Megaron, Vol. 20, No. 2, pp. 278–296, June 2025

Megaron
https://megaron.yildiz.edu.tr - https://megaronjournal.com
DOI: https://doi.org/10.14744/megaron.2025.93274

Article

A bibliometric analysis of green and/or smart hospital buildings and a proposal for an integrated design model

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ARTICLE INFO

Article history
Received: 14 April 2025
Revised: 15 June 2025
Accepted: 21 June 2025

Key words:
Bibliometric analysis; bibliometric mapping; bibliometrix; green hospitals; integrated design approach; integrated design model; science mapping; Scopus; smart hospitals; VOSviewer; Web of Science.

ABSTRACT

This study aims to systematically examine the transformation in hospital architecture through the approaches of "green and smart hospitals" in an era where green and smart technologies are rapidly evolving and the concept of "smart" is increasingly defined as the new "green." In this context, publications on green hospitals, smart hospitals, and green-smart hospitals were compiled from the Web of Science and Scopus databases. A total of 1,178 publications covering the period from August 2024 to February 2025 were analyzed using bibliometric methods. Co-occurrence network analysis, keyword trend analysis, and thematic clustering were conducted through the VOSviewer and Bibliometrix software.

The analysis results reveal that, despite the shared sustainability goals and common design criteria of these two approaches, they are generally handled separately in the literature, and integrated design strategies remain limited. To address this gap, a model consisting of four stages-data collection, analysis, synthesis, and design guidance was developed. The model was structured based on the intersection of sustainability and technological criteria.

In this respect, the study goes beyond bibliometric analysis of existing research by proposing an integrated design model grounded in the gap identified through the analysis. It aims to contribute to future interdisciplinary architectural practices and offer solutions to the current gaps in the literature.

Cite this article as: Özdemir, M., & Tuna, G. (2025). A bibliometric analysis of green and/or smart hospital buildings and a proposal for an integrated design model. Megaron, 20(2), 278–296.

INTRODUCTION

Technology has always shaped architecture throughout history. Beyond being a technical tool, it reflects societal needs and paradigms. With industrialization and Artificial Intelligence-AI based systems, technology has evolved into both a means and an end. Concepts such as ***"Green Building"*** and ***"Smart Building"*** emerged from this transformation and have become key themes in architectural discourse.

Industrialization brought not only progress but also environmental degradation. In response, architecture developed sustainability-oriented paradigms like green and ecological buildings. As resources declined, ***"Green Building Technologies (GBTs)"*** emerged as design-based solutions to restore environmental balance.

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Green technologies focus on the idea of implementing sustainable strategies to keep the environment healthy and support the longer life of all living species (Ajmeena & Rana Mahanta, 2019). It refers to the technologies used in built environments to ensure that users are more comfortable and productive, to minimize environmental impacts such as climate change, energy and water consumption, waste production, etc. (Gibberd, 2019).

These technologies are integrated throughout the building lifecycle, resulting in healthier and more sustainable structures known as ***"Green Buildings (GB)"***.

Technology is not a static phenomenon, and new developments are witnessed every moment in the information age. Many new concepts such as Internet of Things-IoT, Edge Computing, Fog Computing, Cloud Computing, etc., which we were unfamiliar with just ten years ago, have now become a part of daily life (Erdal & Ergüzen, 2020).

At first glance, these concepts can be thought to be related to the fields of science and professions such as computer, software, programming, etc. Of course, it is so in terms of working principle. However, these concepts, which have a wide usage area, are effective in many different sectors such as architecture, health, environment, logistics, wearable technologies, industrial applications, etc. and they are the basic terms for ***"Smart Buildings (SBs) / Intelligent Buildings (IBs)"*** in the field of architectural science.

"Smart building", is the product of new technologies that increase the building's capacity to operate more efficiently, flexibly, interactively and sustainably and enable smarter resources and processes by incorporating information technologies into the design (Froufe et al., 2020). When adapted to architecture and the city, it is an all-encompassing expression of everything created by advanced technological change that is supported to provide safer, healthier, more comfortable and efficient ways of living (Figueiredo et al., 2019). Therefore, when the relationship between architecture and technology is evaluated in the context of smart buildings, there is a directly proportional ***"developing technology-smartness level"***. Smart building technologies are a transformative movement towards more sustainable and efficient designs because they will enable the production of buildings that are both technologically rich and supported by environmentally sound technology.

This approach to creating the ***"Smart and Green"*** is indicative of a broader trend in the building sector that aims to balance technological innovation and development with ecological management (Umoh et al., 2024). In a sense, as technology shapes architecture, the architectural form will use technology in line with sustainability principles and function; being smart will necessitate being green, and being green will necessitate being smart.

Intelligent Buildings Institute-IBI defines smart buildings as buildings in which systems such as Heating, Ventilating and Air Conditioning-HVAC, acoustics, data communication, etc. are integrated with each other to manage resources in a coordinated and efficient manner to maximize user performance, investment and operating cost savings and flexibility (Hawkins, 1983).

In nutshell, all the elements considered for sustainability are similar to the objectives in the smart building concept and working principle and form an intersection in the context of smart building and green building in the spatial dimension. This intersection creates the ***"Green and Smart Building"*** approach, which is the main theme of the study.

As long as they exist, buildings create different impacts according to their scale and function; the impacts continue to affect the environment even after the building is destroyed. As the scale changes and the function becomes more complex, the impacts in both the construction and the process of use change and environmental impacts increase. The environmental impacts of a residential building and an educational or commercial building are different, as are their contributions to sustainability.

The theme of this study, ***"the state of being green and smart for hospitals"***, refers to designing for minimization of adverse effects on the environment and optimization of environmental conditions by balancing green and smart with an integrated manner.

A review of the literature reveals that studies on green and smart hospitals are generally addressed separately, and there is a significant lack of design models that evaluate these two approaches in an integrated manner. Despite their shared sustainability goals, no comprehensive proposal has been developed that combines green and smart systems within a unified framework. Furthermore, there is a notable absence of a concrete design framework in terms of definition, criteria, and implementation across these concepts. This gap complicates both the architectural decision-making processes and the development of performance-based decision support systems. Therefore, this study aims to bridge this gap by establishing a conceptual, functional, and design-oriented link between green and smart approaches. In this context, a bibliometric analysis was conducted on studies related to green hospitals, smart hospitals, and green-smart hospitals retrieved from the Web of Science (WoS) and Scopus databases, demonstrating the need for an integrated design approach in the context of green and smart hospital buildings. Within the scope of the study, the proposed "Green'S'Mart Hospital Model: An Integrated Design Framework for Green and Smart Hospital Buildings" is structured as a holistic model that focuses on the life-cycle stages of green and smart hospital buildings-design, construction, operation (including maintenance

and management), and demolition/deconstruction-as well as the inputs involved in these processes and the resulting outputs. The study aims to develop integrated solutions specific to healthcare facilities, based on the necessity of redefining the built environment through the principles of sustainability and digitalization.

In the first part of the five-chapter study, the subject is explained in general terms and the background of the main theme and definitions are given in the second part. In the third chapter, the study structure was created for the basic problem, questions and solutions that led to the research and in the fourth chapter, bibliometric analysis was carried out to examine the place of the subject in the literature. In the fifth chapter, the results of the analysis are detailed, and suggestions are made based on the findings. The model to be addressed within the scope of the PhD thesis is limited to the scale of the proposal in the article.

THE BACKGROUND AND DEFINITIONS

"Green Buildings" and "Smart Buildings"

Building production has an impact on the environment and human health apart from intensive resource consumption and waste production. For this reason, sustainable pursuits in architecture have emerged over time to minimize resource consumption, waste production and negative health impacts.

Sustainability-based approaches were expressed as "Environmental Design" in the 1970s, "Ecological Design" in the late 1980s and 1990s, and "Sustainable Design" since the mid-1990s (Arsan, 2008). These concepts, which are presented with descriptions such as green, environmentally friendly, healthy, ecological, smart, environmentally sensitive, high performance, etc., are alternatives of each other and are under the umbrella of sustainability.

Green buildings are defined as buildings where green building technologies are used with the aim of creating minimum impact on the environment and these techniques are maintained throughout the life of the building (design, construction, use, demolition/dismantling). They are designed, constructed, used and demolished/dismantled at the end of their life cycle in line with ecological principles to promote user health and minimize the impact of buildings on the natural environment (Kibert, 2004). It is expressed as any form of design that minimizes damage to the environment by integrating with the processes experienced. Integration means that the design respects species diversity, minimizes resource consumption, protects nutrient and water cycles, maintains habitat quality, and considers human and ecosystem health. In a sense, it means effectively adapting to and integrating with the processes of nature (Ryn & Cowan, 2007).

The first examples of green buildings, which are about a century old in origin, were given during the application of passive systems such as underground air cooling box, roof fan, etc. to adjust the indoor temperature of the British Palace building at the first world exhibition in Milan in the 19th century and the design of windows embedded in the walls to refract sunlight in the New York Times and Flatiron Buildings in the 20th century (Li et al., 2014). At this point, it is seen that even a century ago, sustainability in architecture was tried to be supported with technology and equipment as much as the conditions allowed and there was an effort to bring green and technology together.

With the popularization of the idea of sustainability, strategies for smart cities and smart buildings that form the identity of the city have started to be developed in order to ensure sustainability and healthy living conditions at the city scale, and the CityPlace office building, which started construction in 1981, became the "World's First Smart Building" (Hawkins, 1983; The New York Times, 1983). Smart buildings are buildings that address intelligence, control and construction processes as an integrated building system by meeting the elements that positively direct the development of the building such as energy efficiency, sustainability, longevity, comfort and user satisfaction (Buckman et al., 2014). It is shaped by the installation and use of highly integrated building technology systems (Sinopoli, 2010).

When the philosophy of green building and smart building is examined, it is recognized that both approaches are based on sustainability and adopt the idea of "integration", "coordination" and "integration" with effective tools and functions to ensure sustainability. This leads to the ***"Green and Smart Building"*** approach, which is a synthesis of both green and smart.

