



EXPLORING THE EVOLUTION AND TRENDS OF SPACE SYNTAX IN HEALTHCARE BUILT-ENVIRONMENT RESEARCH: A BIBLIOMETRIC OVERVIEW

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ABSTRACT

The relationship between spatial arrangement and social interactions is analyzed by a tool called space syntax. This study provides a bibliometric analysis of the application of space syntax in healthcare research. After performing a “title-abstract-keyword” search in the Scopus database, a total of 101 documents were analyzed using the software VOSviewer and R Bibliometrix. The analysis provides an overview of how journals, authors, countries, and institutions are divided chronologically. The citation patterns of journals, articles, the most cited journals, papers, and keywords' co-occurrence map are all displayed in detail. Findings show, that the most often occurring keywords are space syntax (53), wayfinding (8), evidence-based design, and hospital (6 each), privacy, and visibility (4 each), emergency department, spatial layout, and layout analysis (3 each). The results of this study will help researchers choose their research objectives with a better understanding of how space syntax is currently applied in healthcare-built environment research.

Keywords: space syntax, space syntactic, hospital, healthcare, healthcare-built environment, evidence-based design

I. Introduction

In healthcare built-environment research, space syntax has attracted a lot of attention since it is a powerful analytical tool [1]. Researchers can better comprehend the complex interactions between physical environments, behavioral patterns, and healthcare outcomes because of their distinctive perspectives on the spatial organization [2], [3]. Space syntax offers important insights into how the physical environment affects patient experiences [4], staff workflows, and overall healthcare delivery by investigating the spatial features and connection of various spaces within healthcare environments [5]. Space syntax is a study of spatial structures and how they affect human behavior, [6]. In the context of healthcare research, this method entails examining the design, connectedness, and accessibility of spaces inside healthcare facilities to comprehend how different spatial arrangements affect aspects of healthcare [7]. Researchers can investigate how patient safety [8], wayfinding [9]–[11], circulation [12], [13], “privacy” [4], [14], and interactions between patients and staff are affected by architectural design, among other areas of healthcare delivery [15].

Evaluation of spatial arrangements and their impact on patient outcomes is one of the primary uses of space syntax in healthcare-built-environment research [16]. Researchers have used space syntax analysis to explore the relationship between physical environments and patient falls in hospitals [17]. Researchers have discovered probable design elements that cause falls, such as inadequate visibility or ineffective spatial organization, by examining the connectedness and integration of various areas, including patient rooms, corridors, and nurse stations [18]. The effect of spatial layouts on staff communication and workflow in healthcare environments has also been studied using space syntax [4]. Researchers have determined architectural elements that facilitate or impair staff interactions and collaboration by examining the spatial aspects of work areas, staff break areas, and patient care zones [19].

Understanding how the built environment affects patient happiness and well-being may also be learned using space syntax analysis [1]. Researchers have analyzed how the layout of spaces affects patient comfort, privacy [14], and access to care by analyzing the spatial characteristics of waiting areas [20], consultation rooms, patient rooms and utilities [8], [21], [22]. This knowledge can be used to direct the creation of patient-centred environments that encourage pleasant patient experiences and expedite healing. Healthcare practitioners and architects can build facilities that optimize care delivery and



improve the experiences of patients and employees by adding space syntax analysis into the design process [5].

Bibliometric analysis has become a useful tool for examining and assessing the research landscape of numerous disciplines. According to Van Eck and Waltman [23], bibliometric analysis is a quantitative technique that examines patterns of publication, citation, collaboration, and emerging trends within a particular study topic. It can offer important insights into the trends, patterns [16], [23], [24], and effects of studies that use space syntax in the context of healthcare-built environments research. It is crucial to comprehend the corpus of existing literature on space syntax in healthcare built-environment research for several reasons. It enables researchers to determine the existing state of knowledge, the publication trends over time, the most popular study topics, shifts in research focus, and emerging topics of interest [16], [25], [26].

Although space syntax has emerged as a useful analytical tool in several research fields [27], the literature has not given much attention to its usage and impact in healthcare research. This dearth emphasizes the demand for thorough bibliometric analyses to examine and comprehend the state of the art in this field of study. This bibliometric analysis of space syntax on healthcare-built environment research will aid in identifying patterns of publication over time, prominent authors, participating countries, contributing journals, knowledge gaps, and new research avenues.

II. Methods

The Scopus database was searched during the first week of October 2023 to obtain the bibliographic information needed for this research. The search was carried out with the term "TITLE-ABS-KEY," which stands for "title-abstract-keyword." The keywords include: ("space syntax" OR "space syntactic" OR "visibility graph analysis" OR "space syntax analysis") AND ("healthcare-built environment" OR hospital OR healthcare OR clinic). The search resulted in 101 documents in the Scopus database.

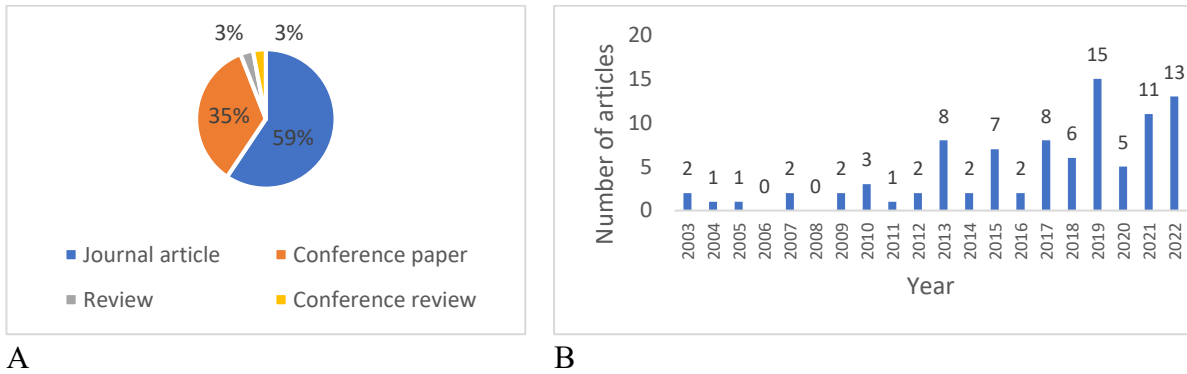
The bibliometric data were analyzed with the software VOSviewer, R Bibliometrix and MS Excel to determine the status of published literature on space syntax in healthcare-built environment research: its publication trends, number of citations, citation network with countries, prominent authors in terms of number of publications and citations, number of organizations, prominent keywords etc.

III. Results

The result is presented in the following themes: trends of publication; analysis of countries/regions; analysis of authors; analysis of organizations; analysis of documents; analysis of keywords; analysis of sources etc.

