Evolution of Hospital Healing Environments in China: A Social Network Analysis

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Abstract
The healing environment in hospitals is of great significance in improving the medical experience of patients and the quality of medical services. In recent years, with the deepening of the people-centered healthcare concept, the design of hospital environments has gradually shifted from being function-oriented to embracing a more humanistic and diversified approach. As an innovative healthcare model, the designing, implementation and evaluation of healing environments must integrate the needs of healthcare workers, patients and families. This study used social network analysis (SNA) to analyze 1291 articles published in the China Knowledge Network (CNKI) database between 1989-2024. Keywords were extracted using the Text-Rank algorithm, and keyword weights and degree of association were calculated using TF-IDF and weighted Jaccard similarity. The network was visualized and analyzed using Gephi software. The study found that research on healing environments in Chinese hospitals has gone through four main phases of development: the exploration phase (1989-1995), the development phase (1996-2005), the stabilization phase (2006-2013), and the extension phase (2014-2024). Emerging keywords from each phase are defined as research topics, which are analyzed through social networks to form six main knowledge clusters. The research theme has gradually evolved from early concerns with spatial layout to a comprehensive multi-dimensional study, including optimization of the physical environment, humanistic care and technological innovation. Research on healing environments of hospitals in China has developed a systematic theoretical framework ranging from functional orientation to humanization. Especially in the last decade, a research paradigm with local characteristics has been established by integrating digital technology and multi-disciplinary knowledge and expanding international perspectives. Future research should further strengthen inter-disciplinary integration, deepen the application of evidence-based design, and promote extensive exchanges with international research.
Keywords: Healing Environment, Hospital Environment Design, Healthcare Environment, Evidence-Based Design, Social Network Analysis, Research Trend, Topics Evolution

Introduction

As an inter-disciplinary field of research that integrates architectural design, environmental psychology and healthcare services, hospital healing environments are of great importance in improving the quality of healthcare, enhancing patient experience and promoting recovery. Since the 1980s, international research on healing environments has formed a relatively mature theoretical system, including supportive design theory (Ulrich, 1991), Attention Restoration Theory (Kaplan & Kaplan, 1989), Biophilic Theory (Ulrich & Gilpin, 2003), Stress Reduction Theory (Ulrich, 1983), etc. According to Ulrich's theory of supportive design, supportive environments can improve the healing process, reduce patient stress and provide other positive outcomes (Ulrich, 1991).

With the emergence of the concept of evidence-based design (EBD), research on hospital healing environments has further emphasized the need to establish an evidence base for evidence-based design (Zimring & Bosch, 2008). Research has shown that improving the healthcare environment through an evidence-based design approach can significantly improve the quality of healthcare services (Malkin, 2007). The study by Rafeeq and Mustafa (2020) showed how optimizing the type of inpatient ward through an evidence-based design approach creates a better healing environment. A study by Rich et al. (2020) validated the effectiveness of supportive design theory in practice and found that optimized design of hospital environments significantly improved patient satisfaction. Today, the design of hospital environments is changing from the traditional functional model to a more humane and intelligent one (Wang & Tzortzi, 2023). Especially in the post-pandemic era of COVID-19, hospital environment design faces new challenges and opportunities, and needs to pay more attention to the safety, comfort and sustainability of the environment (Soalheiro, 2024).

In China, research on healing environments started late, and hospital environment design has its uniqueness. On the one hand, the Outline of the "Healthy China healthy" Plan proposes to integrate the creation of healthy environments into the building of the Healthy China (Cheng, 2022). The design of the hospital environment should be in line with the needs of the times. On the other hand, the influence of traditional Chinese culture on healthcare environments should not be ignored (Wang, 2018). In addition, the accelerated ageing of the Chinese population has placed new demands on hospital environments (Guo, Kong, & Liu, 2023). These factors have influenced the development of research on hospital healing environments in China. However, there is a lack of systematic analysis of the development trend of hospital healing environment research in China. Although studies have been conducted to explore specific factors (He et al., 2018) and evaluation methods (Xu, Yuan, & Cao, 2016) of hospital environments, the overall understanding of the development of research topics and knowledge structure is still inadequate. Therefore, it is necessary to apply scientific methods to systematically research the evolution of healing environments in Chinese hospitals.

With the emergence of network and relational structure studies in the field of academic analysis, there has been a growing interest in methods that applies network and relational analysis (Yang, 2013). Social Network Analysis (SNA) as an emerging research tool, can effectively reveal the relationships and evolution patterns between research topics (Abbasi et al., 2010). By analysing the co-occurrence network of keywords, the knowledge structure and development trend of the research field can be clearly demonstrated (Francis et al., 2024). This method not only identifies research hotspots but also uncovers potential research

opportunities (Martini-Carvell et al., 2024). Therefore, the application of SNA to the research in hospital healing environments can help to reveal the characteristics of the knowledge structure and the evolution of the field.