"Green and Smart Buildings"

Green and smart buildings are buildings that carry the common principles of green and smart design as well as the characteristics of a green building and a smart building separately, supporting, strengthening and monitoring the green side with the smart side, identifying and solving the problems that may arise during the process of use and ensuring that the system continues to function properly. It adopts an understanding that sustainability, which forms the basis of green thinking, will be maintained through smart systems throughout the life cycle.

Buildings that combine a green building approach and smart building technologies are safe, healthy, comfortable, user-friendly, efficient and energy efficient. It optimizes energy management, increases resource efficiency and improves quality of life through the integration of environmental sustainability principles and advanced technology solutions (Wen et al., n.d.). It provides quality control, assurance, efficiency, comfort, accessibility and systematic monitoring

of the activities within it. It aims to increase environmental sustainability and building quality using sustainable, smart, local and recycled materials in its construction. In addition, technologies are used to save time and cost, improve labor quality, improve waste management, produce affordable buildings, etc. (Patil et al., 2022).

The designer's goal is to create healthy buildings using a green and smart approach that ensures monitoring and improvement throughout the building's life cycle. This process spans from design to demolition. The goals of both green and smart systems are aligned, as reflected in their definitions and shared themes in the literature. While green design focuses on environmental principles, smart systems ensure monitoring and control. This article centers on hospital buildings shaped by the synergy of both approaches and explores their place in the literature.

PROBLEMS, RESEARCH QUESTIONS AND METHODOLOGY

The study focuses on the idea of evaluating the state of being green and smart through hospitals in an age where everything has evolved into digital and equipped with smart systems. Within the scope of the study, a large pool of resources including studies on sustainability, technology, green building, smart building, green and smart building, green hospital, smart hospital, green and smart hospitals was created and how the subject was handled in the resources was examined.

The first adopters of smart buildings were banks and offices. Although it has been seen for smart housing, hotels, shopping centers, educational campuses, etc. over time, few research and examples have been recorded for healthcare buildings that humanity always need.

The number of studies conducted in the field of architecture science is insufficient. There are reviews on definitions, components and general characteristics and they are generally in the form of compilations and adaptations of interdisciplinary (computer, software and electrical electronics, etc.) studies to the field of architecture (Table 1).

Each research question is fed by the existence of a possible problem. The main problem for Research Questions-RQs is that the green and smart building approach is not sufficiently addressed for hospitals where health and sustainability is a necessity. In this context, three interrelated research questions are at the center of this study:

"RQ1: What is Green Hospital?"

"RQ2 What is Smart Hospital?"

"RQ3: What is a Green and Smart Hospital, and What is Its Contribution to the Literature?

Buildings create different impacts according to their scale and function, and the impacts persist even after the building is destroyed and the larger the scale and the more complex the function, the greater the impacts. The topic of the study ***"green and smart for hospitals"*** refers to designing for minimization of adverse impacts on the environment and optimization of environmental conditions by balancing green and smart with an integrated approach.

Hospital projects are different from residential, office or service building projects. It is based on many principles, from the work team in construction to the health and comfort of patients and staff. It has a strong aspect of shaping social responsibility and urban design (Castro et al., 2012). For a hospital building to be green and/or smart, it needs to be designed in line with common principles that make it both green and smart, unlike traditional hospital buildings. These principles are as follows (Ozdemir & Tuna Taygun, 2022):

- Realization of hospital building life processes with a holistic approach,
- Integration of design principles required by being green and smart.

Smart hospitals are a type of smart buildings that have gained momentum in the last decade and are the structures in great need of sustainability and technological infrastructure. It is designed with the idea of providing healthy, comfortable and safe environmental conditions to

Table 1. Literature review and summary of the research gap

Topic	Literature			
	Design Criteria	**Evaluation Tools**	**Architectural Literature**	**Interdisciplinary Literature**
Green Hospital Buildings	●	●	●	◑
Smart Hospital Buildings	◑	◑	◑	●
Green and Smart Hospital Buildings	○	◑	○	◑
Legend				

● Criteria Met; ◑ Criteria Partially Met; ○ Criteria Not Met.

different users in different units twenty-four hours a day, seven days a week, providing optimum parameters in terms of temperature, humidity, light, indoor air quality, noise level, etc. and continuously monitoring these parameters and trying to optimizing them when they change (Ozdemir & Tuna Taygun, 2022).

The basic principle is to provide and maintain many operations that cannot be ensured during the usage process of hospital buildings designed with traditional systems. Similarly, technological power is needed for green hospitals to protect and maintain the features that provide greenness throughout the life of the building. These needs have motivated designers, and the idea of implementing both smart and green buildings simultaneously and producing green and smart hospital buildings using the approaches and design principles suggested by both situations emerged (Ozdemir & Tuna Taygun, 2022).

Bibliometric analysis was used to see the current status of the problems that created the central questions of the article and to identify a possible scientific gap. Bibliometrics is the quantitative classification of previously published studies in the literature (Schrader, 1981). The method, referred to as science mapping or bibliometric mapping, is a representation method that shows the relationship between disciplines, fields, specialized subjects and personal documents or authors (Small, 1999). The purpose of these analyses is to reveal the distribution of keywords used in the research, author/co-author, country, citations, etc. and to perform due diligence.

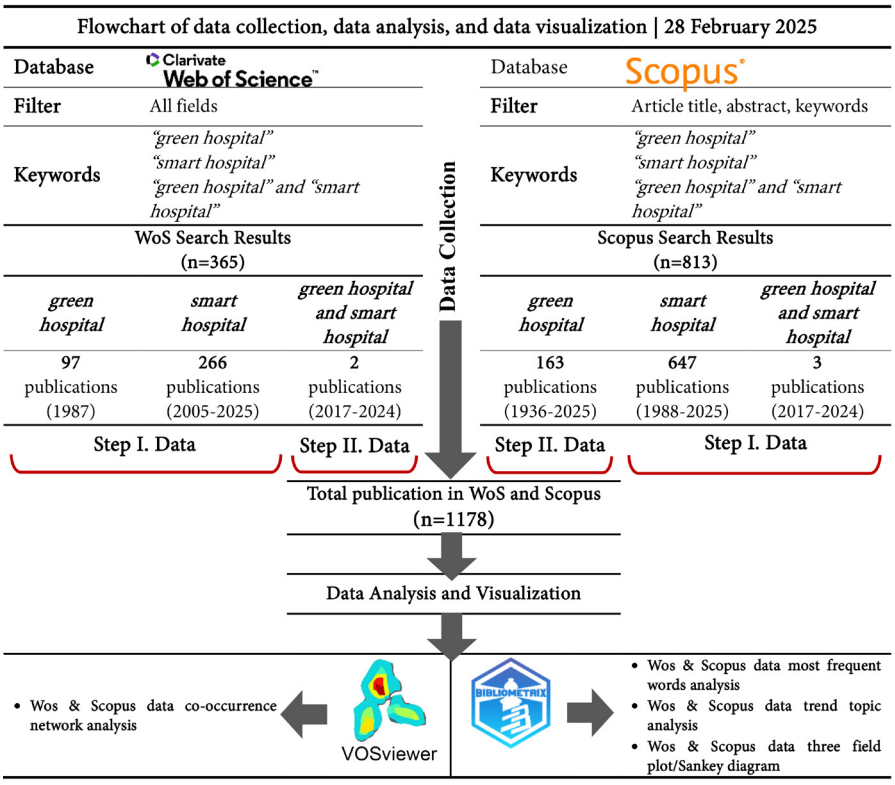
In the article, two of the most popular databases Web of Science (WoS) and Scopus were used to access more data and VOSviewer and Bibliometrix (Biblioshiny app) were used for analysis and visualization. VOSviewer is a software used to create and visualize bibliometric networks related to the selected research topic (VOSviewer, 2025). Other analyses and visualizations were made with Biblioshiny, the web interface of the R package Bibliometrix (Aria & Cuccurullo, 2017). The analysis data was monitored between August 2024 and February 2025; current data recorded in February 2025 was used. In the searches made on WoS Core Collection and Scopus, publications indexed with the keywords "green hospital", "smart hospital", "green hospital" and "smart hospital" were searched with the "All Fields" filter. The study design and methodology, which provide additional context and relevant details concerning the subject, are summarized below (Table 2).

As a result of the searches:

In the WoS database

- 97 publications dated between 1987 and 2025 for "green hospital",
- 266 publications dated between 2005 and 2024 for "smart hospital",

Table 2. Flowchart of the study methodology



- 2 publications dated between 2017 and 2024 for "green hospital" and "smart hospital" were identified.

In the Scopus database

- 1,711 publications dated between 1895 and 2025 for "green hospital",
- 4,478 publications dated between 1988 and 2025 for "smart hospital",
- 21 publications dated between 2017 and 2024 for "green hospital" and "smart hospital" were identified.

In the Scopus database, initial searches conducted using the "All Fields" filter revealed a significant number of interdisciplinary publications that were not directly related to the subject-mostly from fields such as computer science, electrical-electronics, and software engineering. Therefore, the filtering process was revised, and the search was restricted to "Article title, abstract, and keywords."

In this case:

- 163 publications dated between 1936 and 2025 for "green hospital",
- 647 publications dated between 1988 and 2025 for "smart hospital",
- 3 publications dated between 2017 and 2024 for "green hospital" and "smart hospital" were identified.

As a result, 365 publications retrieved from the WoS database and 813 from the Scopus database (reduced from 6,210 after filtering) constituted the final sample of 1,178 publications used in this study. The analyses were conducted in two stages by associating them with the research questions; In the first stage, the "green hospital" and "smart hospital" concepts related to RQ1 and RQ2, and in the second stage, the relationships between the "green and smart hospital" concepts related to RQ3 and the intersectional sustainability were examined.

BIBLIOMETRIC ANALYSIS AND FINDINGS

In the bibliometric analysis of the collected data, VOSviewer and the open-source Bibliometrix R package, along with its web application Biblioshiny (Aria & Cuccurullo, 2017) were utilized. The purpose of using two different analytical tools was to validate the results through outputs from different platforms and to present them in a more comprehensible manner. To fully understand the position of the topics within the literature and to obtain accurate results, no date restriction was applied. Instead, the analysis was conducted using all publications indexed with the relevant keywords in WoS and Scopus up to February 28, 2025. Co-occurrence network and keyword analysis were performed using VOSviewer, while most frequent words, three-field plot/ Sankey diagram, and trend topic analysis were carried out using Bibliometrix (Bibliyoshiny app).

