Mapping Space Syntax as a Computational Tool: A Bibliometric Analysis

Abdul Halim Babbu

Department of Architecture, Jamia Millia Islamia, New Delhi, India

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Abstract

This study presents a bibliometric analysis of the literature on "space syntax." Space syntax studies the relationship between spatial configurations and human behaviour. As the study of space syntax gains relevance in numerous fields, its bibliometric analysis becomes critical for understanding research trends, identifying influential publications, and flagging knowledge gaps. The Scopus database was searched using "title-abstract-keyword", and a total of 2411 peer-reviewed articles were finally examined. Findings demonstrated the evolution of space syntax study over time, with a notable increase in publications in recent years. It provides an updated overview of how currently accessible papers on space syntax are distributed chronologically among journals, authors, nations, and institutions. The top 10 most cited publications on space syntax; the co-occurrence map of keywords; citation patterns of journals and articles; and the most cited journals are all shown in detail. The findings indicate that the number of publications on this subject increased dramatically between 2021 and 2022, with China being the most productive and prominent country in terms of the number of publications (n=712), followed by the United Kingdom (n=511). Citation analysis shows that the United Kingdom has the greatest number of citations (n=3948) followed by the United States (n=2089). According to keyword co-occurrence analysis, the high-frequency keywords include space syntax (n=1567), syntactic (n=1015), urban planning (n=289), spatial configuration (n=265), and spatial analysis (n=254). This study will give researchers a better grasp of the current use of space syntax and will act as a reference for researchers working on this subject to select their own future research goals.

Keywords: space syntax; space syntactic; visibility graph analysis, justified graph; axial integration

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1. Introduction

In the 1970s, Bill Hillier and his colleagues at University College London's Bartlett School of Architecture created "space syntax," a theory and approach for analysing spatial relationships [1]. Space syntax, in its broader sense, is a collection of methods that can be used alone or in various permutations. The core of the space syntax approach is the determination of configurable spatial relationships in the constructed setting. Early in the method's development, Bill Hillier et al., [2] realised that for the field of anthropological studies, space syntax could provide a spatial understanding of the social organisation in settlements from various cultures by illuminating how buildings and settlements affect social relations. Recently, numerous recommendations for new iterations of space syntax that incorporate geographical information science have been made [3], [4].

The study of human behaviour in a variety of circumstances, such as urban settings, structures, and transportation systems, is done using space syntax [5]. It entails examining these systems' spatial characteristics and how they affect, how people move, interact, and experience things. A significant body of literature has been written about the theoretical underpinnings [5]–[8], methodological developments [9]–[12], and empirical applications [7] of space syntax as a result of the academics' sustained interest in the subject over time. The development, trends, and major contributors to the field of space syntax studies are shown through a bibliometric examination of this area of study. This paper seeks to give a thorough bibliometric analysis of space

syntax research, highlighting the major themes, significant works, prolific writers, and new lines of inquiry.

Research on space syntax is essential to comprehending how human behaviour, urban planning, and architecture are impacted by spatial configuration. It improves our living spaces, informs policy, and directs user-centric design. Planners and architects can design environments that enhance our quality of life and foster communal well-being with the help of these insights.

Bibliometric analysis is a quantitative technique that looks at trends in publishing, citing, and teamwork within a certain study area [13], [14]. The bibliometric analysis allows researchers to pinpoint key contributions, knowledge gaps, and new trends in a particular field by methodically analysing the bibliographic data and citation records of works [15], [16]. It provides a data-driven framework for comprehending the dynamics and structure of scientific knowledge, offering insightful information for academics, decision-makers, and practitioners.

A thorough literature search was carried out in Scopus databases, to undertake the bibliometric analysis of space syntax study. Suitable search terms were used, including "space syntax," "visibility graph analysis," "space syntactic," "justified graph," and "axial integration." Numerous articles that were later filtered for quality and relevance were produced by the initial search. The resulting dataset provided a complete overview of the space syntax literature up to date.