In summary, the authors conducted through Social Network Analysis (SNA) to systematically analyse the evolution trend of research on healing environments in Chinese hospitals from 1989 to 2024. The specific objectives include: (1) mapping the evolution characteristics of research topics at different historical phase; (2) identifying the structural characteristics of the keyword co-occurrence network and knowledge clustering; (3) exploring the trends of interdisciplinary integration in the research field. Through this study, it is expected to provide new insights into understanding the development patterns of healing environment research in Chinese hospitals and offer guidance for determining future research directions.

Methodology
This study uses Social Network Analysis (SNA) to investigate the developmental trends of research on healing environments in Chinese hospitals. Initially, a search was conducted in the China National Knowledge Infrastructure (CNKI) database using keywords such as "healing environment," "hospital environment design," "health care design," "evidence-based design," and "rehabilitation environment." A total of 1589 relevant articles were obtained. Subsequently, information including titles, abstracts, and years of publication was screened and sorted to exclude duplicates and literature not pertinent to this study. Ultimately, 1291 articles were included in the analysis. The research spans from 1989 (The first literature in this field was published) to 2024.

Data Processing
We used the Text-Rank algorithm to extract keywords from the titles and abstracts of the literature. The researchers systematically processed the data. We deleted numbers and symbols, unified the singular and plural forms of keywords, and merged synonyms and acronyms to normalize the data. Finally, the extracted keywords were checked and summarized to obtain a word frequency matrix. The study used the term frequency–inverse document frequency (TF-IDF) formula to calculate the keyword weights (Amati & Van Rijsbergen, 2002), highlighting the high-frequency and distinguishable keywords in the research field. The TF-IDF weighting formula was calculated as Eq. (1):

$$W_{t,D} = normalized\ tf(t,D) \times log\left(\frac{|Y|}{|\{y \in Y : t\ appears\ in\ y\}|}\right) (1)$$

In the formula, $tf(t,D)$ is the adjusted value of the sum of keyword frequencies in the annual aggregated data, $|Y|$ is the range of years (35 years in total), $|\{y \in Y : t\ appears\ in\ y\}|$ is the number of years containing the keyword. TF-IDF is a weighted metric used in text mining that indicates the frequency of a word in a document. A higher TF-IDF value indicates a higher frequency of occurrence of the word.

To analyse the degree of association between keywords, we calculated the weighted Jaccard similarity (Chowdhury, 2010). Using the annual frequency information from the frequency matrix, the relationship between keywords S and T was calculated using the Eq. (2):

$$Relatedness(S,T) = \frac{\sum_y mina(S_y,T_y)}{\sum_y maxa(S_y,T_y)} \ (2)$$

The distribution hypothesis theory (Harris, 1954) suggests that when two keywords frequently co-occur in the same year, they are considered to have a higher association, resulting in a higher similarity value. This method effectively reflects the associative characteristics of keywords within a specific time period. By treating keywords as nodes and the similarity between keywords as edge weights, a weighted network is constructed. The Markov Cluster (MCL) Algorithm is then applied to cluster the keyword network (Dongen, 2000).

Data Analysis
Based on the trend of annual changes in similarity, the research development process is divided into four main phases: 1989-1995, 1996-2005, 2006-2013, 2014-2024. The network characteristics of each phase are analysed according to the occurrence of keywords. For the network analysis, the correlation of keywords in each stage is calculated using the above method, and input files for Gephi software are generated. The Gephi software is then used for social network analysis and visualization. The authority score of nodes is calculated using the HITS (Hypertext Induced Topic Selection) algorithm to determine the importance of keywords within the network (Kleinberg, 1999).

This study uses methods such as keyword co-occurrence analysis, cluster analysis and centrality analysis from SNA. Keyword co-occurrence frequency and similarity value reflect the distribution characteristics of research topics across different stages, while cluster analysis is used to identify research dimensions and centrality analysis helps to identify the structural features of the network. The size of the nodes is determined by the authority score derived from Gephi's HITS algorithm, which reflects the importance of the research topics. Gephi software is used for visualization, and the relationships between different clusters are interpreted based on the principle of dense connections formed by key nodes. By comparing the social networks at different phases, the study summarizes the evolution of knowledge and the process of theoretical refinement in Chinese healing environment research.

Results
This study collected 1291 articles (518214 Chinese characters) on Chinese healing environment research from the China National Knowledge Infrastructure (CNKI) database. The research spans from 1989 to 2024, and its development is divided into four phases: the exploration phase (1989-1995), the development phase (1996-2005), the stabilization phase (2006-2013), and the extension stage (2014-2024). The keywords similarity index shows an overall trend of gradual increase in the early phase, fluctuation in the middle phase, and stabilization in the later phase, reflecting the gradual standardization and integration of research trends.