3.1 Publication Trends

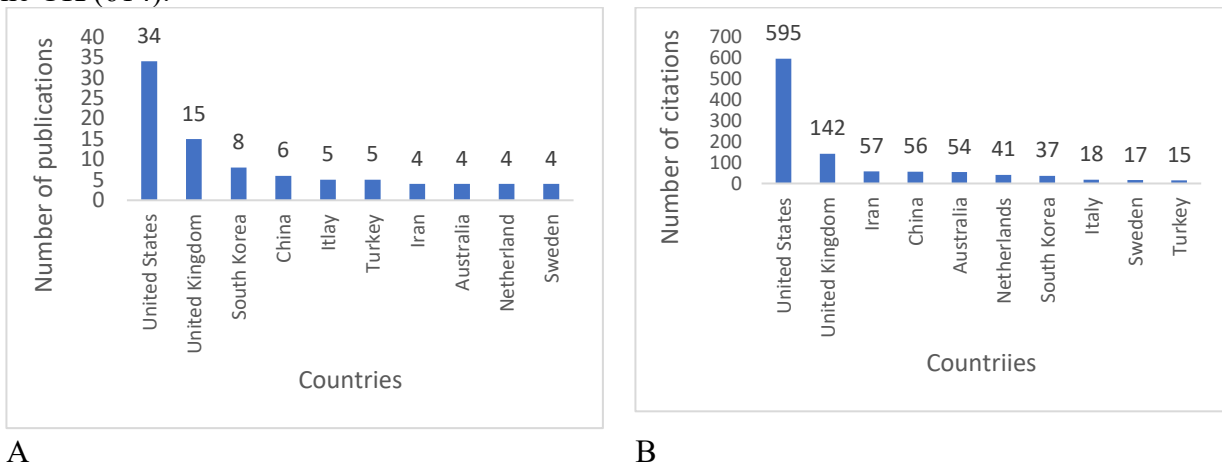
A total of 101 manuscripts of space syntax in healthcare-built environments were analyzed. The publications were categorized as journal articles, conference papers, reviews, and conference reviews based on the type of publication (Figure 1A). The majority of the documents (59%) were journal articles, with conference papers coming in second (35%). Most of the included articles were written in English language. Figure 1B depicts the annual distribution of articles over a decade. In 2003, the first article on space syntax in a healthcare-built environment study was published. The figure shows that before 2013, a very limited number of papers were published. However, a considerable number of articles on this topic were published after 2021.



A Figure 1 Trends in publication on space syntax in healthcare-built environment research. (A) Document type (B) Single-year publication over a decade

3.2 Analysis of countries/region Figure 2A depicts the top ten nations with the most publications. While 31 countries contributed to the publication on space syntax in healthcare-built environment research, only 11 countries published four or more publications demonstrating the deficiencies of this kind of research in many nations. In terms of the number of publications, the United States contributed the most publications (34, 38% of all publications), followed by the UK (15, 17%). More than 60% of the papers in this field came from three countries: the US, the UK, and South Korea.

Figure 2B lists the top ten nations with the most citations. The US ranked first in terms of citation counts (595), followed by the UK (142). Figure 3 describes the network of bibliographic coupling with countries having three or more documents. In this figure, there are four clusters (red, green, blue, and yellow) and 13 items that represent the countries. Cluster 1 (red cluster) has 8 items (Italy, Japan, Netherlands, South Korea, Sweden, Turkey, United Kingdom, and United States), cluster 2 (green) has 3 items (Australia, China, and Iran), cluster 3 (blue cluster) has 1 item (Iraq), and cluster 4 (yellow cluster) has 1 item (Egypt). The size of the circle represents the strength, and the thickness of the curved lines represents the link strength. The US has the highest total link strength (958), followed by the UK (614).



A Figure 2 Countries publication status (A) Top 10 countries with most publications (B) Top 10 nations with most citations

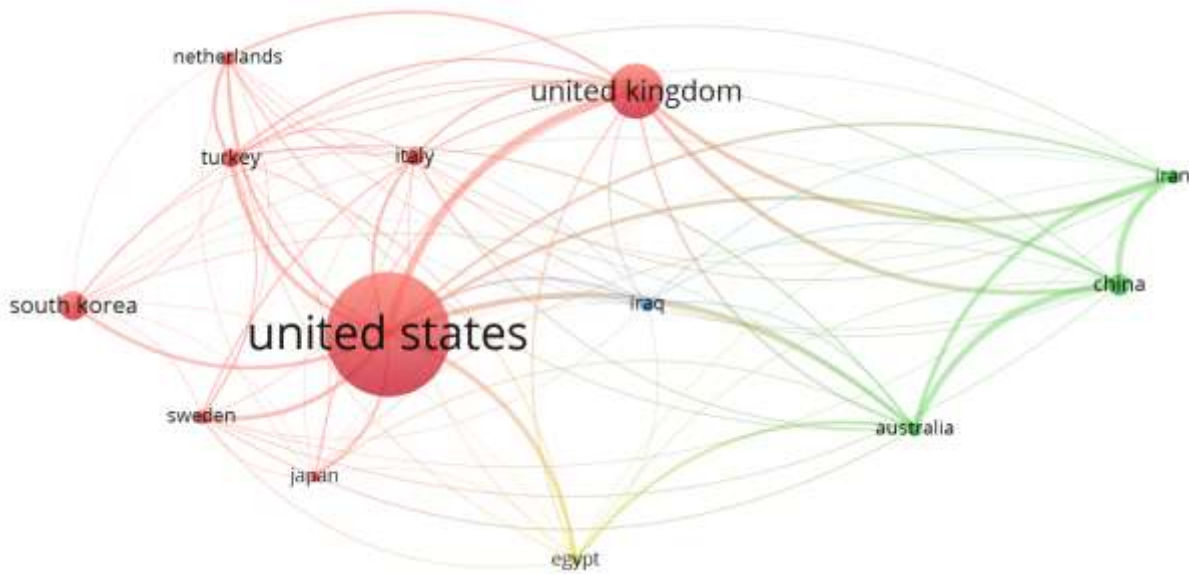


Figure 3 Network visualization of Bibliographic coupling with countries having three or more documents

Table 1 represents the co-authorship data visualization with countries. A nation's minimum document count was set at 4. Out of 31 countries, 11 met the threshold. China and the UK had ranked first in terms of the number of papers co-authored with scholars of other countries having total link strength (6 each), followed by Australia and the US (5 each).

Table 1 Network of Co-authorship network with nations

Nation	Documents	Citations	Total link strength
China	6	56	6
United Kingdom	15	142	6
Australia	4	54	5
United States	34	595	5
Iran	4	57	4
Netherlands	4	41	2
Italy	5	18	1
South Korea	8	37	1
Sweden	4	17	1
Turkey	5	15	1
Iraq	4	9	0

Figure 4 is the graphical network visualization of co-authorship with at least 4 documents of a nation. The links show the strength of their co-authorship, and the sizes of the spheres show the strength of their publication. In this mapping, there were four clusters (red, green, blue, and yellow) with 10 items. Cluster 1 (red cluster) and Cluster 2 (green cluster) had 3 items each with a total link strength of 6 and 5 respectively, cluster 3 (blue cluster) and Cluster 4 (yellow cluster) had 2 items each with a total link strength of 2 and 6 respectively.

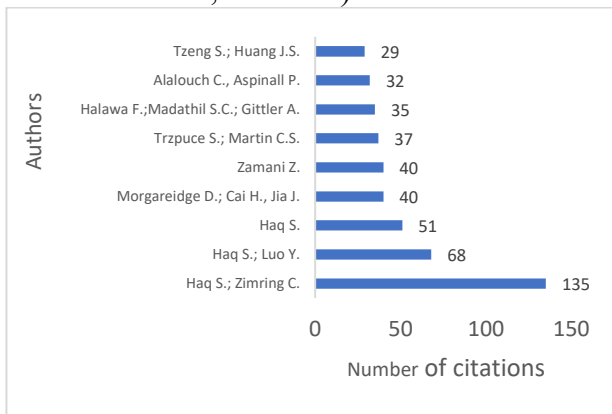


Figure 4 Co-authorship network with countries

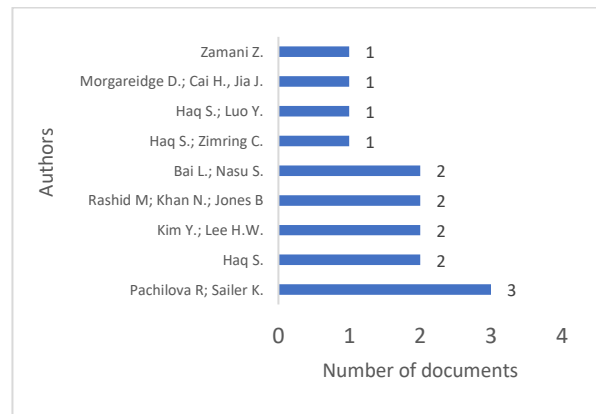
3.3 Analysis of authors

Figure 5A represents the citation network visualization with authors. In terms of the number of citations, Haq S.; and Zimring C. were the most cited authors (135), followed by Haq S.; and Luo Y. (68). The authors Pachilova R.; Sailer K. had the most publications (3), followed by Haq S., Kim Y.; Lee H.W., Rashid M; Khan N.; Jones B, and Bai L.; Nasu S. (2 each) (Figure 5B).