Step I- Analysis and Findings for RQ1 Green Hospital (GH) and RQ2 Smart Hospital (SH)

- **Authors' keywords' co-occurrence network analysis, and most frequent words analysis for GHs and SHs:**

It is an analytical method that examines the relationship between the keywords of the publications produced on the subject of the study and the use of these words together. When the analysis results are visualized, a network structure containing the keywords emerges. Each node in the network shows a keyword, node size shows the repetition of the keyword, and node link shows the simultaneous use relationship between different keywords. Each color represents a specific thematic cluster (Donthu et al., 2021). The most frequent words analysis identifies the most commonly used keywords related to the research topic in the collected data. When visualized, the results are presented in a linear graph showing the frequency of each keyword.

The analysis results of WoS data (Figure 1):

- The keywords of GHs are categorized into five thematic clusters. Purple (carbon footprint-4, covid-19-2, energy-3, environment-6, environmental protection-2, green healthcare-4, green hospital-32, sustainable development-3, sustainable healthcare-3), Red (climate change-7, environment-6, carbon footprint-4, energy, sustainable development-3, energy consumption-2), Blue (sustainability-10, management-3, eco-initiatives, pharmacy carbon footprint-2, green hospital pharmacy-2, zero waste-2), Yellow (energy consumption-2, fuzzy control-2, green building-4, green hospital building-3, hospital-6, leed healthcare-2, patient satisfaction-2) and Green (waste management-4, energy efficiency-2, green benefits-2, green buildings-2, green hospitals-2, hospitals-2) are seen to be clustered under these thematic keyword groups.
- The keywords of SHs are categorized into sixteen thematic clusters. Examples include Cyan (smart hospital-94, facility management (fm)-2, patients-2, augmented reality-2, ehealth-2, fuzzy logic-2), Blue (health care-4, simulation-3), Green (artificial intelligence-11, rfid-8, healthcare-20, smart gateway-2), Red (sensors-8, iot-17), Purple (big data-3, smart hospitals-8, smart healthcare-10, architecture-2, blockchain-3, facility management-2, framework-2, patient care-2, quality of service-2, sensors-8, simulation-3, smart hospitals-8, telecommunications-3, telemedicine-6), Pink (internet of things-23, availability-2, remote sensing-2, internet-of-things (iot)-1), Salmon (smart home technology-2, accessibility-2, automatic speech recognition-2, digital transformation-4, natural language processing-3, rehabilitation hospital-2, smart healthcare-10, smart medical-2, smart medicine-2, smart patient room-3), and others, which are seen to be clustered under these thematic keyword groups.

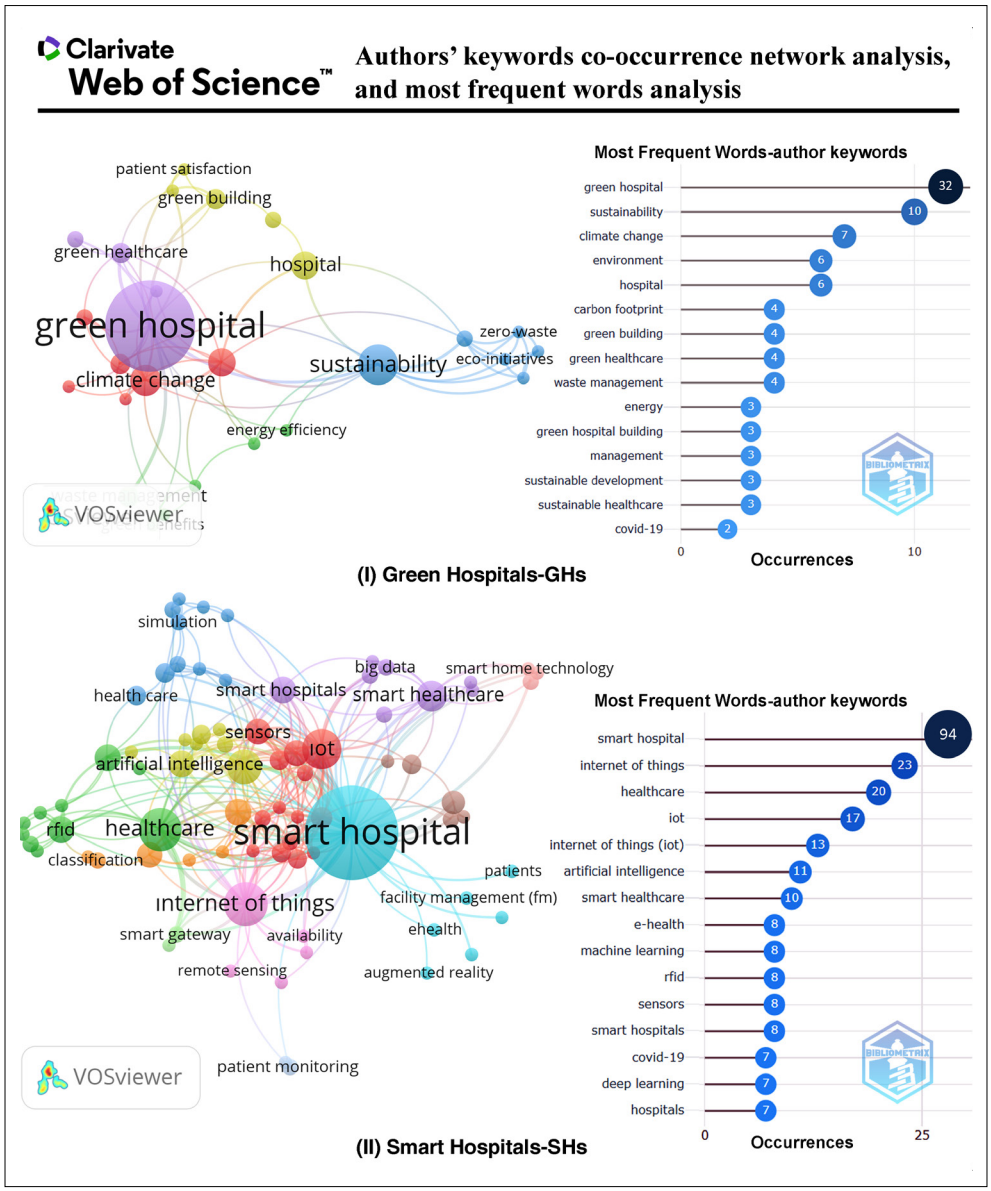


Figure 1. WoS database authors' keywords' co-occurrence network analysis and most frequent words analysis for (I) GHs, (II) SHs.

The analysis results of Scopus data (Figure 2):

- The keywords of GHs are categorized into seven thematic clusters. Cyan (biophilic design-4, green hospital building-2, hospital-6, leed-3, service quality-2), ***Green*** (carbon footprint-5, climate change-9, energy-4, environment-7, environmental protection-2, green healthcare-5, green hospital-38), ***Purple*** (conservation of natural-2, environmental footprint-2, environmental health-2, sustainable development-6, waste management-5), ***Yellow*** (evidence-based design-2, green building-9, leed healthcare-4, sustainable design-2, patient satisfaction-2), Orange (green innovation-2, medical waste-2, sustainable healthcare-5), ***Blue*** (green hospital building-2, hospital-6, service quality-2), ***Red*** (continuous improvement-2, energy efficiency-3, environmental management-2, hazardous waste-3, healthcare-4, healthcare sector-2, hospitals-4, renewable energy-3, supply chain-2) are seen to be clustered under these thematic keyword groups.
- The keywords of SHs are categorized into twenty-seven thematic clusters. Examples include ***Pink*** (smart hospital-165, smart healthcare-21, smart health-9, digital hospital-4), ***Blue*** (internet of things-63, iot-51, smart cities-9, smart technology-2), ***Green*** (hospital-13, healthcare-47, healthcare technology-2, rfid-15), Orange (led-6, localization-3, industry 4.0-4), ***Red*** (energy consumption-2, digital twin-9, simulation-3, fog computing-6, data mining-4), ***Purple*** (home

