-suited for assessing human perceptions of large-scale scenes at a macroscopic level.

4. Discussion

4.1. The multidisciplinary intersectionality of landsenses ecology

Landsenses ecology exhibits a multidisciplinary trend with close ties to the architectural and environmental science disciplines (Fig. 8). The primary focus of landsense research is the creation of landsense experiences. The alignment between landsenses ecology and areas such as landscape design and architectural science, which encompass landscaping and landscape planning, is particularly noteworthy [6,19]. The inevitable integration of landsenses ecology with environmental science and resource utilization signifies its intrinsic development, gradually extending its application to ecological restoration and design [48,49]. The convergence of landsenses

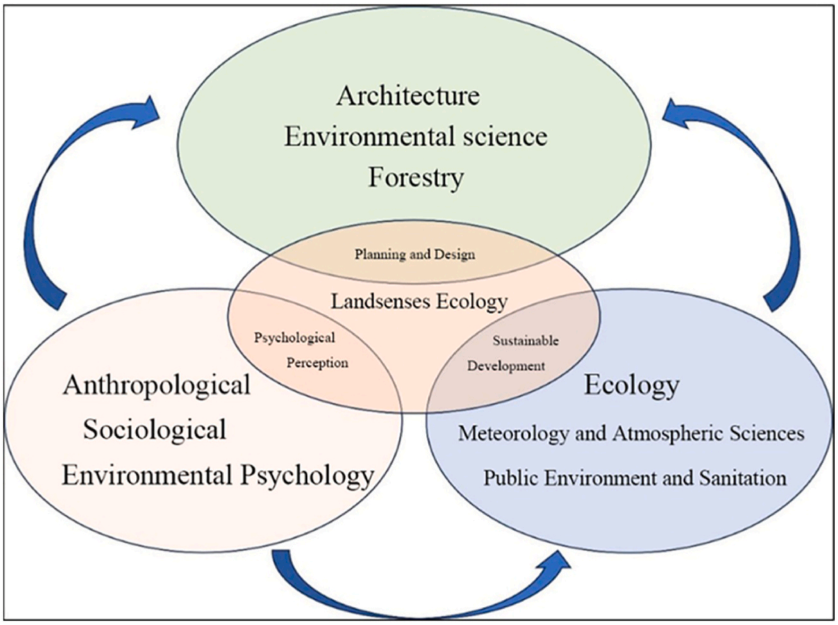


Fig. 8. Multidisciplinary research diagram for landsenses ecology. The disciplines within the light green, flesh-colored, and blue circles correspond to application of landsenses ecology theory at the planning and design, psychological perception and sustainability levels, respectively. The deep blue curved arrows represent the interactive relationships among these three categories of disciplines.

ecology with other disciplines such as electronic information and aesthetics in art demonstrates a promising interdisciplinary nature. Combining with artificial intelligence (AI) could establish a proactive assessment system for landsense experiences [50]. Integration with IoT technology has enabled the effective capture of physical information pertaining to various landscape elements after landsense creation, contributing to a refined evaluation system for landsense experiences when combined with human perceptual factors [51]. Additionally, the fusion of artistic aesthetics with landscape architectural techniques creates landscapes that better align with human landsense enjoyment.

Landsense serves as a scientific foundation for understanding both the physical and psychological aspects of human perception in spatial construction, extending beyond mere environmental beautification effects [5]. The theoretical framework of landsenses ecology comprises three key aspects: sustainable ecological goals; construction methods and measures for landsense creation; and research on the perceptual effects of landscapes on individuals [17]. Mao et al. (2021) investigated the relationship between the landsenses ecological effects of multifunctional urban green spaces, and the leisure services related to green spaces from the perspectives of visual, tactile, auditory, directional, and psychological perception [52]. This study covers landscape ecology and design, and environmental psychology. As the demand for high-quality environments intensifies, there is growing emphasis on visual perception and psychological cognition in spatial environments. However, current research does not incorporate psychological perception into ecologically oriented environmental construction with sustainable development goals. Landsense assessment and creation, and ecological impact evaluation still lack accurate expression. Although Deng et al. (2020) proposed methods for assessing the cultural and aesthetic values of landsenses ecology and provided cases for landscape aesthetic value assessment, a universally accepted quantitative evaluation method remains elusive [53]. Establishing a methodological framework that seamlessly integrates psychological cognition, sustainable development, and ecological environmental protection is imperative for landsenses ecology [53].