The review of the space syntax literature identifies several intriguing trends and advancements. First, there has been a consistent increase in publications throughout time, reflecting the growing interest in the topic. The early research on space syntax mostly concentrated on the theoretical underpinnings

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and methodological developments, establishing the platform for further study. Researchers began using space syntax analysis in a variety of fields as the subject developed, including urban planning [3], [17], architecture [18], [19], transportation [3], [20], and social sciences [21], [22]. The wide range of journals that publish the articles reflects the interdisciplinary nature of space syntax study.

The analysis also identifies the major themes in the literature on space syntax that have emerged throughout time. These topics cover urban morphology and spatial organisation, pedestrian flow, and wayfinding, building and interior design, connection, and accessibility, as well as social interaction and behaviour. The usefulness of space syntax analysis in comprehending human-environment interactions in many circumstances is illustrated by these issues.

The bibliometric analysis also identifies key publications and authors in the literature on space syntax. Theoretical frameworks, methodological innovations, and empirical case studies were all provided in several influential papers that profoundly changed the area. For instance, "The Social Logic of Space" by Bill Hillier et al., [2], which introduced important ideas such as axial lines and integration, is widely recognised as a foundational work in space syntax. Similar to this, several works by well-known writers, such as [10], [23]–[25] have significantly advanced the discipline.

The analysis highlights new trends and directions in space syntax research in addition to the existing contributors. Researchers are increasingly using big data analytics, geographical analysis methods, and computer modelling in their studies as a result of the introduction of new technology and data sources. By combining technology and spatial analysis, we can better comprehend complex spatial phenomena and create more sustainable and energy-efficient constructed environments. In addition, there is growing interest in investigating how space syntactic analysis may be applied in the context of new problems including smart cities, sustainable transportation, and public health.

2. Methods

2.1. Data Collection
The Scopus database was searched in January 2023 to get the bibliographic data used in this study. Numerous search terms relevant to space syntax were employed to find as many bibliographic records as feasible. The search was conducted using the term "TITLE-ABS-KEY" (i.e., "title-abstract-keyword"). As a result, the appropriate publication is shown in the search results if a keyword is included in the title, abstract, or keywords of any article. The keywords used for this investigation include: (("space syntax" OR "space syntactic" OR "visibility graph analysis" OR "space syntax analysis" OR "axial map" OR "convex map" OR "justified graph" OR "axial integration")).

2.2. Data Analysis
A bibliometric is a collection of quantitative methods used to analyse bibliographic data. These tools may thoroughly analyse information linked to the published literature in the field of study, such as publications (year, nation or region, author, etc.), keywords, and citation trend analysis, to assist scholars in fully grasping the field of study's knowledge structure [26]–[28]. CiteSpace, VOSviewer, and R-Package Bibliography are some examples of visualisation and analytic tools [29]. VOSviewer and R were used in this study's data analysis. VOSviewer supports a wide range of bibliometric

studies, such as bibliographic coupling analysis, author co-citation analysis, and document co-citation analysis, allowing the key information of the research field to be grasped quickly [30], [31].

3. Results

3.1. Trends of publications and citations
The search approach yielded a total of 2411 literature items. The bibliometric search results reveal the trend of study on the issue, as shown in Fig. *1*, illustrating that research in the relevant area has increased in the last five years, as has the number of articles. The first article on this subject was published in 1985, and only a small number of articles were generated before 1998. After 2004, however, the number of publications increased. More than 35% of the literature review was published in the recent five years (2018–2022), with the biggest number of articles published in 2022 (n=429 papers, 18.74%).
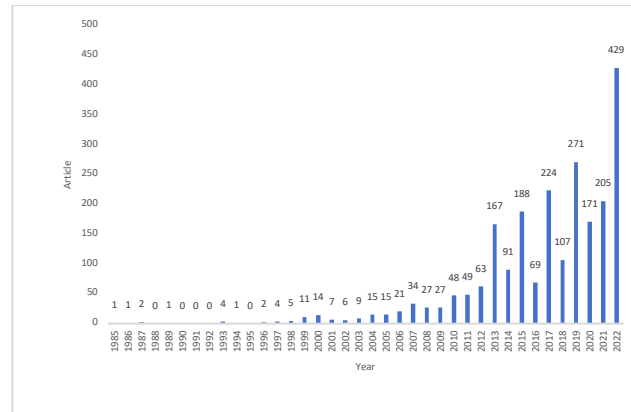