Figure 1 shows the evolution trend of keywords similarity in Chinese hospital healing environment research from 1989 to 2024. During the exploratory phase (1989-1995), the similarity index remained relatively low, but showed a peak value in 1995 (0.061). This period was characterized by exploratory research topics and the research paradigm had not yet stabilized. During the development phase (1996-2005), the similarity index showed significant

fluctuations but an overall upward trend. The lowest similarity index was observed in 1996 (0.009), while a peak value was reached in 2004 (0.082), indicating the gradual deepening of research themes and increasing richness of research content.
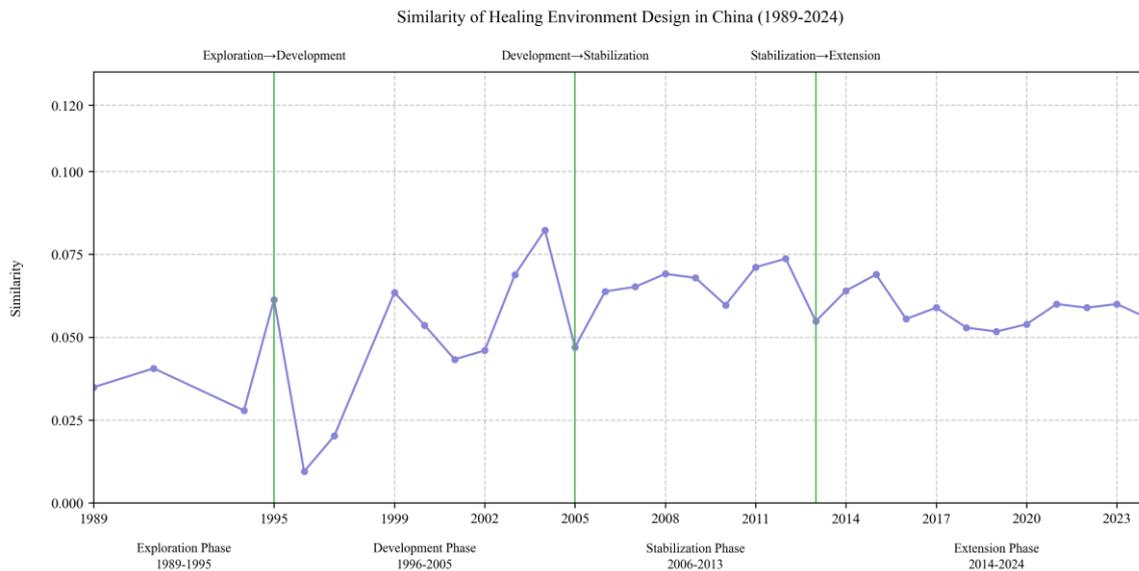

Figure 1: Keywords of similarity in each phase

During the stabilization phase (2006-2013), the fluctuations in the similarity index were significantly reduced, reflecting the maturation of methodology and the establishment of a relatively stable research paradigm. In the extension phase (2014-2024), the similarity index declined slightly but tended to stabilize, suggesting a trend towards diversification of research themes while maintaining a relatively consistent depth of research.

The transition points between phases (1995, 2005 and 2013) were accompanied by significant changes in the similarity index, likely associated with key events such as policy adjustments, theoretical breakthroughs or practical innovations. This trajectory reflects the process of research deepening in the field and provides an important reference for exploring patterns of research evolution.

Figure 2 shows the main keywords and their changing trends in Chinese hospital healing environment research across different phase of development. Analysis of the keyword frequency distribution reveals a significant thematic evolution from 1989 to 2024:
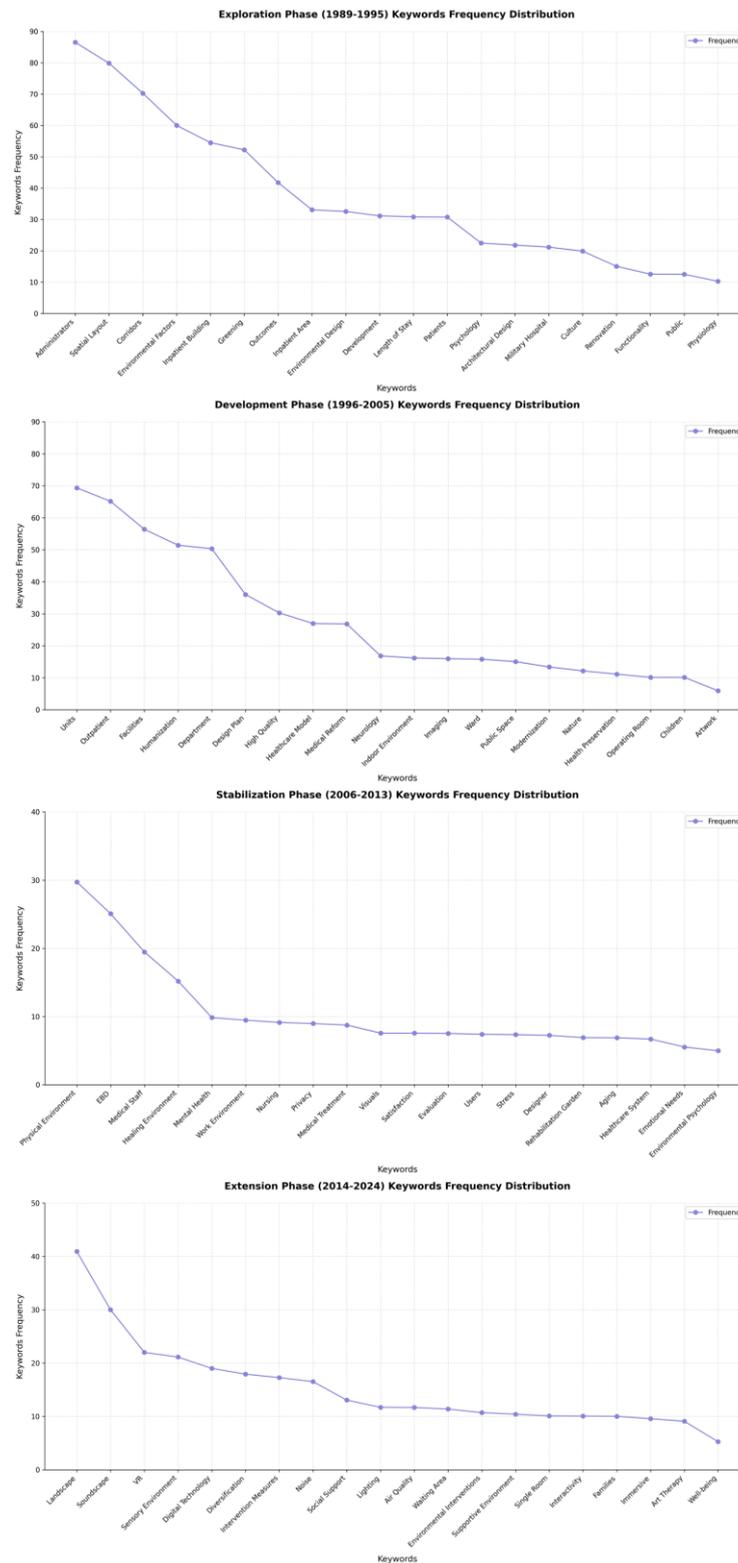
Figure 2: New keywords for each phase (top 20)