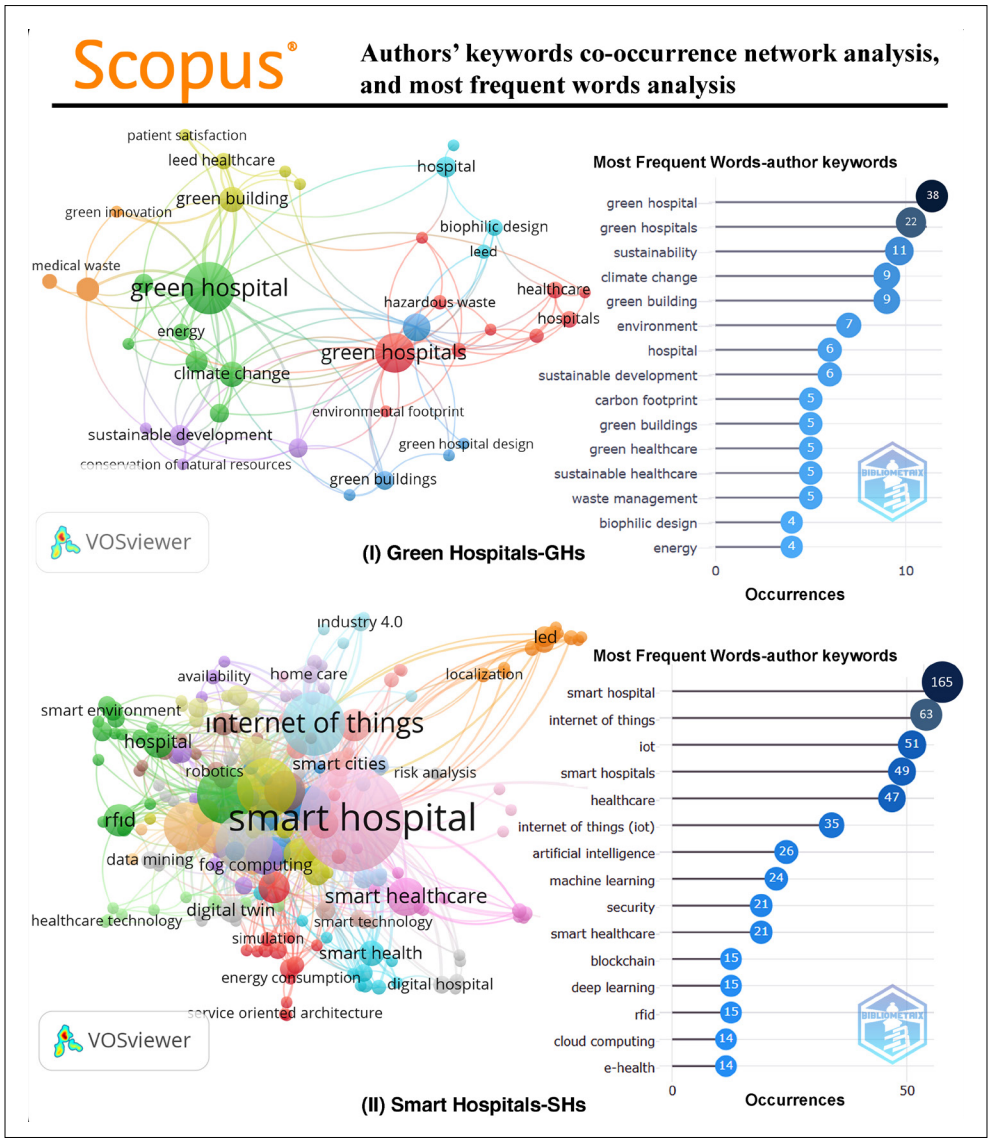


Figure 2. Scopus database authors' keywords' co-occurrence network analysis and most frequent words analysis for (I) GHs, (II) SHs.

care-4, availability-3, risk analysis-2, service-oriented architecture-1, path planning-2), and others, which are seen to be clustered under these thematic keyword groups.

The co-occurrence analysis of author keywords from both Web of Science (WoS) and Scopus databases highlights distinct thematic focuses in studies on Green Hospitals (GHs) and Smart Hospitals (SHs). GHs-related terms predominantly cluster around environmental sustainability and healthcare architecture, emphasizing ecological integration, energy efficiency, and sustainable development. In contrast, SHs related keywords form a broader and more diversified landscape, centered on digital infrastructure and technological innovation. Recurring terms such as smart hospital, internet of things, artificial intelligence, and cloud computing indicate a growing emphasis on intelligent systems and data-driven healthcare models. These differences reflect the dual evolution in hospital research: while GHs studies concentrate on environmental and structural concerns, SHs research is oriented toward automation, system scalability, and digital transformation. Overall, the analysis reveals a clear thematic divergence-GHs aligning with sustainability-driven architectural frameworks, and SHs emerging as complex technological ecosystems-demonstrating the interdisciplinary and evolving nature of hospital-related scholarship.

- **WoS and Scopus database three field plot analysis/ sankey diagram for GHs and SHs**

Three-field plot analysis, performed via Bibliometrix (Biblioshiny app), is an analysis method that evaluates the relationship between certain factors on the subject of

the study. These are variables such as sources, countries, affiliations, keywords, leading authors, cited sources, keyword plus, and the relationships between them are visualized (Yaqoub et al., 2023).

The analysis results of WoS data (Figure 3):

- According to GHs data, the analysis was conducted through (left) Titles-(middle) Author's Keywords-(right) Keywords Plus relationships. In the titles, "green", "hospital", "sustainability", "environment"; in the keywords, "green hospital", "sustainability", "climate change"; in the keywords plus, "healthcare", "performance", "life-cycle assessment", "sustainable development" are prominent. These relationships show that the studies conducted on green hospitals are addressed with an integrated approach with the environmental sustainability dimension.
- According to SHs data, the analysis was conducted through (left) Titles-(middle) Author's Keywords-(right) Keywords Plus relationships. In the titles, "smart", "hospital", "healthcare", "system"; in the keywords, expressions related to digital health technologies such as "smart hospital", "internet of things (IoT)", "machine learning", "artificial intelligence" are prominent. The presence of terms such as "internet", "technology", "management", "framework" in keywords plus shows that these concepts are linked to digital transformation, artificial intelligence and data management in studies on smart hospitals.

The analysis results of Scopus data (Figure 4):

- According to GHs data, the analysis was made through (left) Titles-(middle) Author's Keywords-(right) Keywords Plus relationships. In the titles, "green", "hospital", "sustainability", "management", "health"; in the keywords, "green hospital", "sustainability", "climate change", "green buildings"; in the keywords plus, "hospitals", "waste management", "sustainable

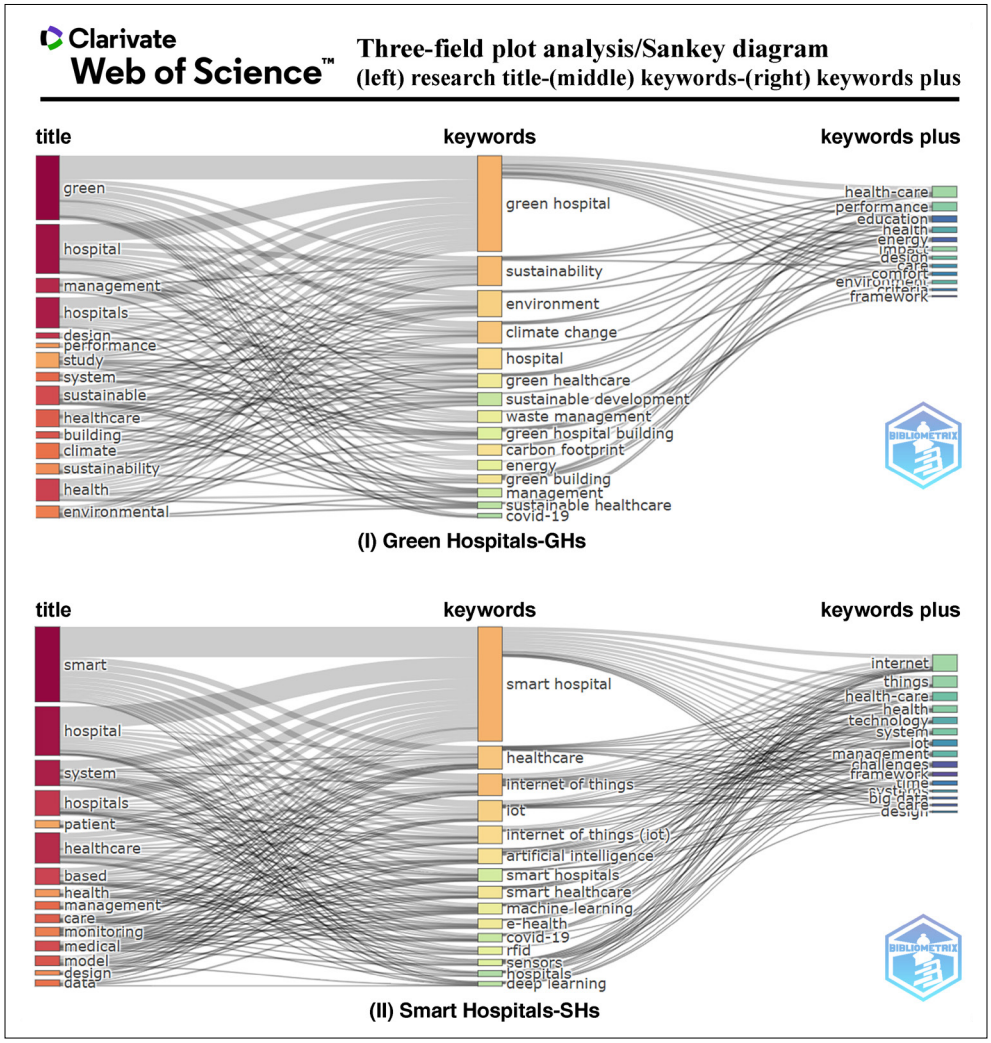


Figure 3. WoS database research title-authors' keywords-keywords plus three-field plot analysis for (I) GHs, (II) SHs.

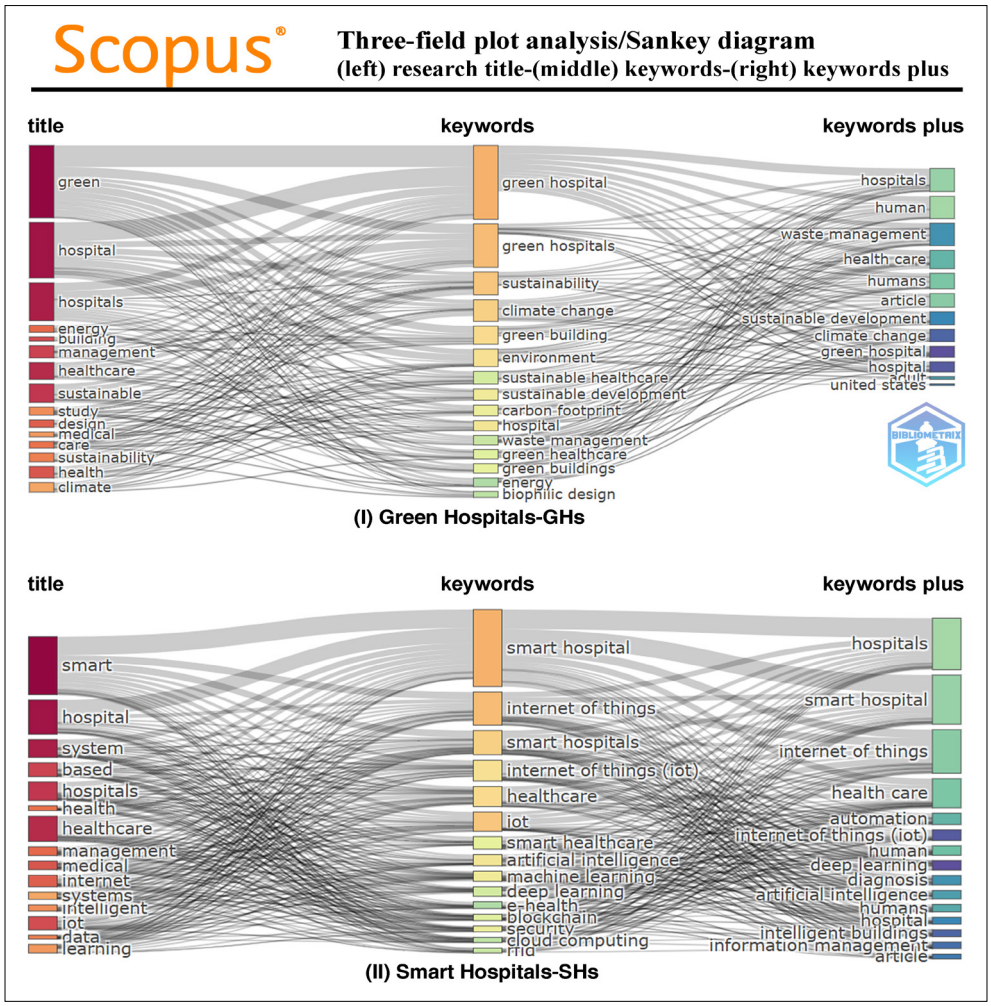


Figure 4. Scopus database research title-authors' keywords-keywords plus three-field plot analysis for (I) GHs, (II) SHs.