Fig. 1. Trends of publication on space syntax

3.2. Analysis of document type and subject category
Table 1, displays the document type, number of documents as well as the percentage share of the documents. They were classified according to their publishing type as journal articles, conference papers, books, book chapters, reviews, conference reviews, editorials, book and note. Journal articles had the highest percentage of documents (n=1244, 51.60%), followed by conference papers (n=1011, 41.93%). In total, detected papers were grouped into 24 study categories The subject category with the biggest proportion of documents was "Social Sciences" (942 records, 21.65% of all publications), followed by "Engineering" (824, 18.94%), Earth and Planetary Sciences (777, 17.86%), and Environmental Science (455, 10.46%), as shown in Table 2 Computer Science; Arts and Humanities; Mathematics; and Energy are among the subject areas having more than 100 documents.

Table 1. Document type

Document Type	No of documents (n)	Percentage of documents (%)
Article	1244	51.60
Conference Paper	1011	41.93
Book Chapter	85	3.53
Review	32	1.33
Conference Review	27	1.12
Editorial	5	0.21
Book	4	0.17
Note	3	0.12

Table 2. Subject categories focusing on space syntax

Subject Categories	Frequencies (n)	Percentage (%)
Social Sciences	942	21.65
Engineering	824	18.94
Earth and Planetary Sciences	777	17.86
Environmental Science	455	10.46
Computer Science	367	8.43
Arts and Humanities	303	6.96
Mathematics	130	2.99
Energy	123	2.83
Medicine	71	1.63
Business, Management and Accounting	64	1.47
Others	295	6.78

3.3. Analysis of affiliations and countries
Fig. *2*, shows a list of the top ten most relevant affiliations. University College London provided the most publications (n=156 articles), followed by Istanbul Technical University (n=65), Bartlett School of Architecture (n=52), Tongji University (n=51), and Northumbria University (n=40).
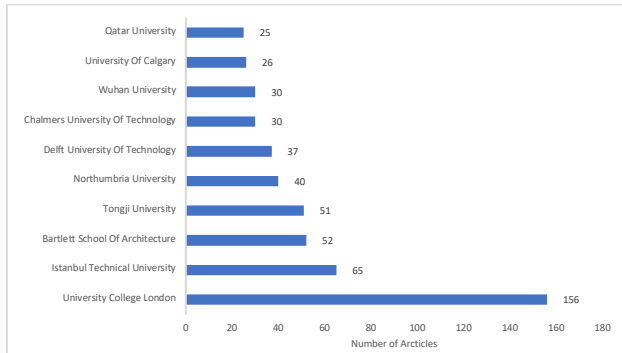

Fig. 2. Most relevant affiliations

The literature on the topic of space syntax came from 76 different nations. Fig. *3*A is a global map of the countries where the literature was written. Seven countries published more than 150 papers, accounting for 54.69% of the total published literature: China published the most papers (n=712), the United Kingdom (n=511), the USA (n=355), Turkey (n=196), Australia (n=162), South Korea (n=156), and Brazil (n=154) as shown in Fig. *3*B. Portugal, Japan, Italy, Sweden, and the Netherlands generated more than 100 publications. Fig. *3*C shows the total citations achieved by the country: the United Kingdom achieved the greatest number of citations (n=3948), followed by the United States (n=2089), China (n=1392), Sweden (n= 1131), and Italy (n= 893).

3.4. Analysis of co-author
The co-authorship analysis of countries was performed using VOSviewer. The minimum number of documents of a country was set to 20. Out of 123 countries, 30 meet the threshold. Fig. *4*, shows a network of co-authorship between nations derived from the main dataset. The sizes of the spheres indicate the relative strength of their publication (measured in terms of the number of documents); the colours indicate the stage of their temporal evolution; and the links indicate the strength of their co-authorship.