Figure 6 depicts the graphical visualization of the bibliographic coupling network with authors. The threshold for documents of an author was set to 2. Out of 92 authors, 5 met the threshold. In this mapping, there are two clusters (red and green), and 5 items in total. Cluster 1 had three items (Bai L.; Nasu S., Kim Y.; Lee H.W., Rashid M.; and Khan N.; Jones B.) and Cluster 2 had two items (Haq S., and Pachilova R.; Sailer K.).



A



B

Figure 5 Citation network with authors (A) Top 10 authors with the most citations (B) Top 10 authors with the most publications

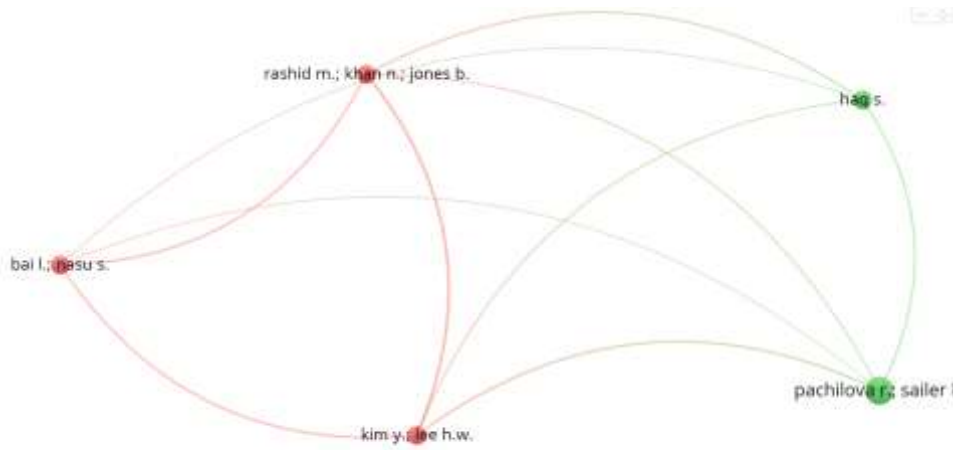


Figure 6 Bibliographic coupling network with authors

Figure 7 shows the corresponding author countries. According to the figure, the US had the highest number of corresponding authors (22) in the category of single-country publication (SCP), followed by Korea (7). United States had also ranked first in corresponding authors (4) in the category of multiple country publication (MCP), followed by Australia (2).

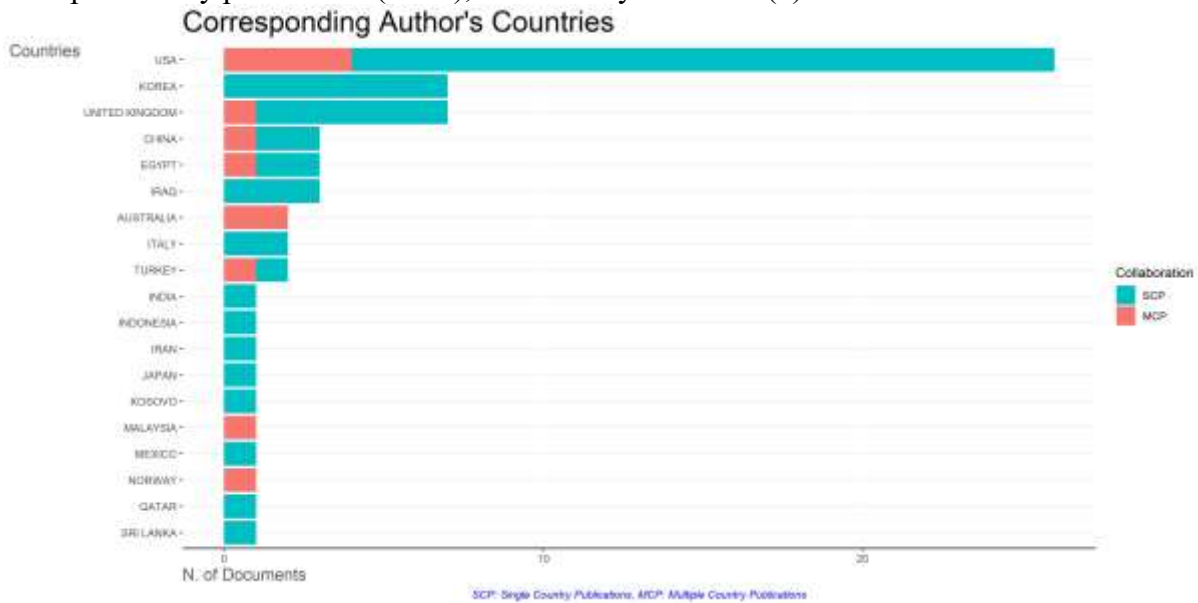


Figure 7 Corresponding author countries

3.4 Analysis of organizations

Figure 8 shows the performance of organizations with two or more publications in terms of space syntax in healthcare-built environment research. A total of 182 organizations contributed to this research area. “Civil and Environmental Engineering Department, University of California, Berkeley, United States” and “Department of Architecture, the University of Kansas, Lawrence, KS, United States” are the most productive organizations in terms of the number of citations (25 each), followed by University College London, United Kingdom (18).

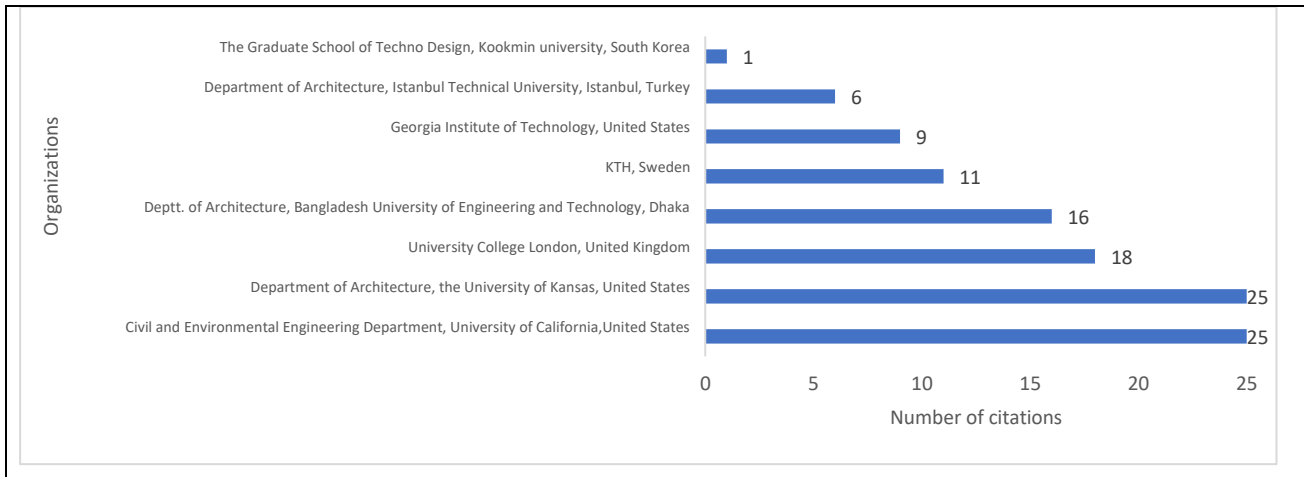


Figure 8 Citation and co-citation visualization: Top 10 organizations with the highest number of citations

3.5 Analysis of documents

Table 2 represents the citation network visualization with documents based on the number of citations. Haq & Zimring [6]: Just down the road a piece: The development of topological knowledge of building layouts has ranked first in terms of the number of citations (135), followed by Haq et al., [7]: Space Syntax in Healthcare facilities research: A review (68).