development", "environmental impact" are prominent expressions. It shows that green hospitals are being worked on in an integrated manner with health, environmental sustainability and waste management. These relationships emphasize the relationship between the studies conducted on green hospitals and issues such as sustainability, waste management and energy efficiency.

- According to SHs data, the analysis was made through (left) Titles-(middle) Author's Keywords-(right) Keywords Plus relationships. In the titles, expressions such as "smart", "hospital", "internet", "monitoring", "system", "learning"; in the keywords, expressions such as "smart hospital", "internet of things", "machine learning", "blockchain", "telemedicine" technological transformation attract attention. The presence of expressions such as "automation", "artificial intelligence", "deep learning", "telemedicine", "security" in the Keywords Plus shows that automation, security and artificial intelligence applications are the priority issues in smart hospitals.

The Sankey diagrams reveal distinct thematic orientations between Green and Smart Hospitals. GHs-related terms consistently converge around sustainability, environmental impact, and healthcare infrastructure, reflecting an ecologically integrated research focus. In contrast, SHs studies emphasize technological transformation, highlighting concepts such as automation, artificial intelligence, and data systems. This contrast demonstrates how GHs are framed within environmental and architectural contexts, while SHs are positioned within a digitally driven, innovation-focused paradigm. The diagrams thus reinforce the evolving divergence in priorities across hospital research, bridging environmental responsibility with intelligent system integration.

- **WoS and Scopus database trend topics analysis for GHs and SHs**

Trend topics analysis performed via Bibliometrix (Biblioshiny app) shows the distribution of trend topics related to the study topic over time. The horizontal axis represents the

years in the analysis, the vertical axis represents trending topics, and the size of the nodes represents the frequency of trending topics (Yaqoub et al., 2023).

The analysis results of WoS data (Figure 5):

- For GHs, between 2016-2018, topics such as "green healthcare", "green hospital building", and "green building" attracted attention and were included in research. It was observed that "sustainable healthcare", "waste management", "carbon footprint", and "environment" were frequently studied between 2019-2020, and "sustainability", "climate change", "management", and "energy" were frequently studied between 2022-2023. The "green hospital" topic showed a significant increase in 2022 and became one of the most researched topics.
- For SHs, topics such as "pervasive computing", "rfid", "data mining", and "smart home" attracted attention in the early periods, while "IoT", "cloud computing", and "security" gained importance between 2016-2017. As of 2018, artificial intelligence-based applications such as "machine learning", "artificial intelligence", "deep learning" and after 2020, "digital twin", "remote sensing", "smart hospitals" and "AI", "blockchain", "5G", "interoperability" related to technological developments were discussed in the studies.

The analysis results of Scopus data (Figure 6):

- For GHs, between 2016-2018, topics such as "green healthcare", "green hospital building", and "green building" attracted attention and were included in research. It was observed that "sustainable healthcare", "waste management", "carbon footprint", and "environment" were frequently studied between 2019-2020, and "sustainability", "climate change", "management", and "energy" were frequently studied between 2022-2023. The "green hospital" topic became

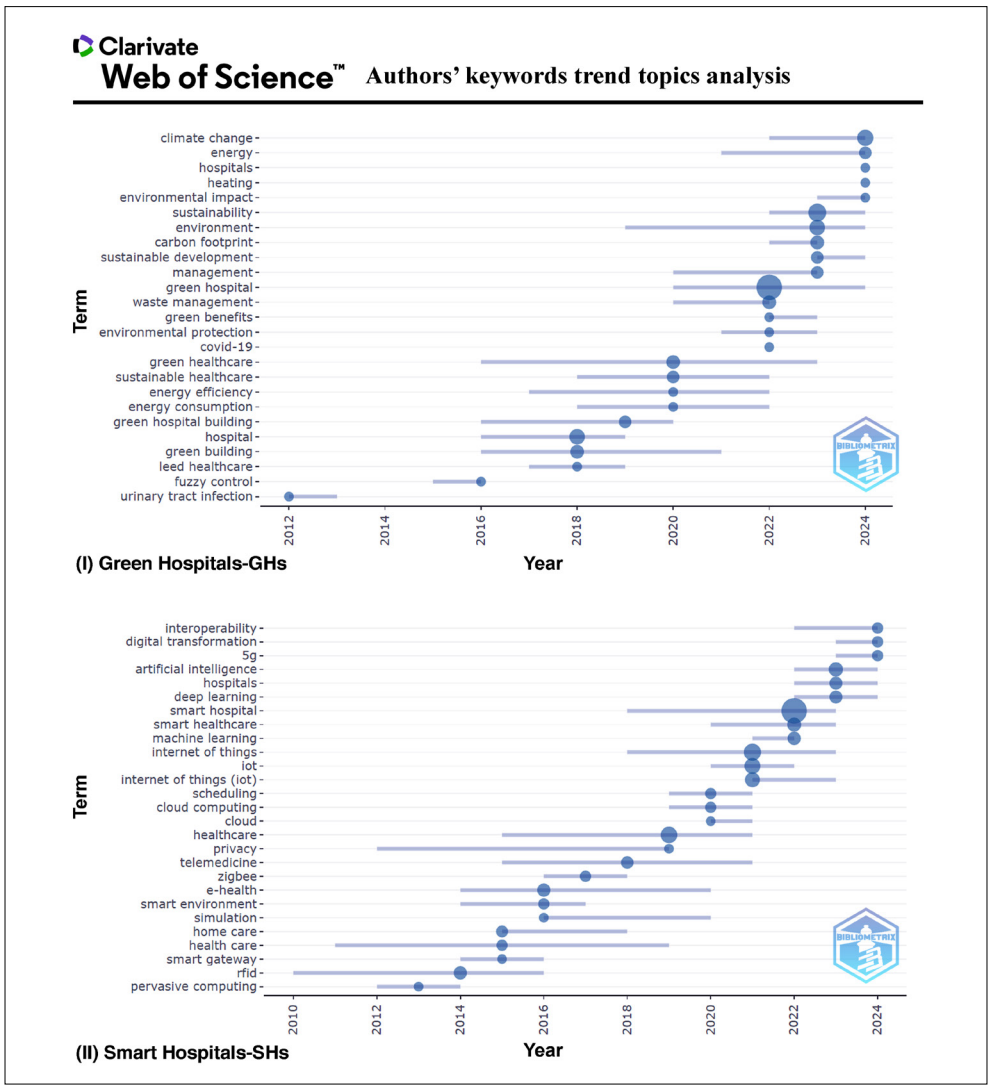


Figure 5. WoS database authors' keywords trend topic analysis for (I) GHs, (II) SHs.