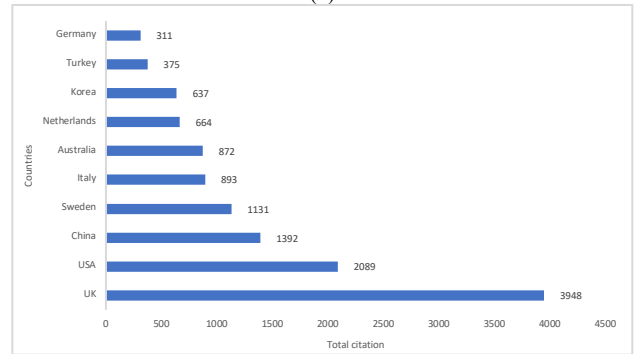Table 3, shows the relationship of the top ten co-authorship with countries. The United Kingdom has the

highest total link strength (n=139), followed by the USA (n=111), China (n=105), Netherlands (n=79), and Australia (n=66). The United Kingdom, United States and China appear more interested in further research on space syntax.
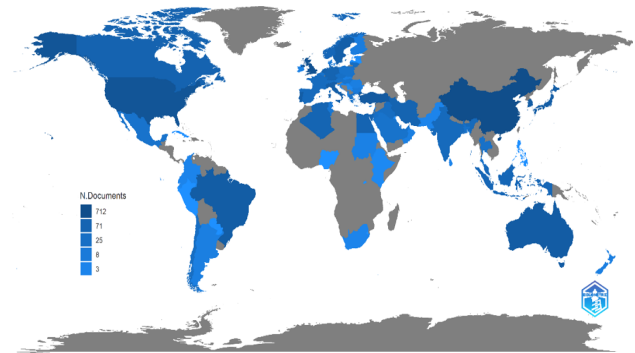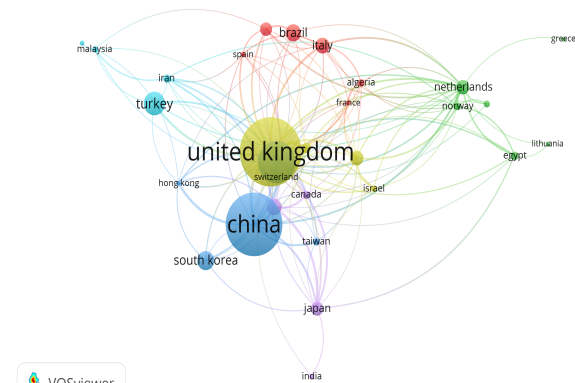

(a)
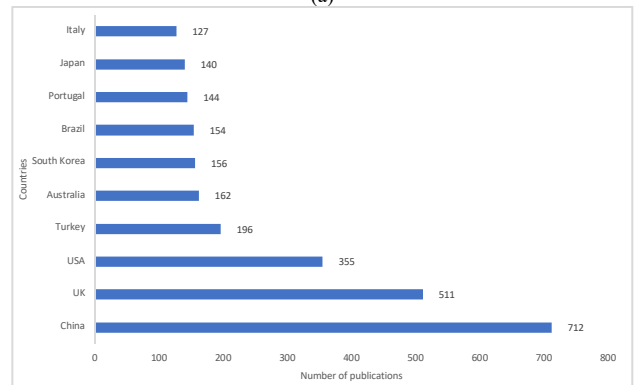
(b)

(c)

Fig. 3. World map depicting the distribution of countries

Fig. 4. Network map of co-authorship between countries with more than twenty publications.

Table 3. Relationship of top 10 co-authorship with countries

Country	Documents	Citations	Total link strength
United Kingdom	390	7683	139
United States	240	5232	111
China	360	1795	105
Netherlands	81	1205	79
Australia	96	1360	66
Japan	80	493	48
Norway	45	350	44
German	58	789	41
Sweden	85	1511	39
Canada	48	459	39

3.5. Citation analysis

The citation analysis revealed that 453 documents had more than 10 citations.

, shows the top ten documents with the most citations. "Natural movement: or, configuration and attraction in urban pedestrian movement" received the most citation (n=1029); followed by "The network analysis of urban streets: A primal approach" (n= 517); Network and psychological effects in urban movement (n=441); "Space syntax: A brief introduction to its logic and analytical techniques" (n=377); and "From axial to road-centre lines: A new representation for space syntax and a new model of route choice for transport network analysis" (n=363).