Table 2 Top 10 documents with the highest number of citations

First author	Year	Title	Source	Citation
Haq S; Zimring C	[6]	Just down the road a piece: The development of topological knowledge of building layouts	Environment and Behavior	135
Haq S.; Luo Y.	[7]	Space Syntax in healthcare facilities research: A review	Health Environments Research and Design Journal	68
Zamani Z.	[4]	Effects of Emergency Department Physical Design Elements on Security, Wayfinding, Visibility, Privacy, and Efficiency and Its Implications on Staff Satisfaction and Performance	Health Environments Research and Design Journal	40
Morgareidge D.; CAI H.; JIA J.	[22]	Performance-driven design with the support of digital tools: Applying discrete event simulation and space syntax on the design of the emergency department	Frontiers of Architectural Research	40
Haq S.	[28]	Investigating the syntax line: Configurational properties and cognitive correlates	Environment and Planning B: Planning and Design	38
Trzpuć S.J.; Martin C.S.	[5]	Application of space syntax theory in the study of medical-surgical nursing units in urban hospitals	Health Environments Research and Design Journal	37
Halawa F.; Madathil S.C.; Gittler A.; Khasawneh M.T.	[17]	Advancing evidence-based healthcare facility design: a systematic literature review	Health Care Management Science	35

Alalouch C.; [14]	Spatial attributes of hospital multi-bed wards and preferences for privacy	Facilities	32
Aspinall P.			
Tzeng S.-Y.; [29]	Spatial forms and signage in wayfinding decision points for hospital outpatient services	Journal of Asian Architecture and Building Engineering	29
Huang J.-S.			
Chen X. et.al. [30]	Keratoconus detection of changes using deep learning of colour-coded maps	BMJ Open Ophthalmology	28

Figure 9 shows the bibliographic coupling network visualization with documents having five or more citations. Again, the size of the circle represents their strength of publications, the thickness of lines represents link strength and the colour represents their clusters. There are six clusters in this mapping, clusters 1, 2 and 3 had 11,10 and 8 items respectively, clusters 4 and 5 had 3 items each, and cluster 6 had 2 items. The largest blue circle symbolizes the author Haq S; Zimring C [6], has the most citations (135) and has a total link strength of 29.

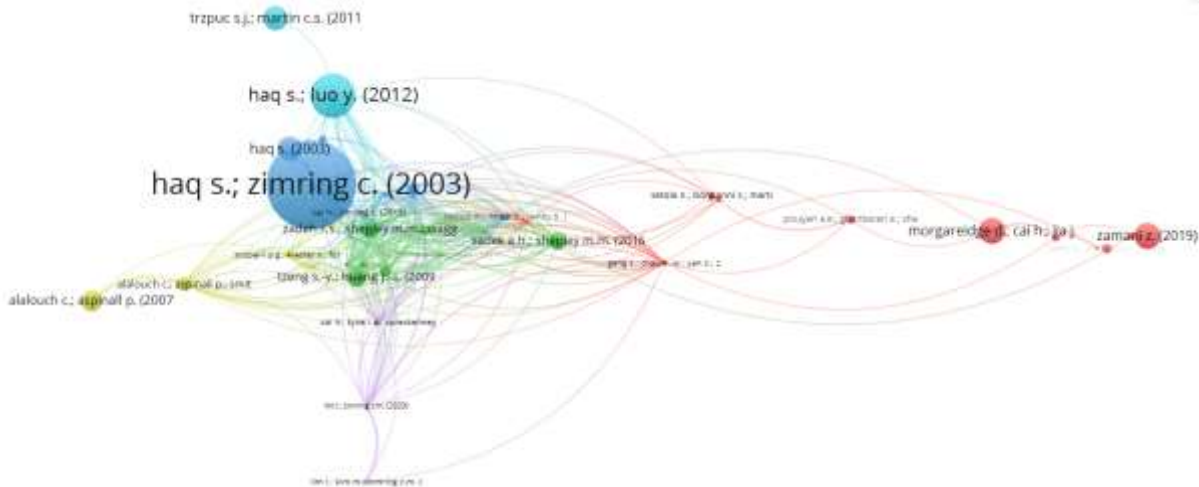


Figure 9 Bibliographic coupling visualization of documents with five or more citations

3.6 Analysis of keywords

Table 3 represents the co-occurrences network visualization with author keywords. The minimum number of occurrences of keywords was set to 3 in VOSviewer. Out of 359 keywords, 24 met the thresholds. “Space syntax” scored first rank with total link strength (54); followed by evidence-based design (12); hospital and wayfinding (10 each).

Table 3 Co-occurrence network with author keywords

Keyword	Occurrences	Total link strength
Space syntax	53	54
Evidence-based design	6	12
Hospital	6	10
Wayfinding	8	10
Agent-based	3	8
Privacy	4	8
Visibility	4	8
Emergency department	3	7
Spatial analysis	3	7
Layout analysis	3	6

Figure 10 shows the network visualization map of co-occurrences with the author's keywords. There were seven clusters with 24 items and 92 total link strengths in this mapping. Cluster 1-4 had the highest number of items (4 each), followed by Cluster 5 and 6 (3 items each), and cluster 7 (2 items).

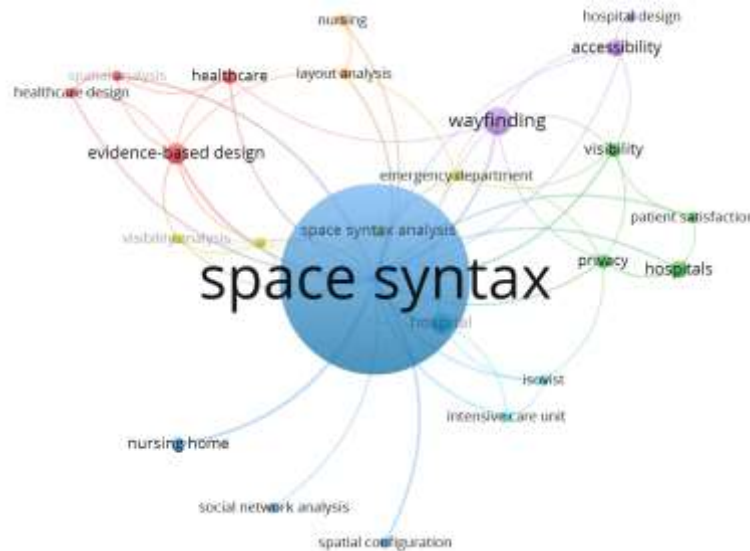


Figure 10 Co-occurrences network with author keywords

3.7 Analysis of sources

Table 4 represents the citation network visualization with source. According to the table the source “Health Environments Research and Design Journal” scored the highest citations (288), followed by “Environment and Behavior” (135). Figure 11 shows the network visualization of bibliographic coupling with sources having two or more documents. The mapping displays four clusters (red, green, blue, and yellow) with 14 items. The red cluster had the highest number of items (4) with a total link strength (236), followed by the green cluster with items (4) and total link strength (139).