4.2. Disciplinary boundaries of landsenses ecology

Currently, there is no distinct demarcation between landsenses ecology and landscape architecture. Dong et al. (2022) posit that the relationship between landsenses ecology and landscape architecture is close, with landsenses ecology inheriting rich elements from Chinese classical philosophy but evolving within the context of modern information and sensor technologies [5]. The predominant research methods involve reductionist, analytical, and quantitative analyses. The discipline identified in this study, landsenses ecology, is aimed at sustainable development, encompassing a holistic consideration of factors such as individuals' physical perception and psychological cognition of space. It focuses on the construction of landsense experiences in spatial environments. Compared to traditional ecology, landsenses ecology incorporates the theory of environmental–behavioral relationships, where the relationship between environmental stimuli and landsense evaluation constitutes the mechanism for landsense creation, ultimately aiming for sustainable development. In contrast to landscape architecture, the ecological and sustainable aspects of landsense creation are overlooked and lacking in landscape architecture.

In terms of research methodology, landsenses ecology primarily involves the quantitative analysis of human perceptual experiences, aiming to inform more rational planning and design based on the obtained results [54]. Both disciplines share a common foundation in prioritizing human-centric approaches; however, landsenses ecology places greater emphasis on objective and indirect environmental factors influencing human perceptual levels [55]. In contrast, landscape architecture predominantly originates from aesthetic preferences inherent in human beings. The application of both landsenses ecology and landscape architecture seek to create more pleasant environments through design, adhering to a people-centric philosophy that prioritizes human needs and perceptions. This distinction lies in the immediate impact of post-implementation on landscape architecture, which is challenging to update or renovate after prolonged use. Ecological landscape architecture does not maintain the initial design. In contrast, the application of landsenses ecology benefits from the pursuit of sustainable development goals and implementation of optimization models [50]. This aligns more closely with the requirements of ecological civilization strategies. Moreover, in terms of human perception, landsenses ecology aided by a more sophisticated assessment system better fulfills the spiritual needs of individuals.

4.3. Application of landsenses ecology

Landsenses ecology is predominantly applied in practical project engineering, such as urban planning and landscape design, and contributes to the pursuit of sustainable development goals. The application of landsenses ecology encompasses spatial multiscale features, ranging from the creation of landsense experiences in outdoor spaces as small as a few dozen square meters to the adjustment of land-use planning for all regions. These diverse scales demonstrate the constructive dimensions within which landsenses ecology can enhance environmental perceptual levels (Table 2). Zhao et al. (2020) explored the enhancement of ecological services in urban ecological spaces from the perspective of landsenses ecology, focusing on the Shunyi District in Beijing [9]. In a longitudinal process, Lu et al. (2020) employed landsenses ecology theory to investigate the planning and design of urban wetland parks, constructed a smart park using environmental IoT technologies, and established a progressive model of gradual improvement [6].

The application of landsenses ecology theory is inseparable from land-use planning, construction, and management. However, within the framework of "landsense," the term "land" implies significance, as different land-use and changes often affect the physical perception and psychological cognition of the public. Zhang et al. (2021) acquired panoramic images with latitudinal and longitudinal coordinates using the Beijing Tencent Street View dataset. Subsequently, the models were trained using the MIT Place Pulse Google Street View dataset to capture the perceptions of beauty, safety, liveliness, richness, boredom, and suppression, thereby enabling the establishment of a perceptual map. Thus, the impact of land-use type on landscape perception was elucidated [44], providing suggestions for urban development aimed at enhancing public perception.

The application of landsenses ecology often necessitates comprehensive monitoring of ecological processes through the integration of IoT technologies to acquire quantitative landsense data. However, the current assessment framework for landsenses ecology has not yet been fully developed, and the diversity of data processing methods has led to variations in evaluation results. The rapid development of AI technology presents an opportunity to enhance the landsenses ecology assessment framework by integrating IoT, coded data, and artificial intelligence technologies, as articulated by Tang et al. (2020) [50].

4.4. Quantitative characterization of landsense

The evaluation framework of landsenses ecology was constructed using various methods, generating diverse assessment indicators for landsense experiences that were broadly categorized into direct subjective and indirect objective indicators. The direct subjective indicators proposed by Dong et al. (2022) include landsense diversity, perceptual integration, susceptibility, stimulus frequency, recollection, acquisition, and spatial perception [5]. The indirect objective indicators introduced by Mao et al. (2021), include touch, wind perception, and orientation [52]. Direct subjective indicators represent individuals' psychological cognizance of spatial environments, whereas indirect objective indicators are generally less directly related to landsenses ecology theory.