Table 4. Top 10 most cited papers in Scopus on space syntax

Rank	Authors	Title	Year	Citation	Source Title	Affiliation Country
1	Ref. [1]	Natural movement: or, configuration and attraction in urban pedestrian movement	1993	1029	Environment & Planning B: Planning & Design	UK
2	Ref. [24]	The network analysis of urban streets: A primal approach	2006	517	Environment & Planning B: Planning & Design	UK
3	Ref. [25]	Network and psychological effects on urban movement	2005	441	Lecture Notes in Computer Science	UK
4	Ref. [10]	Space syntax: A brief introduction to its logic and analytical techniques	2003	377	Environment and Behavior	USA
5	Ref. [3]	From axial to road-centre lines: A new representation for space syntax and a new model of route choice for transport network analysis	2007	363	Environment and Planning B: Planning and Design	UK
6	Ref. [4]	Space syntax: Some inconsistencies	2004	320	Environment and Planning B: Planning and Design	USA
7	Ref. [2]	Creating life: or, does architecture determine anything?	1987	275	Architecture & Comportment/Architecture & Behaviour	USA
8	Ref. [15]	Space syntax and spatial cognition: Or why the axial line?	2003	250	Environment and Behavior	UK
9	Ref. [26]	Integration of space syntax into GIS: New perspectives for urban morphology	2002	227	Transactions in GIS	France
10	Ref. [32]	A structural approach to the model generalization of an urban street network	2004	218	GeoInformatica	France

3.6. Co-citation analysis

By using a co-citation analysis with referenced authors, the most well-known authors in the literature on space syntax were found. The co-citation analysis revealed that 241 authors had more than 50 citations as shown in Fig. 5. The sphere sizes represent the relative strength of their publications (based on citation), the colour of the spheres represents the stage in their chronological development, and the strength of the linkages represents the number of citations they have received. Table 5, shows 10 authors with the most citations. The author Hillier B. received the most citations (n=6732), followed by Hanson J. (n=2522), Penn A. (n=2384), Turner A. (n=1959), and Peponis J. (n=1248).

Table 5. Authors with the most citation

Author	Citations	Total link strength
Hillier B.	6732	56543
Hanson J.	2522	26001
Penn A.	2384	30756
Turner A.	1959	23165
Peponis J.	1248	16770
Xu J.	711	10295
Jiang B.	678	8119
Van Nes A.	608	7735
Vaughan L.	590	7504
Batty M.	562	7638

3.7. Analysis of keywords occurrences

The most popular search terms in the Space syntax category are displayed in Fig. *6*. While the relative text size shows how frequently the clusters occur, the different colour represents how dense they are [33]. The co-occurrence analysis of all keywords revealed that 811 keywords had more than 5 occurrences. Fig. *7*, depicts the visualisation keywords' co-occurrence network, the high-frequency keywords include space syntax (n=1567), syntactic (n=1015), urban planning (n=289), spatial configuration (n=265), spatial analysis (n=254), urban design (n=153), urban morphology (n=153), accessibility (n=145), land use (n=144), urban growth (n=135), housing (n=119), and architectural design (n=118). The high-frequency keywords indicate the current research hotspots.
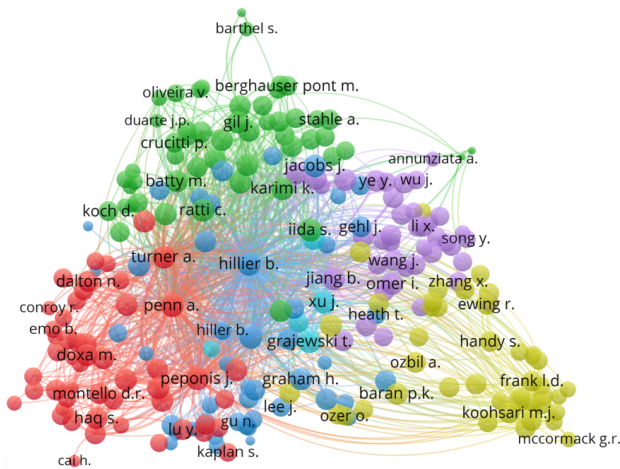