Exploratory Phase (1989-1995), research focused on the physical environment and basic infrastructure. Keywords such as "Spatial Layout", "Corridors", "Administrators", "Public", "Military Hospitals", "Greening" and "Outcomes", reflects the development direction of China's healthcare system in the early 1990s.

Development Phase (1996-2005), the focus changed to specific medical spaces. Keywords such as "Ward", "Department", "Outpatient" "Units", "Neurology", "Medical Reform" and "Humanization". This phase reflected a transition in the design of hospital environments from functional to human-centered approaches.

Stabilization Phase (2006-2013), research explored multi-dimensional factors such as "Physical Environment", "EBD", "Healing Environment", "Medical Staff", "Emotional Needs" and "Mental Health". This phase emphasized the integration of theory and practice in hospital environment design.

Extension Phase (2014-2024), the focus expanded to include innovative technologies and specific environmental factors. Keywords such as "Landscape", "VR", "Digital Technology", "Lighting", "Noise", "Interventions Measures", "Art Therapy", reflects a shift from singular physical space design to a diversified and digitized comprehensive development approach.

The process of keywords evolution illustrates the trajectory of hospital environment design in China, moving from an emphasis on the basic physical environment to the optimization of spatial functions, then to the integration of theory and practice, and finally to the balanced development of technological innovation and diversification.

In order to systematically understand the development trends and changes in the knowledge structure of hospital healing environment research in China, this study uses SNA to Identify the relationships between keywords. **Figure 3** shows a network based on the co-occurrence of keywords across each phase with high connectivity and high weighted, resulting in 6 knowledge clusters. The size of the nodes in the figure represents the frequency of keyword co-occurrence, the thickness of the lines indicates the strength of the relationships between keywords, and different colours reflect different thematic clusters. The visualization allows a clear observation of the knowledge structure and thematic distribution characteristics in this filed.
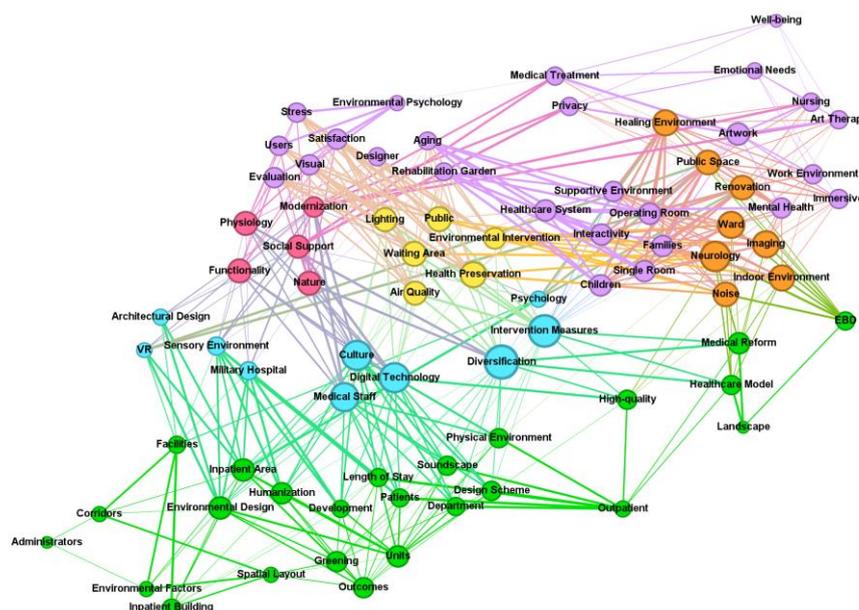