Table 4: Top 10 sources with the highest number of citations

Source	Documents	Citations
Health Environments Research and Design Journal	16	288
Environment and Behavior	1	135
Facilities	2	54
2013 International Space Syntax Symposium	8	52
Frontier of Architectural Research	2	40
Environment and Planning B: Planning and Design	1	38
Healthcare Management Science	1	35
Journal of Asian Architecture and Building Engineering	3	33
BMJ Open Ophthalmology	1	28
Journal of Cataract and Refractive Surgery	2	24
Lean Construction Journal	1	18

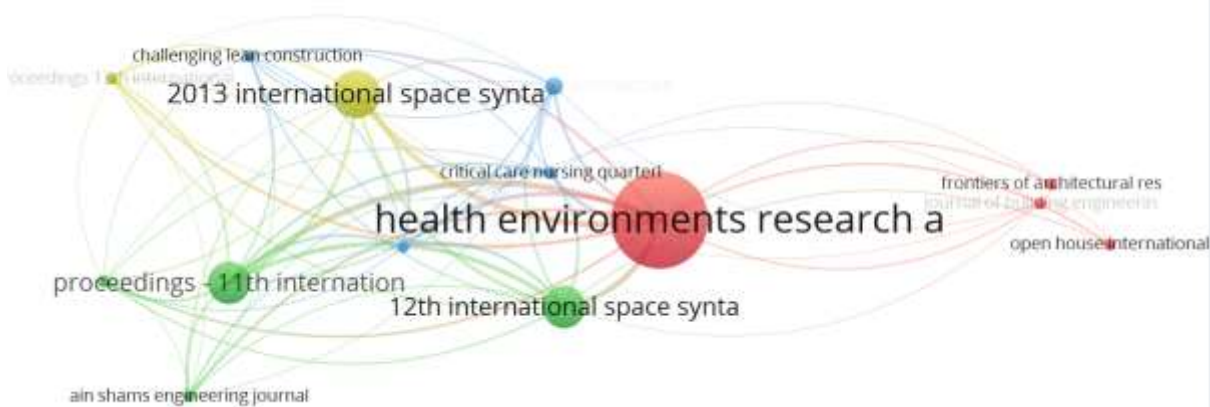


Figure 11 Network visualization of Bibliographic coupling with a source having at least three documents of source

3.8 Analysis of space syntax research in hospital departments

Several authors have explored different hospital departments through the perspective of space syntax, offering insightful contributions to the field of healthcare research and design. Analysis revealed that the “spatial layout”[31]–[35], “inpatient ward” [8], [14], [18], [36], [37], “nursing unit”[5], [18], [21], [38], “emergency department” [22], [27], [39], “outpatient department”[29], [40], have been examined for improved healthcare outcomes and patient & staff experiences. The authors' collaborative efforts highlight the importance of space syntax in deciphering hospital departmental complexities and cultivating a comprehensive understanding of the field of healthcare architecture.

3.9 Analysis of current themes

The current themes and the potential research areas were identified through keyword analysis. The analysis revealed that “privacy” [4], [14], [41], [42], “visibility” [4], [5], [18], [43], “wayfinding” [4], [9]–[11], [13], [29], “evidence-based design” [17], [27], [31], [43]–[45], “healing environments” [1], [46], “hospital ward layout” [36], [37] are frequent themes in the literature. These topics demonstrate the varied ways in which space syntax analysis is used to comprehend how spatial arrangements affect patient experiences [47], employee productivity, and health outcomes [5]. Numerous research studies have investigated how the physical layout of healthcare facilities affects the likelihood of patient falls [48], [49]. Researchers have found architectural elements that cause falls, such as long corridors [50], low visibility [51], and complex design, by utilizing space syntax analysis to investigate the connectedness and integration of various areas within hospitals.

The analysis also revealed the influence of spatial layouts on staff communication and processes as an important research issue [1]. The relationship between spatial layouts and staff performance [4], and collaboration in healthcare settings has been investigated through research using space syntax analysis [5], [21], [40]. Researchers have discovered design elements that help or impede staff collaboration and workflow by examining the spatial characteristics of workspaces, nursing stations, and patient care zones [38], [40]. According to Alalouch et al. [14], spatial syntax analysis can demonstrate the value of closeness and visibility in fostering good staff communication, which ultimately improves patient care.

3.10 Analysis of Country, keyword, and source relationship

Figure 12 shows the relationship of the author’s country, keywords, and sources (journals) in three field plots using the Sankey diagram. Sankey diagrams are a kind of graphic that illustrates the flow of values from one set to another. Sankey diagrams are used to visualize quantitative data regarding flows, their connections, and their change [52]. The author's country (AU_CO) is on the left, keywords (DE) are in the centre and cited sources (CR_SO) are on the right. The size of the rectangle represents the frequency which is proportional to the nodes it contains, and the thickness of connecting lines represents the strength of the relationship.

The figure displays the top 10 countries in the left field, the middle field containing the keywords used by these countries, and the right field containing the primary cited sources. It is evident from the middle field that the researchers are more interested in "space syntax," "evidence-based design," "hospital," "wayfinding," and "healthcare." These are hot topics that academics are paying more attention to. It is evident from the left field that the United States has produced the most publications.

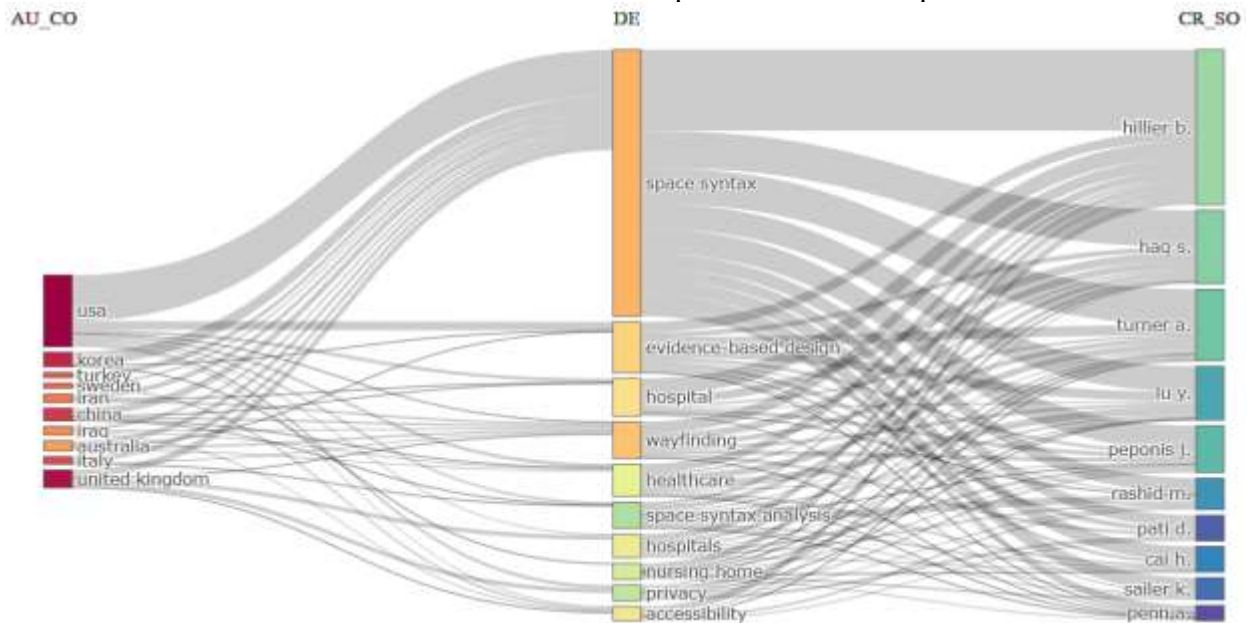


Figure 12 Three field plot

IV. Discussion

This bibliometric analysis of space syntax in healthcare built-environment research yielded useful insights into the trends of publication, patterns, major themes, prominent countries, influential authors, participating organizations, highly cited documents, frequently used keywords, and rising fields of research. The analysis of publishing trends offers an overview of the evolution of space syntax in healthcare-built environment research. Data analysis reveals that the first paper on this topic came out in 2003, and very few articles were published before 2018. The highest number of publications was recorded in the year 2019. This reflects an increasing interest in space syntax in healthcare-built environment research. The publishing trends shed light on the geographical dispersion of this field's study. Data analysis shows a concentration of space syntax research in healthcare originating predominantly in the US, the UK, South Korea, and China.