Landscape perception, studied from the perspective of environmental psychology, delves into the interactions between environmental elements and human beings. It encompasses human behavioral and emotional responses to external environmental stimuli based on personal sensations, such as visual, auditory, tactile, gustatory, and olfactory perceptions [56]. Landscape perception is primarily characterized by two categories of indicators: physical perception, comprising visual, auditory, tactile, and olfactory dimensions (Table 2); and psychological cognition, including safety, cultural, and ethical dimensions (Tang et al., 2020) [50]. There is considerable research on physical perception indicators; however, the study of psychological cognition remains underdeveloped and lacks a comprehensive indicator system. Han et al. (2021) grounded their work in landsenses ecology theory and Maslow's hierarchy of needs to establish a comprehensive evaluation system for residents' community perceptions, considering physical, psychological, and cultural aspects [57]. Liu et al. (2020) conducted a population landsense assessment via questionnaires [16].

Landsense willingness embodies the comprehensive perception expressed by the subject toward the environment or landsense carriers. Currently, the willingness is obtained primarily through questionnaires and interviews. However, with the advancement and application of social sensing technologies, such as big data and the metaverse, landsense willingness is expected to transition from questionnaire surveys toward integrated evaluations incorporating immersive virtual environments and real-life behavioral assessments. Landscape perception necessitates deep integration of IoT and AI to facilitate efficient acquisition, processing, analysis, and application of data. Advanced information technology is employed to integrate, process, express, and uniformly manage landsense data derived from perceptual functions [5].

4.5. Future issues in landsenses ecology

The evolution of key research themes in landsenses ecology from 2013 to 2022 can be discerned from the co-occurrence networks of keywords (Figs. 4 and 5) and burst terms (Figs. 6 and 7). The research focus transitioned from the initial stages of smart and digital cities to ecological planning and human habitats, expanding further to encompass landscape design and assessment, and psychological perception. This trend suggests a shift in landsense research from large-scale planning and strategic studies to recent investigations of small-scale landscape design, residential areas, human psychological and visual perception. The trajectory of landsenses ecology research is progressing toward human habitat environmental and landsense experiences. Regarding future research in landsenses ecology, exploring the feedback characteristics of human landsense perceptions on landsense effects is crucial. Such exploration is essential for urban planners and designers to maintain, enhance, and augment ecosystem services. As defined by Zhao et al. (2013), sustainable development involves preserving, enhancing, and augmenting ecosystem services to provide sustainable well-being for both contemporary and future generations [58]. Landsenses ecology contributes to the realization of sustainable development objectives.

5. Conclusions

An analysis of the relevant literature on landsenses ecology from the CNKI and WOS from 2015 to 2022 indicated a concentration of research output in 2020, with a subsequent decline in publication numbers. The authors predominantly belonged to a few research teams, with relatively weak interconnectivity among them. Most publications were found in *Acta Ecologica Sinica* and the *International Journal of Sustainable Development and World Ecology*, with most originating from research institutions under the Chinese Academy of Sciences. This lack of a diversified development space underscores the importance of expanding the academic scope and impact of landsenses ecology for future development. The focal points of landsenses ecology include landsense creation, ecosystem services, and ecological restoration with a disciplinary emphasis on architecture, environmental science, and ecological restoration. Commonly employed research methods to quantify landscape perception include online data semantic segmentation, psychological experiments, physical monitoring, questionnaire surveys, software interpretation, and GIS analysis. Quantitative analyses of landscape perceptions have predominantly focused on subjective psychological perspectives, revealing a deficiency in integrated assessments involving both subjective and objective perceptions. Future quantitative analyses of landsense experiences, leveraging deep integration of IoT and AI, necessitate comprehensive studies that encompass both subjective and objective perceptions to facilitate efficient and rapid acquisition, processing, and analysis of perception data, enabling the integration, processing, expression, and unified management of data outcomes with landsenses functionalities.

Landsenses ecology, a major branch of landscape architecture and design, places greater emphasis on perceptual restoration and quantitative evaluation than engineering disciplines. In contrast to landscape and urban ecology, landsenses ecology places a stronger emphasis on planning, design, and practical applications. Future advancements should prioritize stronger integration with VR, AI, and IoT, amalgamating these technologies with perceptual quantification methods to establish a comprehensive evaluation model for landsense creation services, thereby contributing more effectively to global sustainable development.

Data availability statement

The data supporting this study's findings are available upon request, Interested researchers can contact the corresponding author to obtain access to the data.

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Additional information

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Declaration of competing interest

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