Figure 3: Thematic clusters in healing environment in China

Through social network analysis, Cluster 1 (green nodes) focuses on the infrastructure and function of healthcare spaces, keywords such as "Physical Environment", "Spatial Layout", "Corridors", "Facilities", "Environmental Design", "Outpatient", "Units", "Length of Stay" and "Outcomes". Cluster 2 (purple nodes) focuses on healthcare services and needs, keywords such as "Nursing", "Satisfaction", "Evaluation", "Stress", "Mental Health", "Emotional Needs", "Art Therapy" and "Well-being". Cluster 3 (orange nodes) revolves around environmental experience and Specific space, includes keywords such as "Indoor Environment", "Noise", "Public Space", "Ward" and "Neurology". Cluster 4 (blue nodes) emphasizes technological innovation and humanistic care, including keywords such as "VR", "Digital Technology", "Sensory Environment", "Interventions Measures", "Medical Staff", "Culture" and "Psychology". Cluster 5 (yellow nodes) focuses on specific environmental factors, with keywords such as "Lighting", "Air Quality", "Waiting Area". Cluster 6 (pink nodes) highlights health and humanistic factors, including keywords such as "Nature", "Physiology", "Functionality" and "Social Support". The network structure shows that different clusters are densely connected by core nodes, indicating strong relationships between these research themes. In particular, the frequent interactions between themes such as "Environmental Design", "EBD", "Digital Technology" and "Intervention Measures" shows a multi-dimensional integration trend in Chinese healing environment research.

Figure 4 shows the SNA of keywords co-occurrence at each phase, highlighting the different thematic network characteristics of research on healing environments in Chinese hospitals at different phase.
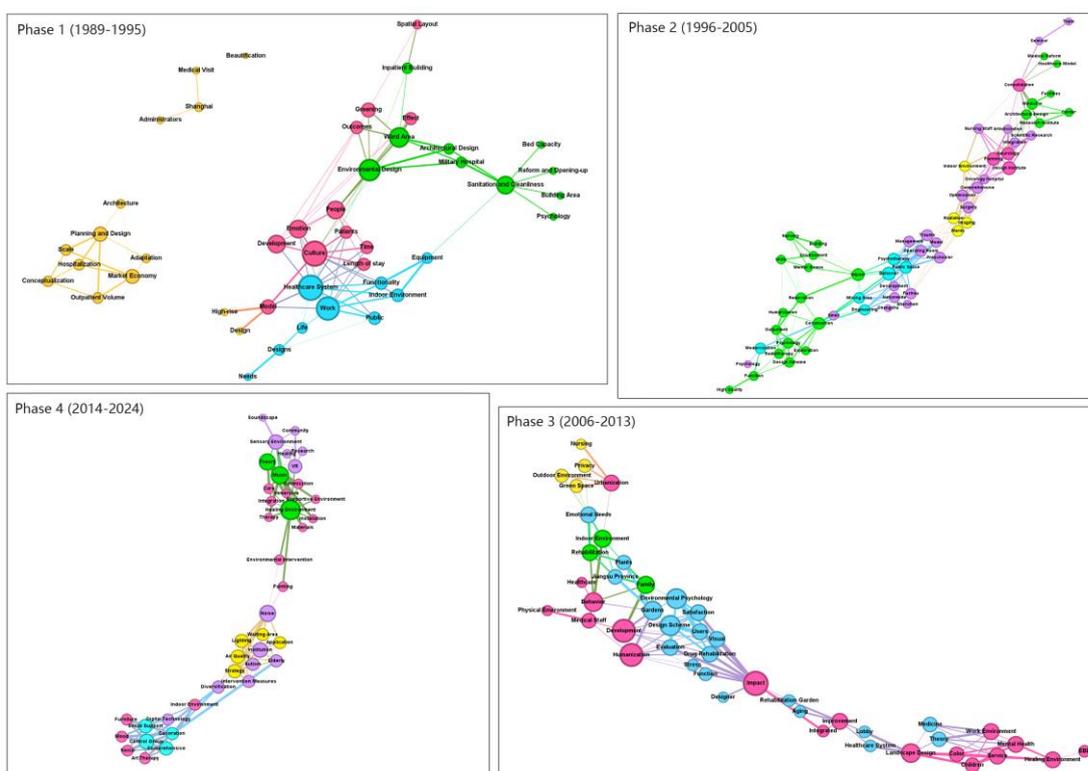

Figure 4: SNA of each phase of healing environment

Exploration Phase (1989-1995), the relatively small number of published resulted in lower connectivity between research topics compared to later phases. The network structure is

more dispersed. A core cluster with "Environmental Design", and two subnetworks focusing on "Administrators" and "Architectural Design". Keywords such as "Spatial Layout", "Corridors" "Indoor Environment" shows that early research focused on spatial studies. Keywords "Length of Stay", "Outcomes", "Emotion" reflect evaluate the effectiveness of healing environments. Keywords such as "Public", "Military Hospitals" reflects the characteristics of China's healthcare system in the 1990s, the research mainly focused on public and military hospitals.