The author productivity and author collaborative networks have been identified by this bibliometric analysis. It identified writers who have significantly advanced the study of space syntax in healthcare research. These authors have produced a sizable number of articles, received many citations, or maintained a steady research output throughout time. Data revealed that the author Haq S.; Zimring C. has the highest number of citations (135), whereas the author Pachilova R.; Sailer K. has the highest number of documents (3) in this field of study. This data not only sheds light on the contributions of certain scholars but also points to potential multidisciplinary cooperation.

Citation analysis offers important insights into the significance and influence of space syntax studies in built environments and healthcare research [53]. The relevance of the research can be determined by examining citation counts. The articles “Just down the road a piece: The development of topological knowledge of building layouts” authored by Haq et al., [6]; “Space Syntax in healthcare facilities research: A Review” by Haq et al., [7]; “Effects of Emergency Department Physical Design Elements on Security, Wayfinding, Visibility, Privacy, and Efficiency and its Implications on Staff Satisfaction and Performance” by Zamani Z. [4]; “Performance-driven design with the support of digital tools: Applying discrete event simulation and space syntax on the design of the emergency department” by

Morgareidge et al., [22]; and “Investigating the syntax line: Configurational properties and cognitive correlates” by Haq [28] are some of the articles which received highest citations. These publications helped establish space syntax as a useful tool in healthcare-built-environment research.

The yearly trend themes produced by R software are depicted in Figure 13. According to the figure, "hospitals," "human," and "space syntax," are some of the trend themes in this area having the highest term frequency (26 each) in the year 2019. "Syntactics" scored the highest term frequency (41) in the year 2017.

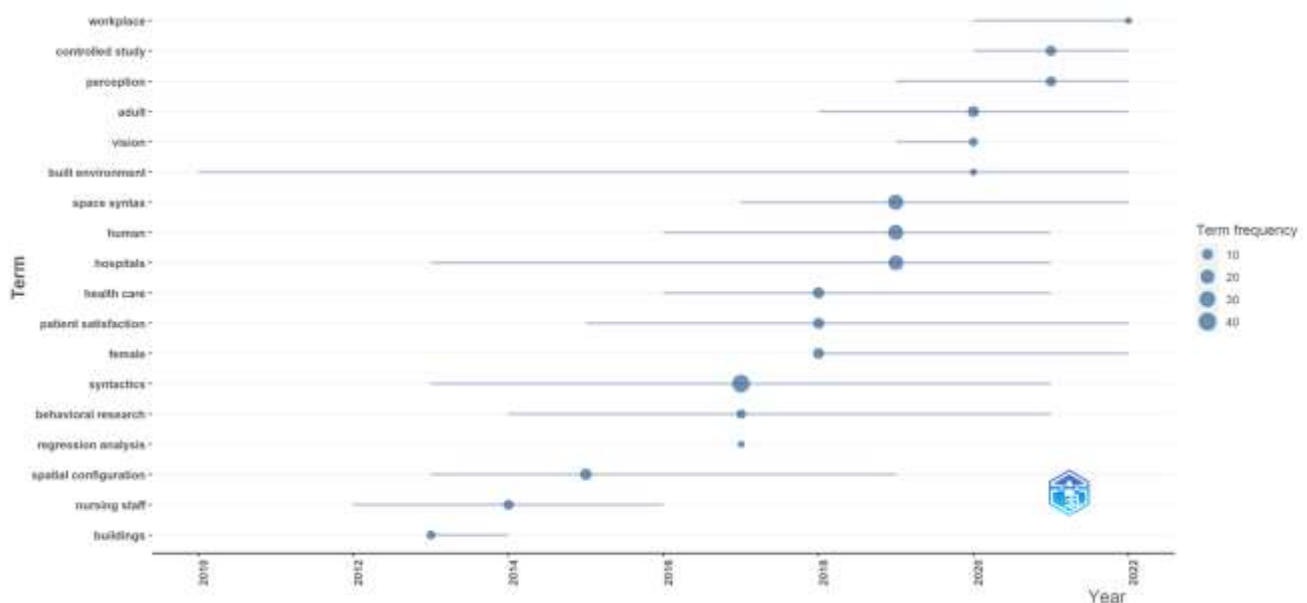


Figure 13 Trend topics during one decade

The study found gaps in the body of literature that offer prospects for further research. While studies have examined the effects of space syntax on wayfinding, visibility, and privacy, there is still room for more investigation into how spatial layouts affect patient outcomes like satisfaction, stress, and healing. The investigation also uncovered a dearth of research on the use of space syntax in healthcare settings, including long-term care facilities, pediatric facilities, and specialized healthcare units opening possibilities for future research.

The findings indicate several implications for upcoming work on space syntax in healthcare-built environments. To effectively utilize the potential of space syntax analysis, there is a need for expanded interdisciplinary collaboration. A thorough understanding of the effect of spatial arrangements on healthcare outcomes can be attained by involving architects, healthcare experts, and researchers from various disciplines. Future studies should also focus on addressing the geographic disparity found in the reviewed studies.

V. Conclusion

This research provides a comprehensive view of space syntax in healthcare-built environment research. Though space syntax has been around for over 40 years, its application in healthcare research has been encouraging in the last decade. This analysis shows that, before 2013, there was a dearth of research in the field of space syntax in healthcare. However, the rise in the number of recently published articles reveals that there has been significant study in this field. It is interesting to note that work in healthcare research appears to follow the general development pattern of space syntax. While some researchers closely examine the plan and, depending on their focus, suggest new, frequently composite variables, others reexamine previous studies to provide greater confidence in the published results. To show converging results and bolster robust evidence-based design decisions, enough studies should be conducted of the first kind.



Despite the vast array of disciplines that comprise healthcare research, the integration of spatial analysis, as offered by space syntax, is relatively unexplored. This study reveals that few countries actively participate in the cooperative initiatives, indicating a lack of attention paid to the use of space syntax in healthcare research. Space syntax has been used in healthcare research by very few authors. The findings show that the United States is a significant contributor in terms of the number of papers and number of citations; followed by the United Kingdom. The author Haq S & Zimring C has received the most citations. The United States has the highest number of corresponding authors. Civil and Environmental Engineering Department, University of California, Berkeley, United States is the most productive organization in terms of the number of citations. The document “Just down the road a piece: The development of topological knowledge of building layouts” authored by Haq et al., [6] in the year 2003 has received maximum citations. The maximum number of journal articles were published in “HERD: Health Environments Research and Design Journal.”

The analysis illustrates the development of space syntax in healthcare research, identifies major research subjects, evaluates author productivity and collaboration networks, and highlights the significance of space syntax studies through citation analysis. By highlighting the necessity of interdisciplinary cooperation, global representation, and examination of understudied themes, this analysis adds to the body of existing knowledge and influences future research orientations. Researchers can increase the use of space syntax in healthcare-built-environment research and improve healthcare outcomes and patient-centred environments by utilizing the insights provided by this bibliometric analysis.