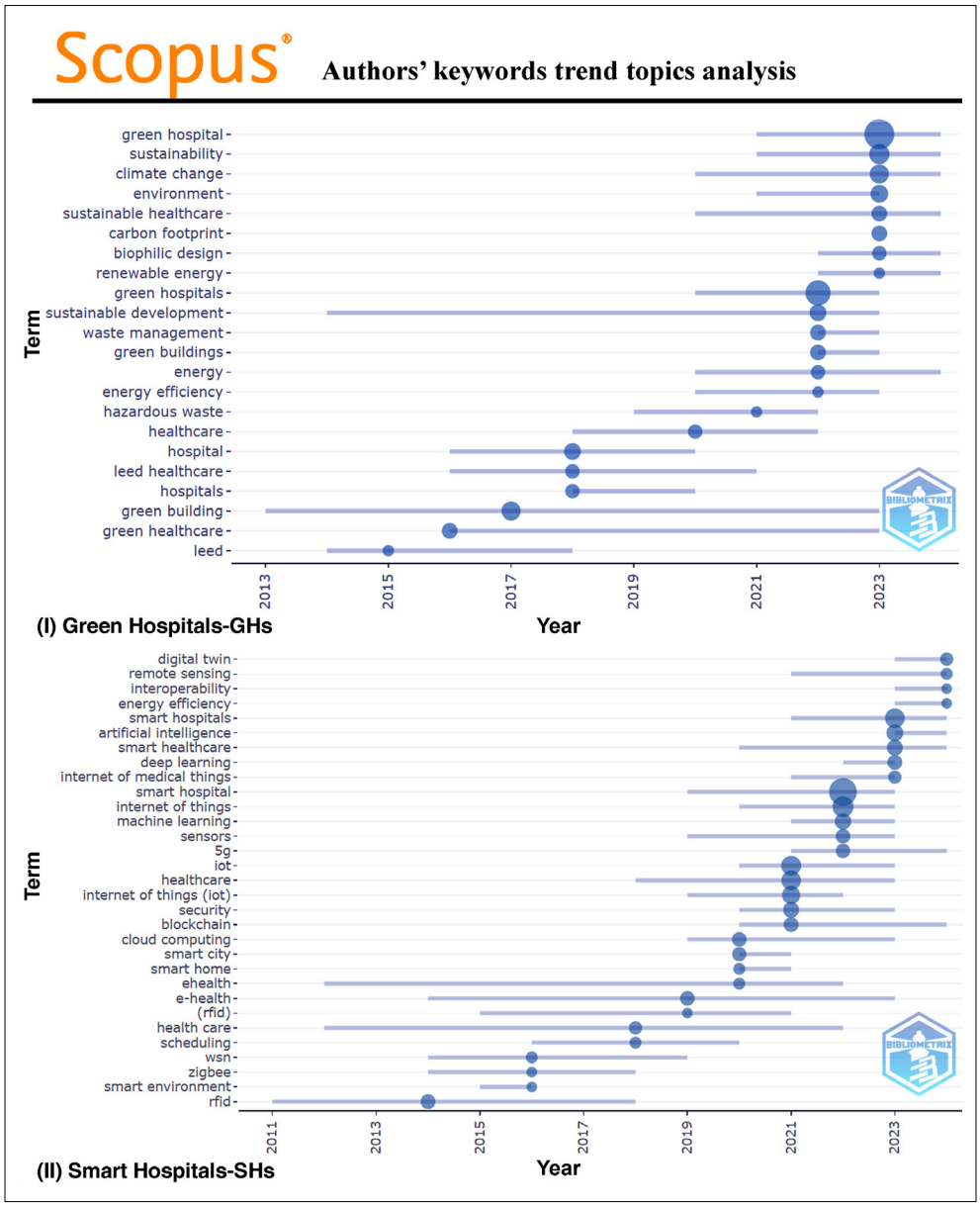


Figure 6. Scopus database authors' keywords trend topic analysis for (I) GHs, (II) SHs.

one of the most researched topics in 2022.

- For SHs, in the early periods, topics such as "pervasive computing," "Radio Frequency Identification-RFID," "data mining," and "smart home" attracted attention and were included in research. It was observed that "IoT," "cloud computing," and "security" gained prominence between 2016-2017, while from 2018 onwards, artificial intelligence-based applications such as "machine learning," "artificial intelligence," and "deep learning" became prevalent. After 2020, studies frequently addressed topics like "digital twin," "remote sensing," and "smart hospitals," along with technology-related concepts such as "AI," "blockchain," "5G," and "interoperability.

According to the analysis results, in GHs studies, environmental themes such as "green building," "waste management," and "sustainability" became prominent after 2016, with "green hospital" emerging as a key term in recent years. In SHs literature, post-2018 trends show a rapid rise in topics like "AI," "IoT," "machine learning," and "blockchain," reflecting a shift toward data-driven healthcare and digital transformation.

Step II- Analysis and Findings for RQ3 Green and Smart Hospital (GRSH)

- **Authors' keywords' occurrence network analysis, and most frequent words analysis for GRSHs**

The analysis results of WoS and Scopus data (Figure 7):

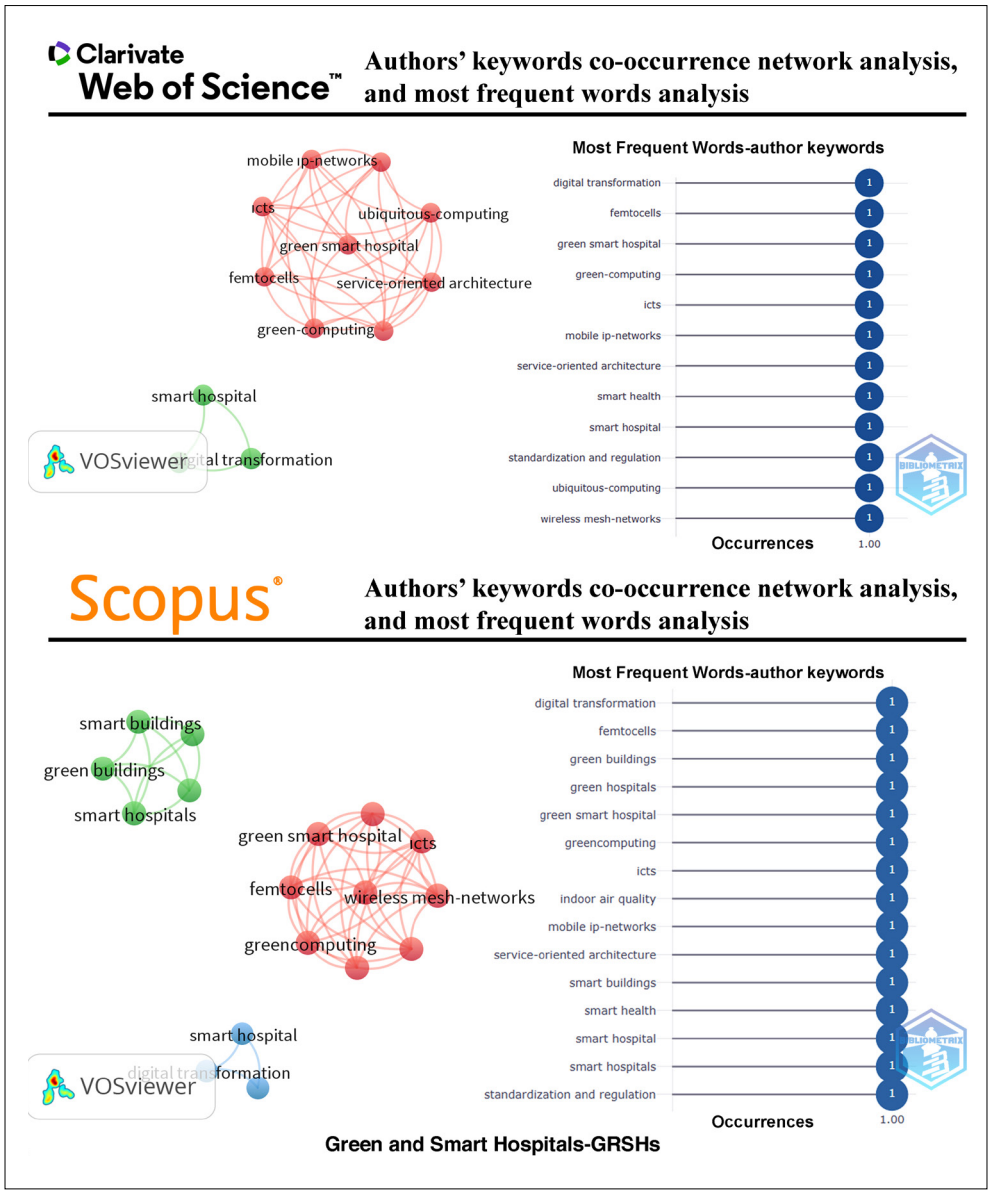


Figure 7. WoS and Scopus database authors' keywords' co-occurrence network analysis, and most frequent words analysis for GRSHs.

- The GRSHs keywords obtained from WoS categorized into two thematic clusters. Red (femtocells, green buildings, green hospitals, green smart hospital, green computing, icts, indoor air quality, mobile ip-networks, service-oriented architecture, smart buildings, smart hospitals, standardization and regulation, ubiquitous-computing, wireless mesh-networks -1), and Green (digital transformation, smart hospital, smart health-1),
- The GRSHs keywords obtained from Scopus are categorized into three thematic clusters. Red (femtocells, green smart hospital, green computing, icts, mobile ip-networks, service-oriented architecture, standardization and regulation, ubiquitous-computing, wireless mesh-networks -1), Green (green buildings, green hospitals, indoor air quality, smart buildings, smart hospitals-1), and Blue (digital transformation, smart hospital, smart health-1) are seen to be clustered under these thematic keyword groups.
- GRSHs network analysis has a different network structure than GHs and SHs analyses. Some items in the collected data are not connected. Therefore, there is no connection between some cluster items and separate clusters are seen. 12 items are not connected for WoS data of GRSHs. The largest cluster of connected items consists of 9 items, and 17 items are not connected for Scopus data of GRSHs, the largest cluster of connected items consists of 9 items again.

Although the publications originate from different databases (WoS and Scopus), the overlapping data suggest that GRSHs studies are limited and largely stem from the same sources, indicating a lack of distinct research.

- **WoS and Scopus database three field plot analysis/ sankey diagram for GRSHs**

The analysis results of WoS and Scopus data (Figure 8):

- According to GRSHs WoS data, unlike the (left) Titles-(middle) Author's Keywords-(right) Keywords Plus (left) relationship in other three field plot analyses, it was made through Titles-(middle) Author's Keywords-(right) Abstract relationships because the number of data collected from the WoS database is not sufficient to obtain the three-field plot. Expressions such as "hospital", "smart", "enable", "green", "efficiency", "computing" show that smart and green hospitals are associated with the concepts of efficiency-digitalization-environmental sustainability in the studies.
- According to GRSHs Scopus data, the analysis was made through (left) Titles-(middle) Author's Keywords-(right) Keywords Plus relationships. Expressions such as "hospital-care", "data-driven", "hospitals", "indoor air quality (IAQ)", "green", "smart", "review" stand out in the studies. Especially the existence of concepts such as "indoor air quality" and "air" related to health, comfort and environmental conditions shows that smart system elements and environmental sustainability dimensions are examined together in the studies.
- **WoS and Scopus database trend topics analysis for GRSHs**

The analysis results of WoS and Scopus data (Figure 9):

- According to WoS data for GRSHs, topics such as "smart hospital", "smart health", "digital transformation" have attracted attention in 2023 and have been heavily included in research. On the other hand, concepts such as "green computing", "green smart hospital" have gained importance in studies in recent years.