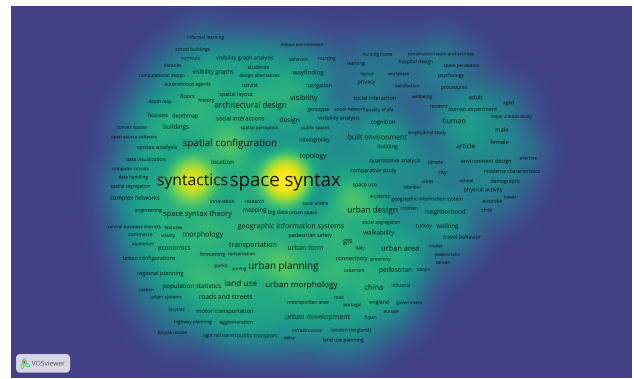**Fig. 5.** Network map of journals that receive more than 50 citations.

Fig. 6. Frequently used keywords in the database
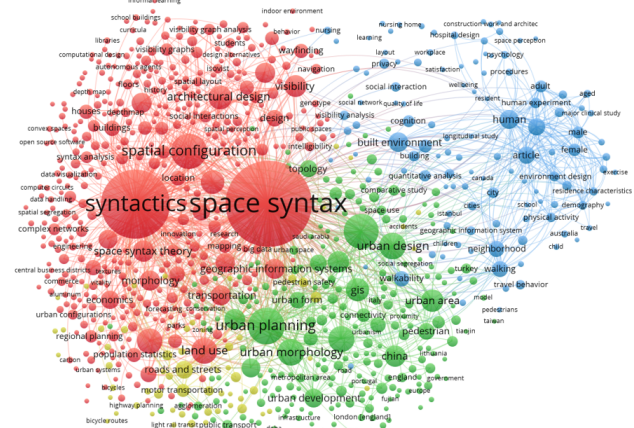

Fig. 7. Visualisation keywords co-occurrence analysis

4. Discussions

The bibliometric study of space syntax offers insightful information on the development, trends, and major contributors to the discipline. The constant increase of publications on space syntax throughout time is one of the major trends noted in the bibliometric study. The growth trajectory of space syntax research from 1985 to 2022 is shown in Fig. *1*. A comparatively small number of publications were seen in the early years, which was indicative of the field's infancy. But beginning in 2004, there was a noticeable surge of articles, a symptom of the growing popularity of space syntax analysis.

Numerous variables are responsible for the increase. First, the theoretical and methodological basis of space syntax was created by the foundational works of Hillier et al., [2] and other early scholars, which subsequently drew more researchers to the subject. Additionally, a wider variety of research projects have been made possible by the application of space syntax analysis in many different fields, thanks to improvements in computational modelling approaches and the growing availability of data [34]. The interdisciplinary character of space syntax study has also aided in its development. Urban design, healthcare, architecture, transportation, and social sciences are just a few fields where space syntax is used [20], [35], [36]. Researchers from other fields have been drawn to this interdisciplinary appeal, creating a wide body of literature in the area.

Understanding the connection between urban architecture, spatial organisation, and human behaviour [37] is at the heart of space syntax study. Researchers have investigated how spatial arrangements affect social interactions, movement patterns, and urban activity. Insights

into the ways that spatial organisation affects urban dynamics have been gained through the examination of roadway networks, building layouts, and open spaces [38]–[40]. It is attempted to comprehend how individuals move across cities and choose their paths by examining the connection and accessibility of urban places. Street network layouts, pedestrian traffic, and spatial cognition have all been the subject of studies [41].

The spatial organisation and layout of buildings have been studied, and the effects of various configurations on human performance and behaviour have been examined using space syntax. Building accessibility, spatial functioning, and the effect of spatial design on user experience are only a few of the topics covered by this research theme [15], [23]. It has been worked to improve urban planning and design practises by looking at the connectivity between various areas and the accessibility of different urban amenities. This subject is especially important for enhancing pedestrian networks, resource distribution equity, and transportation systems [9], [42]. Researchers have investigated how the design of spaces affects interpersonal interactions, teamwork, and social cohesiveness. This theme examines the effects of spatial configurations on social networks, community development, and social integration beyond just physical [43] [25].