The topic in the healthcare-built environment research includes “privacy,” “visibility,” “wayfinding”, “spatial layout”, “evidence-based design,” and “healing environments”. These limited findings revealed the need for additional research on space syntax in the built environment of healthcare. The systematic application of space syntax can provide researchers with fresh approaches for creating an efficient healthcare-built environment. A thorough investigation of each identified publication could be done in the future to provide a systematic in-depth perspective on this growing research topic.

References

- [1] D. A. Rafeeq and F. A. Mustafa, “Evidence-based design: The role of inpatient typology in creating healing environment, hospitals in Erbil city as a case study,” *Ain Shams Eng. J.*, vol. 12, no. 1, pp. 1073–1087, Mar. 2021, doi: 10.1016/j.asej.2020.06.014.
- [2] A. H. Babbu and M. Haque, “Effects of the Physical Environment of Pediatric Healthcare Settings on Health Outcomes of Patient & Family and Staff,” *Int. Trans. J. Eng. Manag. Appl. Sci. Technol.*, vol. 12, no. 12, Sep. 2021, doi: 10.14456/ITJEMAST.2021.240.
- [3] B. Meka, V. Navakazi, and F. Xërxa Beqiri, “Assessment of primary Health Care Facilities in Kosovo using Space Syntax Analysis,” *J. Sci. Humanit. Arts - JOSHA*, vol. 8, no. 3, 2021, doi: 10.17160/josha.8.3.764.
- [4] Z. Zamani, “Effects of Emergency Department Physical Design Elements on Security, Wayfinding, Visibility, Privacy, and Efficiency and Its Implications on Staff Satisfaction and Performance,” *Health Environments Research and Design Journal*, vol. 12, no. 3. pp. 72–88, 2019. doi: 10.1177/1937586718800482.
- [5] S. J. Trzpuć and C. S. Martin, “Application of space syntax theory in the study of medical-surgical nursing units in urban hospitals,” *Health Environments Research and Design Journal*, vol. 4, no. 1. pp. 34–55, 2011. doi: 10.1177/193758671000400104.
- [6] S. Haq and C. Zimring, “Just down the road a piece: The development of topological knowledge of building layouts,” *Environ. Behav.*, vol. 35, no. 1, pp. 132–160, 2003, doi: 10.1177/0013916502238868.
- [7] S. Haq and Y. Luo, “Space Syntax in Healthcare Facilities Research: A Review,” *HERD Heal. Environ. Res. Des. J.*, vol. 5, no. 4, pp. 98–117, Jul. 2012, doi: 10.1177/193758671200500409.
- [8] R. Pachilova and K. Sailer, “Providing care quality by design: a new measure to assess hospital



ward layouts,” *J. Archit.*, vol. 25, no. 2, pp. 186–202, Feb. 2020, doi: 10.1080/13602365.2020.1733802.

[9] M. S. Chen, Y. T. Ko, and W. C. Hsieh, “Exploring the planning and configuration of the hospital wayfinding system by space syntax: A case study of cheng ching hospital, chung kang branch in taiwan,” *ISPRS International Journal of Geo-Information*, vol. 10, no. 8. 2021. doi: 10.3390/ijgi10080570.

[10] Z. K. Ismael and K. F. Khalil, “Space Performance Assessment of a Relocatable Health Facility: Mosul Hospital as a Case Study,” *Buildings*, vol. 12, no. 10, 2022, doi: 10.3390/buildings12101539.

[11] E. M. Khotbehsara, R. Askarizad, M. Mehrinejad, S. N. Nasab, and K. Somasundaraswaran, “The impact of COVID-19 on visitors’ wayfinding within healthcare centers,” *Ain Shams Eng. J.*, vol. 14, no. 5, p. 101957, May 2023, doi: 10.1016/j.asej.2022.101957.

[12] K. A. Youssef and A. M. A. Youssef, “Promoting spatial cognition in hospital buildings using space syntax analyses,” *Journal of Engineering and Applied Science*, vol. 69, no. 1. 2022. doi: 10.1186/s44147-022-00153-w.

[13] A. E. Pouyan, A. Ghanbaran, and A. Shakibamanesh, “Impact of circulation complexity on hospital wayfinding behavior (Case study: Milad 1000-bed hospital, Tehran, Iran),” *J. Build. Eng.*, vol. 44, p. 102931, Dec. 2021, doi: 10.1016/j.job.2021.102931.

[14] C. Alalouch and P. Aspinall, “Spatial attributes of hospital multi-bed wards and preferences for privacy,” *Facilities*, vol. 25, no. 9/10, pp. 345–362, Jul. 2007, doi: 10.1108/02632770710772450.

[15] R. M. Z. Carmelo Cali, “Communication in healthcare environments- some reflections on space syntax,” *Riv. Ital. di Filos. Linguaggio*, vol. 15, pp. 86–98, 2021, doi: 10.4396/20210608.

[16] A. H. Babbu, “Mapping Space Syntax as a Computational Tool: A Bibliometric Analysis,” *J. Eng. Sci. Technol. Rev.*, vol. 16, no. 6, pp. 82–89, Dec. 2023, doi: 10.25103/jestr.166.10.

[17] F. Halawa, S. C. Madathil, A. Gittler, and M. T. Khasawneh, “Advancing evidence-based healthcare facility design: a systematic literature review,” *Health Care Manag. Sci.*, vol. 23, no. 3, pp. 453–480, Sep. 2020, doi: 10.1007/s10729-020-09506-4.

[18] W. J. Cai H, Ameen I, Sprecklimeyer K, “Impact of Visibility and Accessibility on Healthcare Workers’ Hand-Hygiene Behavior: A Comparative Case Study of Two Nursing Units in an Academic Medical Center,” *Heal. Environ. Res. Des. J.*, vol. 14, no. 2, pp. 271–288, 2021, doi: 10.1177/1937586720962506.

[19] N. Setola, S. Borgianni, M. Martinez, and E. Tobari, “The role of spatial layout of hospital public spaces in informal patient-medical staff interface,” 2013.

[20] F. A. Mustafa and S. S. Ahmed, “The role of waiting area typology in limiting the spread of COVID-19: Outpatient clinics of Erbil hospitals as a case study,” *Indoor Built Environ.*, p. 1420326X2210796, Mar. 2022, doi: 10.1177/1420326X221079616.

[21] H. Cai and C. Zimring, “Cultural impacts on nursing unit design: A comparative study on Chinese nursing unit typologies and their U.S. counterparts using space syntax,” *Environ. Plan. B Urban Anal. City Sci.*, vol. 46, no. 3, pp. 573–594, Mar. 2019, doi: 10.1177/2399808317715639.

[22] D. Morgareidge, H. CAI, and J. JIA, “Performance-driven design with the support of digital tools: Applying discrete event simulation and space syntax on the design of the emergency department,” *Front. Archit. Res.*, vol. 3, no. 3, pp. 250–264, Sep. 2014, doi: 10.1016/j.foar.2014.04.006.

[23] N. J. Van Eck and L. Waltman, “CitNetExplorer: A new software tool for analyzing and visualizing citation networks,” *Journal of Informetrics*, vol. 8, no. 4. pp. 802–823, 2014. doi: 10.1016/j.joi.2014.07.006.

[24] O. Hakimi, H. Liu, and O. Abudayyeh, “Digital twin-enabled smart facility management: A bibliometric review,” *Front. Eng. Manag.*, Apr. 2023, doi: 10.1007/s42524-023-0254-4.