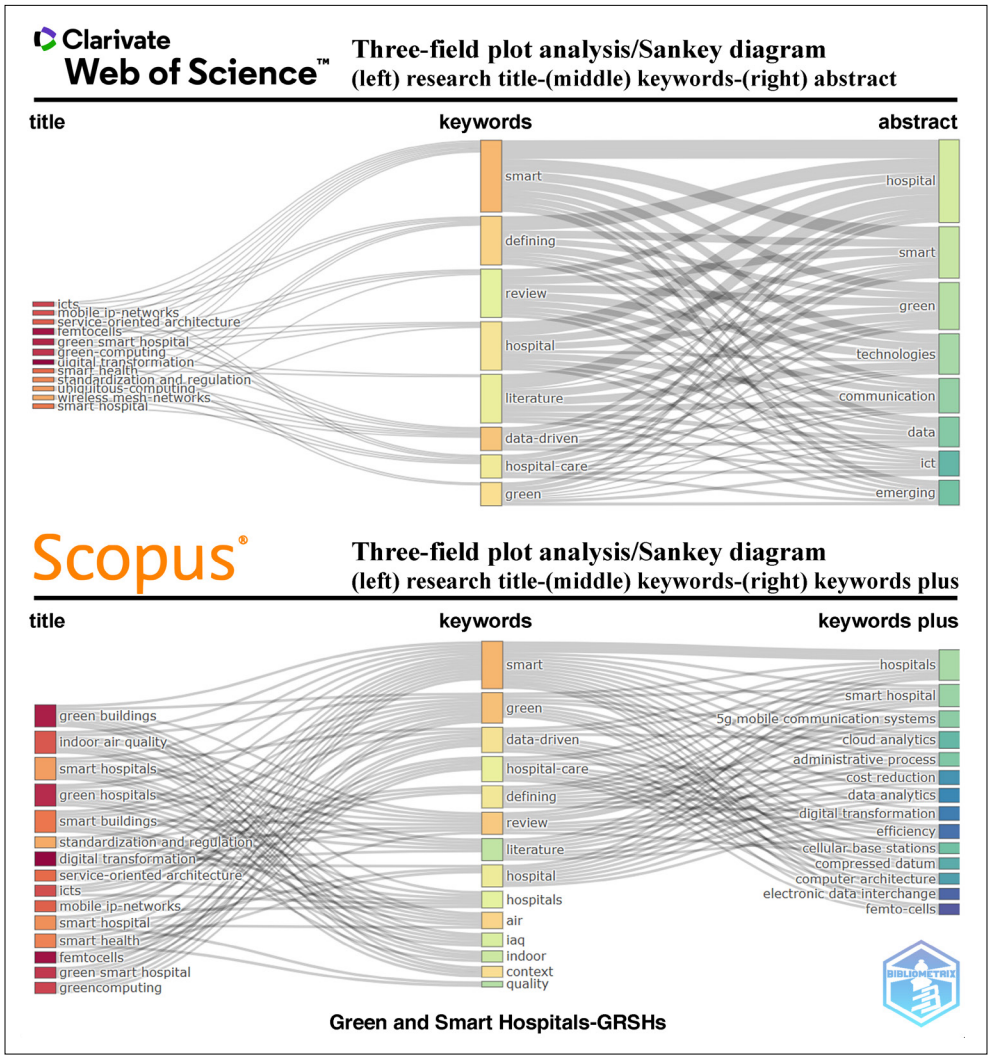


Figure 8. WoS and Scopus database research three-field plot analysis for GRSHs.

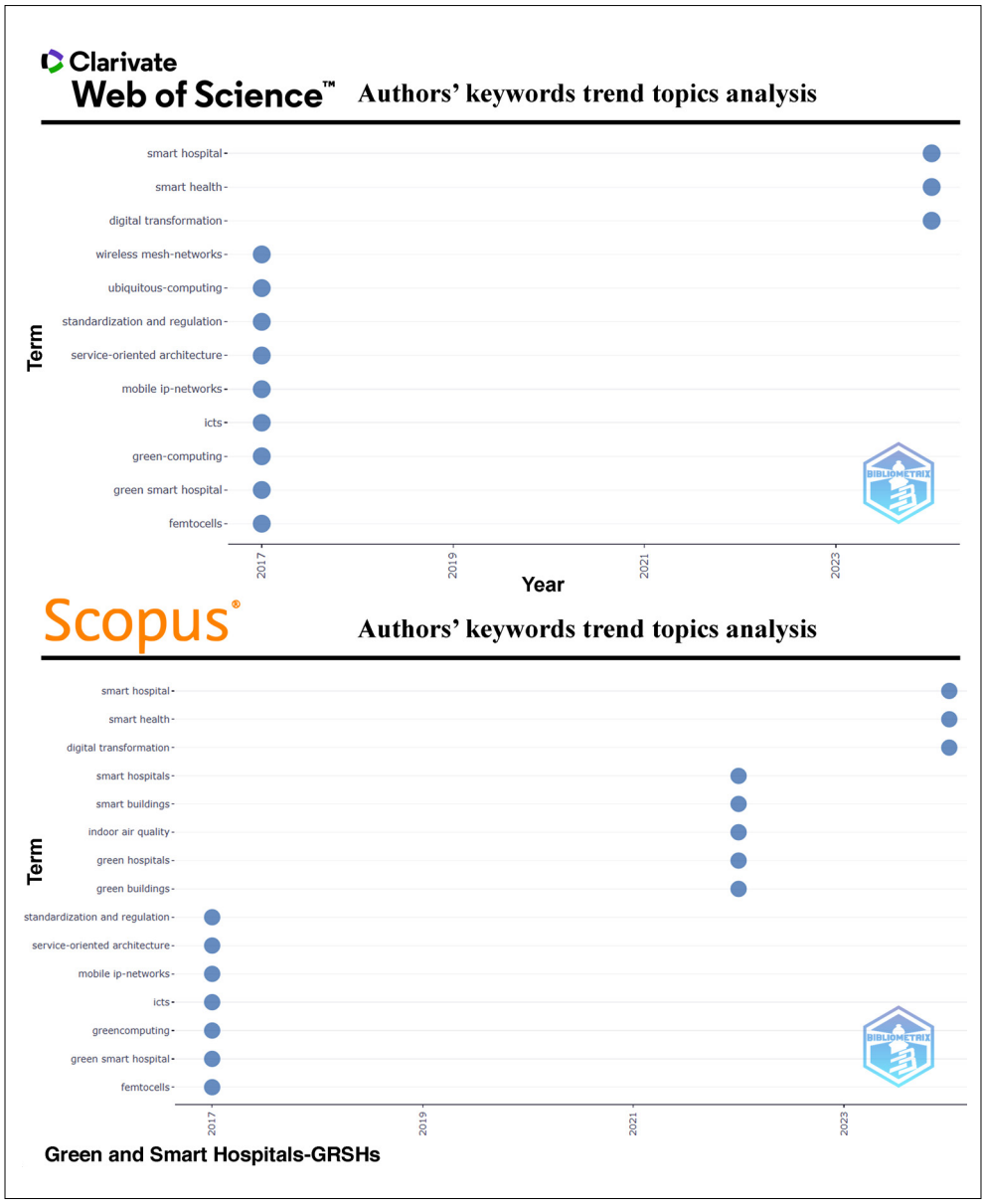


Figure 9. WoS and Scopus database authors' keywords trend topic analysis for GRSHs.

- According to GRSHs Scopus data, environmental sustainability-based topics such as "smart hospital", "digital transformation", "green hospitals", "green buildings", "indoor air quality" have been included in research.

In both databases, GRSHs studies have increasingly focused on environmental sustainability and digital health by 2023, indicating a strengthening trend toward interdisciplinary research within the field.

The bibliometric analyses conducted in the second phase of the study were addressed not only quantitatively but also qualitatively, and their contributions to the literature were evaluated. Two publications from the WoS database and three publications from the Scopus database were examined using the keywords "green hospital" and "smart hospital" in relation to RQ3. Two of the publications found in the WoS database also appear in the Scopus database, while the third Scopus entry is a book chapter.

Spyropoulos et al. (2017), Toward the Data-Driven "Smart" And "Green" Hospital-Care focused on the use of information and communication technologies (ICTs) in smart and green hospitals. It was predicted that hospitals are complex and high-cost structures and energy, and resource efficiency can be achieved with ICTs. Although not directly related to architectural design, the study shows how digital systems can serve green hospital goals at the implementation level (Spyropoulos et al., 2017).

Ozdemir & Tuna Taygun (2022), Green and Smart

Hospitals: A Review in the Context of Indoor Air Quality examined indoor air quality (IAQ) in green and smart hospital buildings. The study questioned the integration of smart building technologies with green technologies and how they support them in the context of HVAC. The architectural dimension was addressed at a conceptual level, implementation and design were not detailed. The study offers a perspective on the integration of smart technologies with green hospital buildings in the context of indoor air quality, which is a common principle for both approaches (Ozdemir & Tuna Taygun, 2022).

Anthopoulos et al. (2024), Defining the "Smart Hospital": A Literature Review is conducted to define the concept of a smart hospital, examine its historical development, and provide features that differentiate it from other hospital designs (green, hybrid, and agile hospitals). The study emphasizes the role of new generation technologies such as big data, artificial intelligence, the internet of things (IoT), cloud computing, and 5G in increasing the efficiency and quality of healthcare services. The conceptually strong study clearly reveals the basic features that distinguish the smart hospital concept from other models, and it provides a theoretical basis for smart hospitals (Anthopoulos et al., 2024).

All three studies above address the concepts of green and smart hospitals from important perspectives, but architectural design and spatial decision processes are limited or indirectly included (Table 3). In this context, architecture-based, holistic and application-oriented approaches are needed.

As a result, according to the literature research, analysis and findings it is concluded that

- Studies have gained importance and increased especially after Covid-19 pandemic,
- Existing studies largely address the issues of green building, smart building, green hospital, smart hospital and are numerous,
- The common goal in almost every study is to ensure economic-social-environmental sustainability,
- The concepts of smart hospital, green and smart building, green and smart hospital have not been examined in depth in the context of architectural design or there is no design method,
- In existing studies on green and smart hospital, technological components such as IoT, Radio Frequency Identification-RFID, computing, e-health are mainly addressed and the technological side is more dominant, however the relationship with architectural design has not been examined,
- The conceptual framework of the studies is presented rather than technical or practical aspects,
- In studies on smart hospitals and green and smart hospitals, electronic infrastructure and software systems are prioritized rather than architectural design.

CONCLUSION AND PROPOSAL

The analyses and mapping results revealed that, for GHs, SHs, and GRSHs, the most frequently recurring keywords are predominantly associated with sustainability and its environmental, social, and economic dimensions. These keywords-such as energy efficiency, renewable energy, smart energy management, water management, waste management, indoor environmental quality, lighting control, natural ventilation, thermal comfort, patient comfort, staff comfort, resource optimization, green materials, certification compliance, etc.-are found to be closely related to the most frequent terms, concepts, and thematic topics identified in the literature.