The book "The Social Logic of Space" by Hillier and Hanson is regarded as a classic in the field of space syntax study [38]. Key ideas including axial lines, integration, and depth map analysis were first proposed in this landmark work. By creating the theoretical basis for comprehending the connection between spatial configurations and human behaviour, it paved the way for later research [15], [26].

Authors have established the idea of "accessibility" and provided a methodical way to describe urban mobility patterns using the concepts of space syntax [9], [44]. They offered insightful information regarding the connection between spatial structure and pedestrian movement. A computational tool for analysing visibility graphs and depth maps was described in Turner's publication "Depthmap: A Programme to Perform Visibility Graph Analysis" [45], [46]. Researchers were able to analyse visual accessibility inside spatial environments and investigate the visibility characteristics of spatial configurations because of methodological advancement.

The bibliometric study also identified new paths and trends in the literature on space syntax. These new directions reflect how spatial analysis is developing and how new technologies and data sources are being used. As computer modelling methods progress, researchers are incorporating simulation methods more frequently to comprehend complicated spatial phenomena. To study human behaviour in spatial environments and examine the effects of various spatial configurations, agent-based modelling, network analysis, and machine learning techniques are being used [24], [34], [47].

The idea of smart cities, which focuses on utilising technology and data to improve urban liveability and sustainability, has received a lot of attention recently. The optimisation of transportation networks [43], the discovery of effective land use patterns, and the development of pedestrian-friendly settings are all made possible by space syntax analysis, which is a critical component of the design and planning of smart cities [4], [11], [20].

Exploring the connections between space syntax analysis and public health is becoming more and more popular [4], [8], [48], [49]. Researchers are examining the effects of spatial arrangements on outcomes related to physical exercise, social well-being, and mental health [50]. Designing environments that encourage active living, increase access to healthcare services, and improve social contact are all done using space syntax analysis [19], [51]–[53]. These new paths show how space syntax research is always changing as it adapts to new problems and makes use of technology and data analysis advances.

5. Conclusions

The bibliometric study of space syntax research offers insightful information on the development, trends, and major contributors to the area. According to the analysis, there has been a consistent rise in publications over time, which reflects the expanding popularity of space syntax analysis. It identified study themes that cover several facets of spatial analysis and its connection to behaviour in humans. It was discovered that extensive research in this area is being done in both developed and developing nations around the world. In terms of publications, China has emerged as the most active nation in terms of number of publications (n=712), followed by the United Kingdom (n=511). Based on the total citations, the United Kingdom has emerged as the top cited country (n=3948), followed by the United States (n=2089). Authors with the greatest number of citations are listed in Table 5; Hillier B. has the highest number of citations (n= 6732), followed by Hanson J. (n= 2522). Based on publishing types (such as journal articles, conference articles, books, and book chapters), as well as subject categories (such as social science, engineering, earth and planetary sciences etc.), their works were compared in Table 1 and Table 2.

The findings of this study can provide invaluable insights by identifying research trends, mapping research networks, assessing impact, and highlighting key contributors. It draws interdisciplinary connections, uncovers underexplored areas, and synthesizes knowledge for researchers. It also tracks the evolution of the field over time and provides information to practitioners and policymakers in the fields of architecture and urban planning. This review helps to shape the direction of future research and interdisciplinary collaborations, ultimately advancing our understanding of spatial configuration and its impact on human behaviour and enhancing the field's development and relevance.

The theoretical underpinnings, methodological developments, and empirical applications of space syntax analysis have been greatly influenced by influential publications and authors. This analysis identifies new directions, such as the application of space syntax analysis in smart cities and public health, as well as the combination of computer modelling. To further the area of space research, researchers, policymakers, and practitioners can use this analysis as a foundation for their future work.

This study, despite its contributions, has some limitations. Firstly, the data extraction is limited to the Scopus database; therefore, future research should include additional datasets from other databases to improve the results. Secondly, this study was limited to journal articles. As a result, the research findings may not fully reflect the entire available literature on space syntax as a computational tool. The limitations mentioned above provide excellent opportunities for further research. To overcome these limitations, future studies may use data from multiple sources and a set of parameters for evaluations, coherence, and linkages.

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