During the Development Phase (1996-2005), there was a closer relationship between the keywords. The high weight values of keywords such as "Psychology" and "Humanization" indicate a shift in research focus from basic physical environments to humanistic care. Keywords such as "Ward", "Neurology", "Units" and "Center" reflect the specification of the research space. The appearance of keywords such as "Shenzhen", "Changsha", "Fuzhou", "Mining Area" and "Oncology Hospital" reflect the research scope more specific, moving from nationwide research to regionally focused research.

The Stabilization Phase (2006-2013) shows a network structure centered around the keyword "Impact," dispersing outward. Keywords such as "EBD", "Healing Environment", "Theory" reflect the development of theoretical frameworks. Keywords "Rehabilitation", "Evaluation", "Satisfaction", "Stress" indicates the impact of healing environments on medical experiences again. Keywords "Users", "Medical Staff", "Family" Indicates that research is beginning to focus on populations other than patients. Keywords such as "Aging" and "Healthcare System" highlight the connection between healthcare and demographic changes.

The Extension Phase (2014-2024) shows a multi-centered and multi-layered network structure. Closely linked clusters are formed around three main themes: "Sensory Environment", "Indoor Environment" and "Healing Environment". Keywords such as "Noise", "Music", "Lighting", "Air Quality", "Materials" reflect the transition of healing environment research from theoretical to practical application, focusing on the optimization of specific environmental factors. Keywords such as "Digital technology", "VR" and "Immersive" indicate the integration of technological innovation and multi-sensory experiences of healing environment research. Keywords "Intervention Measures", "Art Therapy", "Control Group" indicate a transition from observational research to empirical research. Keywords "Autism" and "Elderly" reflect the growing attention to the needs of specific populations.

Discussion
Principal Results
Through social network analysis, this study systematically identifies the developmental and evolutionary patterns of research on healing environments in Chinese hospitals from 1989 to 2024. Based on our analysis, the development of this field was divided into four phases: exploration, development, stabilization and extension. Changes in the keyword similarity index reflect the evolution of the knowledge system in this field. The low similarity during the exploration phase (1989-1995) reflects the thematic dispersion characteristic of early studies. Fluctuations in the similarity index during the development phase (1996-2005) indicate an expansion in the range of research topics. The stabilization phase (2006-2013) shows steady changes in the similarity index, reflects the establishment of a relatively mature research

paradigm. During the extension phase (2014-2024), variations in the similarity index reflect a trend towards diversified development in the field.

There is a significant time gap between this evolution process and international research on healthcare environments. Compared with the systematic research started by Western countries in the 1970s (Ulrich, 1984), related research in China started later, but the speed of development is fast and the integration is strong. Particularly in the last decade, research on healing environments in China has evolved from a sole focus on physical environments to a multi-disciplinary paradigm that includes digital technologies, art therapy and environmental psychology. This is consistent with the concept proposed by Lotem (2018) that technological advances are catalysing a paradigm shift in medicine. The establishment of this research paradigm not only demonstrates China's academic progress in this area, but also reflects its continued pursuit of scientific rigor in the design of healthcare environments.

The keyword characteristics of the Exploration Phase (1989–1995) are based on the social context of China during this period. The research focused mainly on the basic elements of the hospital, such as the physical environment and spatial layout, which were closely related to the practical needs of China at the beginning of the medical system reform in the 1990s (Wang, 2014). Against this background, the design of general hospitals in China has shifted from merely meeting functional requirements to emphasizing the safety, efficiency, and comfort of the medical environment (Lü & Liu, 2005). During this period, increased national investment in healthcare drove improvements and developments in hospital infrastructure (Ruan, 1992). Keywords "Environmental Factors" and "Psychology" indicate that the research has preliminarily recognized the influence of the environment on people. The dispersed characters of the keywords in this period reveal several problems. Firstly, Chinese hospital buildings adopt Western flexible design theories to meet their functional requirements, indicating that the design of Chinese hospitals relies on foreign models (Zhang, Sun, & Jiang, 2001). In addition, the lack of specialized research institutions and stable research teams has made it difficult to establish a sustained and in-depth research paradigm. This research status is consistent with Ulrich described that traditional hospital architecture and environmental design emphasize functionality and efficiency, with insufficient attention paid to the psychological and social needs of patients (Ulrich, 2000). Nevertheless, the exploratory research at this phase laid an important foundation for subsequent development. Through the accumulation of data and practical experience, a research approach to hospital environment design with Chinese characteristics gradually took shape.

The keywords during the Development Phase (1996-2005) reflect a transformative shift. Keywords such as "Humanization", "High Quality", "Modernization", "Medical Reform" are closely related to the developments of this period. In 1997, The State Council of The People's Republic of China "Decisions on Health Reform and Development" clearly proposed the concept of patient-centered service, providing a political foundation for the shift in research focus (The State Council of the People's Republic of China, 2005). With China's accession to the WTO and the opening up of the healthcare market, advanced international hospital management concepts and environmental design methods have flooded into the country, driving a shift in research perspectives (Zhang & Wu, 1996; Wang, 2005). Against the background of healthcare reform, the design of hospital environments has gradually shifted from a purely functional focus to one that emphasizes the social and psychological needs of

individuals, with the aim of creating a human-centered healthcare environment (Tang & Huang, 2004). This is in line with Ulrich's supportive design theory (Ulrich, 1991). Compared to the previous phase, the research themes in this phase shifted from basic infrastructure to humanistic care. However, the theoretical framework was not yet fully established and the research still had distinct transitional characteristics.