The study analysed the concept of green and smart buildings in hospital architecture through bibliometric analysis of 1178 publications using VOSviewer and Bibliometrix. The results revealed that the most frequent keywords for GHs, SHs, and GRSHs-such as energy efficiency, renewable

Table 3. Comparative analysis of selected studies

Study	Design Criteria	Evaluation Tools	Architectural Literature	Interdisciplinary Literature
Spyropoulos et al. (2017), Toward The Data-Driven "Smart" and "Green" Hospital-Car	◑	●	○	●
Ozdemir and Tuna Taygun (2022), Green and Smart Hospitals: A Review in the Context of Indoor Air Quality	●	◑	◑	◑
Anthopoulos et al. (2024), Defining the "Smart Hospital": A Literature Review	◑	◑	○	◑
Legend				

● Criteria Met; ◑ Criteria Partially Met; ○ Criteria Not Met.

energy, indoor environmental quality, thermal comfort, and resource optimization-are clustered under sustainability and its environmental, social, and economic dimensions. These parameters are largely common to both GHs and SHs (Figure 10). Thus, integrating green and smart hospital approaches can guide designers toward a unified design framework and simplify decision-making processes.

When the design of hospital buildings is examined through the lens of green and smart technologies, it becomes clear that the concepts of "green hospital" and "smart hospital" are both well-defined in the literature, with overlapping design components largely aligned with shared sustainability goals. However, the extent of this overlap, the depth of its treatment in the literature, and the existence of a scientific gap formed the foundation of the research problem. To investigate these issues, a bibliometric analysis was employed. The results supported the study's initial assumptions by demonstrating substantial convergence between the design components of green and smart hospitals. However, the analyses also confirmed that studies addressing these two approaches in an integrated manner-both theoretically and practically-are significantly limited. In this respect, the research problem highlighted the necessity of a bibliometric analysis; the results of which reinforced the study's purpose and provided a foundation for the development of the proposed integrated design model.

The analysis indicates that research on Green and Smart Hospitals (GRSHs) remains limited. Although the data reviewed spanned from August 2024 to February 2025, little advancement was identified in the integrated design of green and smart hospital buildings. While the quantity of research is not a direct indicator of necessity, the goal here is not to count publications, but rather to understand how these hospital typologies are addressed—individually and collectively—and what contributions they make to architectural discourse. The findings suggest that despite the shared goals between green and smart hospitals, existing studies are both quantitatively insufficient and thematically fragmented, reinforcing the need for integration. Although many shared design principles exist for green and smart hospitals, a standard definition, method, tool, or guideline that brings these two approaches together has not yet been established in the literature. While both concepts exist independently, how they should be interpreted and applied by designers remains uncertain. In response to this, the study proposes an integrated "Green'S'Mart Hospital Model," developed through comparative network analyses of GHs, SHs, and GRSHs, structured around their common goals and shared components.

The model consists of following four steps (Figure 11):

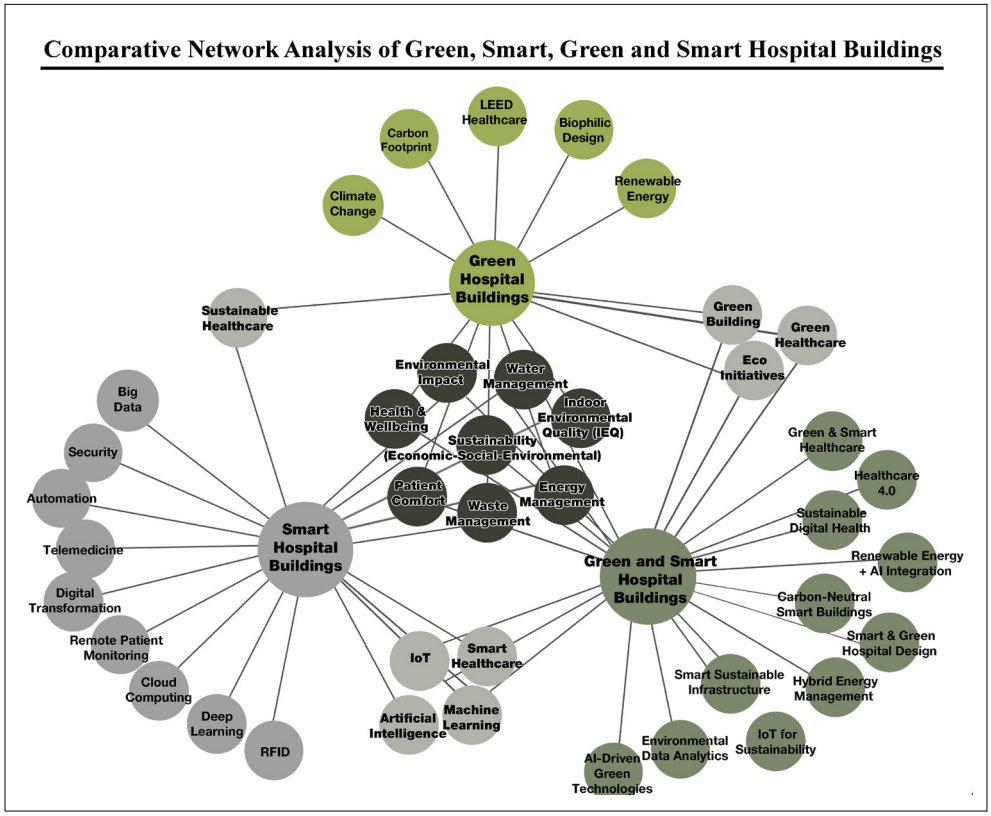


Figure 10. Comparative network analysis of GHs, SHs, GRSHs (Figure prepared by the Authors).

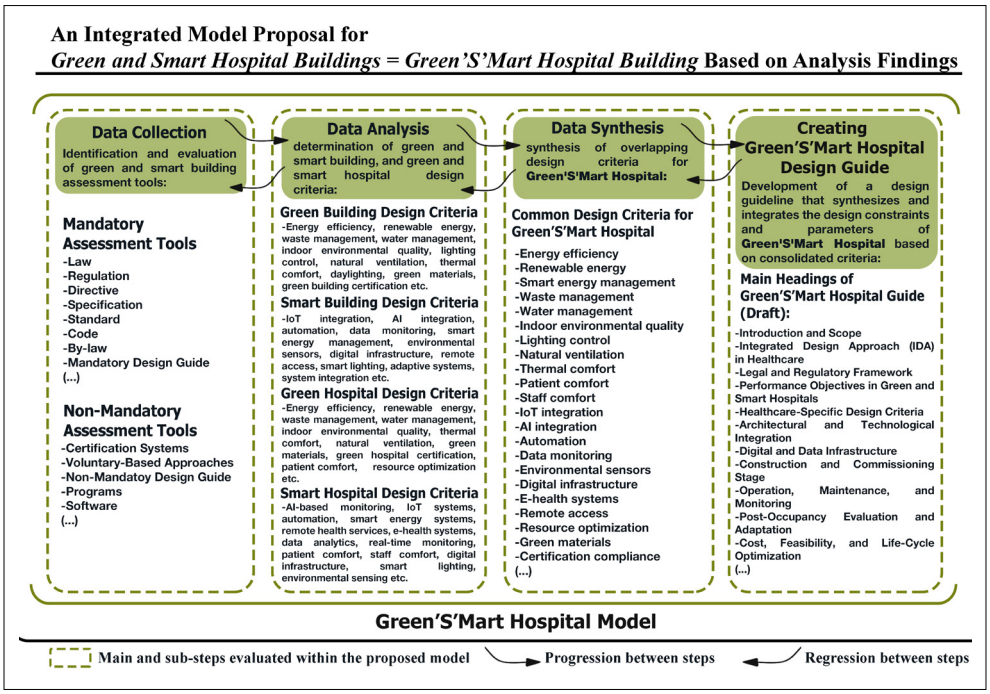


Figure 11. Green'S'Mart hospital proposed model based on the findings comparative network analysis GHs, SHs, GRSHs (Figure prepared by the Authors).

- **Data Collection:** Determination of current green and smart building assessment tools from the resource pool obtained during the literature research,
- **Data Analysis:** Analysis of the criteria in the collected green and smart building tools,
- **Data Synthesis:** Synthesizing the analysed green and smart building main and sub-criteria,
- **Design Guide:** Creation of a design guide that includes the criteria, constraints and requirements of green and smart hospital buildings based on overlapped common criteria of green and smart hospital building.

The main and sub-steps of the model are addressed within the scope of the PhD thesis supported by the Yildiz Technical University Scientific Research Project Coordination Graduate Thesis Project.

In architectural research, where sustainability and technology intersect, new questions will generate new methods. This study aimed to explore the intersection of sustainability and smart technologies in hospital architecture and to identify their shared design criteria. It contributes to the field by mapping the scientific landscape through bibliometric analyses and uncovering the fragmented nature of integrated approaches. Through the comparative network analysis of GHs, SHs, and GRSHs, the study proposes the Green'S'Mart Hospital Model as a conceptual framework to unify sustainable and smart design strategies. Future research may test and refine the model through real-world implementations, performance assessments, and interdisciplinary collaborations. Expanding the model with user-centred data, environmental metrics, and policy frameworks may further enhance its practical relevance and applicability across various healthcare design contexts.

ETHICS: There are no ethical issues with the publication of this manuscript.

PEER-REVIEW: Externally peer-reviewed.

CONFLICT OF INTEREST: The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

FINANCIAL DISCLOSURE: This study is supported financially by Yıldız Technical University Scientific Research Projects Coordination Unit under project number FDK-2022-4882.

ACKNOWLEDGEMENT: This article was prepared based on the PhD Thesis of Melda ÖZDEMİR, conducted under the supervision of Prof. Dr. Gökçe TUNA within the Department of Architecture, Building Program, at Yıldız Technical University Institute of Science. "This work has been supported by Yildiz Technical University Scientific Research Projects Coordination Unit under project number FDK-2022-4882."

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