[25] Z. Xiao, Y. Qin, Z. Xu, J. Antucheviciene, and E. K. Zavadskas, “The Journal Buildings: A Bibliometric Analysis (2011–2021),” *Buildings*, vol. 12, no. 1. 2022. doi: 10.3390/buildings12010037.



- [26] A. Khudhair, H. Li, G. Ren, and S. Liu, "Towards Future BIM Technology Innovations: A Bibliometric Analysis of the Literature," *Appl. Sci.*, vol. 11, no. 3, p. 1232, Jan. 2021, doi: 10.3390/app11031232.
- [27] N. El-Hadedy and M. El-Husseiny, "Evidence-Based Design for Workplace Violence Prevention in Emergency Departments Utilizing CPTED and Space Syntax Analyses," *HERD Heal. Environ. Res. Des. J.*, vol. 15, no. 1, pp. 333–352, Jan. 2022, doi: 10.1177/19375867211042902.
- [28] S. Haq, "Investigating the syntax line: Configurational properties and cognitive correlates," *Environ. Plan. B Plan. Des.*, vol. 30, no. 6, pp. 841–863, 2003, doi: 10.1068/b2960.
- [29] S. Y. Tzeng and J. S. Huang, "Spatial forms and signage in wayfinding decision points for hospital outpatient services," *J. Asian Archit. Build. Eng.*, vol. 8, no. 2, pp. 453–460, 2009, doi: 10.3130/jaabe.8.453.
- [30] X. Chen *et al.*, "Keratoconus detection of changes using deep learning of colour-coded maps," *BMJ Open Ophthalmol.*, vol. 6, no. 1, pp. 19–22, 2021, doi: 10.1136/bmjophth-2021-000824.
- [31] A. H. Sadek and M. M. Shepley, "Space Syntax Analysis: Tools for Augmenting the Precision of Healthcare Facility Spatial Analysis," *HERD Heal. Environ. Res. Des. J.*, vol. 10, no. 1, pp. 114–129, Oct. 2016, doi: 10.1177/1937586715624225.
- [32] Z. Jia, P. Nourian, P. Luscuere, and C. Wagenaar, "Spatial decision support systems for hospital layout design : A review," *J. Build. Eng.*, vol. 67, no. October 2022, p. 106042, 2023, doi: 10.1016/j.job.2023.106042.
- [33] H. Cai and C. Zimring, "Cultural impacts on nursing unit design : A comparative study on Chinese nursing unit typologies and their U . S . counterparts using space syntax," 2017, doi: 10.1177/2399808317715639.
- [34] G. Jeon, H. Lee, and Y. Kim, "A Primarily Study on Hierarchy according to the Spatial Configuration of Nurse Station in Geriatrics Hospital," *Adnavced Sci. Technol. Lett.*, vol. 100, pp. 1–5, 2015.
- [35] M. Jang, "The relationship between spatial characteristics and social interaction of older adults with dementia in nursing homes," *J. Asian Archit. Build. Eng.*, vol. 22, no. 1, pp. 175–187, 2023, doi: 10.1080/13467581.2022.2043874.
- [36] R. Pachilova, K. Sailer, and M. King, "The dynamic nature of caregiver communication networks and spatialised work processes in hospital wards," *Proc. - 11th Int. Sp. Syntax Symp. SSS 2017*, pp. 18.1-18.19, 2017.
- [37] R. Pachilova and K. Sailer, "Ward layout, Communication and Care Quality," 2019.
- [38] R. S. Zadeh and M. M. Shepley, "Rethinking Efficiency in Acute Care Nursing Units : Analyzing Nursing Unit Layouts for Improved Spatial Flow," *Heal. Environ. Res. Des. J.*, vol. 6, no. 1, pp. 39–65, 2012.
- [39] B. Meka, V. Navakazi, and F. X. Beqiri, "Effects of spatial configuration on the patient ' s journey to the Emergency Department," *City, Territ. Archit.*, 2023, doi: 10.1186/s40410-023-00203-7.
- [40] K. Sailer, R. Pradinuk, and D. Mackinnon, "How Strongly Programmed is a strong programme building?: A comparative analysis of outpatient clinics in two hospitals," 2013.
- [41] C. Alalouch, P. Aspinall, and H. Smith, "On locational preferences for privacy in hospital wards," *Facilities*, vol. 27, no. 3/4, pp. 88–106, Feb. 2009, doi: 10.1108/02632770910933125.
- [42] P. G. Scupelli, S. Kiesler, and S. R. Fussell, "Using isovist views to study placement of large displays in natural settings," *Conf. Hum. Factors Comput. Syst. - Proc.*, pp. 2645–2650, 2007, doi: 10.1145/1240866.1241056.
- [43] Haq, "Where we walk is what we see- Foundational Concepts and analytical techniques of space syntax," *Cent. Heal. Des.*, pp. 1–15, 2018, doi: 10.1177/1937586718812436.
- [44] L. Lim, M. Kim, and C. M. Zimring, "Measuring Interpersonal Visual Relationships in Healthcare Facilities: The Agent Visibility Model and SAVisualPower Tool," *Heal. Environ. Res. Des. J.*, vol. 12, no. 4, pp. 203–216, 2019, doi: 10.1177/1937586719842357.



- [45] A. H. Babbu, "Evidence based design:A sustainable approach for planning and designing pediatric healthcare environments," *J. Des. Built Environ.*, vol. 24, no. 02, pp. 57–70, 2024, [Online]. Available: <https://ejournal.um.edu.my/index.php/jdbe>
- [46] S. O'Hara *et al.*, "Macro-cognition in the Healthcare Built Environment (mHCBE): A Focused Ethnographic Study of 'Neighborhoods' in a Pediatric Intensive Care Unit," *Heal. Environ. Res. Des. J.*, vol. 11, no. 2, pp. 104–123, 2018, doi: 10.1177/1937586717728484.
- [47] H. Cai *et al.*, "Impact of inpatient unit design features on overall patient experience and perceived room-level call button response," *Int. J. Environ. Res. Public Health*, vol. 18, no. 18, 2021, doi: 10.3390/ijerph18189747.
- [48] R. I. Shorr, S. Ahrentzen, S. L. Luther, C. Radwan, and B. Hahm, "Examining the Relationship Between Environmental Factors and Inpatient Hospital Falls : Protocol for a Mixed Methods Study Corresponding Author :," *JMIR Res. Protoc.*, vol. 10, pp. 1–9, 2022, doi: 10.2196/24974.
- [49] A. H. Babbu and M. Haque, "Design Characteristics for Sustainable Pediatric Healthcare Environments: Stakeholder's Perception," *Eur. J. Sustain. Dev.*, vol. 12, no. 1, p. 113, Feb. 2023, doi: 10.14207/ejsd.2023.v12n1p113.
- [50] M. Rashid, J. Wineman, and C. Zimring, "Space, behavior, and environmental perception in open-plan offices: A prospective study," *Environment and Planning B: Planning and Design*, vol. 36, no. 3, pp. 432–449, 2009. doi: 10.1068/b33034.
- [51] Y. Lu and C. Zimring, "Can Intensive Care Staff See Their Patients? An Improved Visibility Analysis Methodology," *Environ. Behav.*, vol. 44, no. 6, pp. 861–876, Nov. 2012, doi: 10.1177/0013916511405314.
- [52] P. Riehmman, M. Hanfler, and B. Froehlich, "Interactive sankey diagrams," *Proceedings - IEEE Symposium on Information Visualization, INFO VIS.* pp. 233–240, 2005. doi: 10.1109/INFVIS.2005.1532152.
- [53] L. Deng and N. H. Romainoor, "A bibliometric analysis of published literature on healthcare facilities' wayfinding research from 1974 to 2020," *Heliyon*, vol. 8, no. 9. 2022. doi: 10.1016/j.heliyon.2022.e10723.