Keywords during the Stabilization Phase (2006-2013) show characteristics of theoretical integration, which is the inevitable result of the evolution of the discipline. Keywords such as "Physical Environment", "EBD", "Healing Environment" and "Mental Health" indicate a shift in research perspective from a singular focus on the physical environment to a multidimensional, integrated approach. In 2006, Ministry of Health launched a national hospital management initiative that emphasizes the improvement of healthcare environments to provide patients with clean, comfortable, warm and private treatment environments (The State Council of the People's Republic of China, 2006). The emphasis on the humanistic attributes of the healthcare environment was further strengthened by the implementation of the new healthcare reform plan in 2009 (The State Council of the People's Republic of China, 2009). The development of international evidence-based design research (Ulrich et al., 2008) has also provided theoretical support for related studies in China. The stabilization phase marked a change in design concepts, bringing Chinese hospital environment design to a new stage of theoretical support. Research on healing environments became more scientific.

The research themes during the Extension Phase (2014-2024) reflect the integration of innovative technologies and diversification. Keywords such as "VR", "Digital Technology", "Environmental Intervention" and "Art Therapy" highlight the in-depth extension of the research field. This shift can be attributed to three reasons. First, the implementation of the Outline of the "Healthy China 2030" Plan provided policy support for the digital transformation of healthcare environments (The State Council of the People's Republic of China, 2016). Second, the outbreak of the COVID-19 pandemic has increased the demand for smart and touchless hospital environments (WHO, 2022). Third, China has conducted systematic empirical studies to validate the effectiveness of digital technologies in healing environments. Studies by Hao et al. (2022) have shown that VR has significant healing benefits in areas such as emotional intervention, cognitive training and motor rehabilitation. Examples include improving patients' mental health through virtual natural landscapes and biophilic environments. In terms of the trend towards diversification, the integration of theories and methods from different fields such as environmental psychology, architectural acoustics, lighting environments and art therapy has created a unique research paradigm. This development trend is in line with the concept of "Integrated Healthcare Environments" proposed by Wang and Wang (2021). Overall, research in this phase not only achieved innovation in technology and theory, but also provided new directions for the development of healing environments in hospitals in the post-pandemic era.

Through social network analysis, this study identified six knowledge clusters in the field of research on healing environments in Chinese hospitals, which can be grouped into three research dimensions. The analysis revealed that the largest cluster (green node group) is centered on medical space infrastructure. This proves that the design of healing environments must achieve a balance between functionality and efficiency within a limited space, while

maintaining spatial harmony and unity (Lv & Liu, 2024). The formation of this cluster reflects the importance of spatial research in the healing environments. The second cluster (purple and orange node groups) is centered around hospital user service experience, highlighting the importance of optimizing the healthcare environment to enhance patient satisfaction and comfort (Feng & Yu, 2012). The third cluster (blue, yellow and pink node groups) focuses on technological innovation and environmental interventions, reflecting an emerging trend in technology-enabled optimization of the healing environment. For example, Shen, Xu, and Xu (2024) integrated 5G communication technology with hospital information systems to facilitate the implementation of a multidisciplinary collaborative bedside management model, thereby optimizing the overall healing environment. The network connections between these clusters are dense, and this network relationship confirms the mutual integration of healing environment research with multidisciplinary knowledge. Currently, some educational programs in the United States have begun to bridge courses in fields such as healthcare, architecture, industrial design, and human-computer interaction to design more effective and safer healthcare environments (Lamb et al., 2010).

We observed three integration characteristics of the clusters: first, with the continuous development of the hospital healing environment system, rigorous empirical research linking the design of the hospital physical environment with healthcare outcomes has emphasized the integration of theory and practice (Ulrich et al., 2008). This is reflected in the high concentration of keywords within the relevant clusters in this study. Second, as healthcare models change and technology advances, the design of healing environments faces new challenges and opportunities. This is reflected not only in the intersection of healing environments with disciplines such as psychology, architecture and environmental science, but also in the emergence of keywords such as art therapy and digital technology. Third, healing environments in hospitals have a dual mission of functionality and humanism, as evidenced by innovations in user experience and evaluation systems (Sweeney, Frow, Payne, & McColl-Kennedy, 2023), these clusters were highly connected in this study. The construction of this multidimensional knowledge network indicates that research on healing environments in Chinese hospitals has already developed a diversified knowledge system with theoretical support.

From the social network analysis of each phase, we can observe that the healing environment research in China shows phased characteristics at different times. The changes in the network structure clearly reflect the deepening and broadening of the research topics. During the Exploration Phase (1989-1995), the network structure exhibited a decentralized feature, with "Environmental Design" at the core and scattered outwards to physical environmental factors such as "Spatial Layout" and "Corridors". This is consistent with the early characteristics of medical architecture research, as Ulrich et al. (2008) pointed out that early studies primarily focused on one-dimensional physical environmental factors and lacked systematic empirical research support.

In the Development Phase (1996-2005), the network structure showed a higher degree of connectivity compared to the first phase, with research topics becoming more closely integrated. Keywords such as "Humanization", "Psychology", "Behavior" had the highest weight values and the most connections with other keywords, which is consistent with the

trend described by Jiang and Verderber (2016), where research on healthcare environments in China shifted from a functional orientation to a more human-centered approach.

The network structure during the Stabilization Phase (2006-2013) also reflects the integration of theories. The high weight and connectivity of keywords such as "EBD" and "Theory" confirm the importance of the evidence-based design methodology as emphasized by Devlin and Arneill (2003). The close association of keywords such as "Users", "Medical Staff" and "Family" reflects the idea proposed by Rashid (2010) that the design of hospital environments should take into account the participation of multiple stakeholders.

The network structure in the Extension Phase (2014-2024) reflects the interdisciplinary and diversified development trend. The main clusters revolve around the three core nodes of "Sensory Environment", "Indoor Environment" and "Healing Environment". The links with keywords such as "Digital Technology" and "VR" highlight the role of these technologies in optimizing hospital environments (T. Yang et al., 2024). The close association of keywords such as "Intervention", "Art Therapy" and "Control Group" further confirms the crucial role of empirical research methods in the evaluation of healthcare environments (Dijkstra et al., 2006). The evolution of network structures over various phases indicates a paradigm shift in the research of healing environments. The co-occurrence patterns of keywords illustrate the development of a distinctively Chinese theoretical framework for healing environments. Additionally, the multi-center network structure underscores the significance of interdisciplinary research in advancing healing environments.

Limitations

This study shows the evolution of Chinese hospital healing environment research through social network analysis, however, there are several limitations that need to be addressed in future research. First, the data source is limited to the China National Knowledge Infrastructure (CNKI) database, and this single data source may result in the omission of some important literature. Secondly, due to the geographical limitations of the study, it did not fully include Chinese healing environment research published in major international journals, which affects the comprehensive assessment of the development of China's hospital healing environment from a global perspective. Third, although the social network analysis method can reveal the general characteristics of knowledge structures, it has limitations in dealing with semantic relationships and lacks an in-depth understanding of the evolution of core concepts. In addition, the large time span of this study presented challenges in maintaining continuity in the analysis, which may have affected the in-depth interpretation of certain historical periods. Finally, as a quantitative study, there is room for improvement in the interdisciplinary application of this research.

Conclusion

The research on healing environments in China has undergone significant development from 1989 to 2024. It began with an exploratory phase focusing on infrastructure construction, moved to a human-centered development phase, progressed to a stable phase emphasizing evidence-based design, and finally entered an expansion phase characterized by technological innovation and multidisciplinary integration. Through social network analysis, this study identified six major knowledge clusters covering dimensions such as medical space infrastructure, user service experience, technological innovation and environmental

intervention. The trajectory of evolution not only reflects the shift in Chinese medical environment design from a functional orientation to a more humanized approach, but also demonstrates progress in both theoretical development and practical application. Particularly in the last decade, with the introduction of new technologies such as virtual reality and digital technologies, and the integration of interdisciplinary knowledge in environmental psychology, architectural acoustics and light environments, research on healing environments in Chinese hospitals has developed into a research system with distinct local characteristics.

Although research on healing environments in Chinese hospitals started relatively late, its speed of development and integration have shown unique advantages. Studies have shown that through the rapid absorption of advanced international experience and local innovations, China has established a multidimensional research framework that includes the optimization of the physical environment, humanistic care and technological innovation. The formation of this research framework has not only promoted the scientific and standardized design of hospital environments, but also provided important references for the construction of medical environments in the post-pandemic era. Future research should further strengthen interdisciplinary integration, combining theories from architecture, medicine, psychology, art, environmental science and other disciplines. It should also deepen the application of evidence-based design methods, promote extensive communication with international research while maintaining local characteristics. These developments will contribute to the theoretical improvement and practical innovation of healing environments in Chinese hospitals and drive the progress of China's healthcare system.

Abbreviations
SNA: Social Network Analysis
CNKI: China National Knowledge Infrastructure
WHO: World Health Organization
WTO: World Trade Organization
TF-IDF: Term Frequency–Inverse Document Frequency
MCL: Markov Cluster Algorithm
HITS: Hypertext Induced Topic Selection
COVID-19: Coronavirus Disease
EBD: Evidence-based Design
VR: Virtual Reality

Acknowledgement
Not applicable.

Ethics Approval and Consent to Participate
Not applicable.

Consent for Publication
Not applicable.

Availability of Data and Materials
The data used and analyzed during the current study are available from the first author on request.

Competing Interest

The authors declare no competing interests.

Funding

This study did not receive any funding support.

Authors' Contributions

YY and GW designed the project. YY collected data. YY and GW analysed the data. YY and GW wrote the manuscript. YY conducted the visualization. KS supervised the project. KS reviewed the manuscript. All authors contributed to the manuscript.

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