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# Space Syntax has Come of Age: A Bibliometric Review from 1976 to 2023

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### Abstract
Despite numerous reviews of space syntax research, there has been little emphasis on the field's main characteristics and tendencies, including publication trends, geographical distribution, leading authors and institutions, collaboration networks, influential publications, research fronts, and research gaps. Bibliometric analysis techniques were employed to review nearly five decades of publications (1976–2023) drawn from multiple data sources to assess the field's annual trend of publications; its social, intellectual, and conceptual structures; and future research directions. The findings provide an overview of the landscape of space syntax studies and a valuable reference for a wide range of academics and professionals.

## Introduction

Space syntax is a theory and method for understanding the relationship between the urban environment and human behavior (Lamprecht 2022). Pioneered by Bill Hillier (1937–2019) and his colleagues in the late 1970s (Hillier et al. 1976) and early 1980s (Hillier and Hanson 1984) and developed further since then, it enables modeling and analyzing urban spaces to understand the social logic of cities, i.e., how the way in which streets are related to one another—or the configuration of streets—is associated with people's movement, activity, and behavior (Hillier and Hanson 1984). Space syntax considers the level of connectedness and analyzes how the spatial layout, *ergo* spatial configuration, of the network as a whole predicts the intensity of space usage patterns such as movement flows and face-to-face encounters (Hillier and Vaughan 2007). Supported by research evidence, Hillier stressed that spatial configuration is the generator of movement flows (Hillier et al. 1993) that determines land use patterns (Hillier 1996a, 1996b). This understanding of the configuration—function relationship helps to explain how design and planning affect human occupancy and makes it possible to forecast the likely consequences of design changes.

Previous studies on spaces syntax have mainly focused on describing its basic concepts and terms (Klarqvist 1993; Yamu, van Nes, and Garau 2021), explaining its philosophies (Penn 2003, 2021; Seamon 2020) and wider toolbox of methods (Al-Sayed et al. 2014; Bafna 2003; Hillier, Yang, and Turner 2012; Turner 2004; Turner et al. 2001), presenting its applicable strengths (Lamprecht 2022; Osman and Suliman 1994) and local-scale research trends (Park 2015), and discussing its methodological strengths and limitations (Batty 2004, 2013; Pafka, Dovey, and Aschwanden 2020; Ratti 2004; Suonperä Liebst and Griffiths 2020). Additionally, several reference books (Hanson

1998; Hillier 1996b; Hillier and Hanson 1984) and a textbook (van Nes and Yamu 2021) have been written on space syntax mathematics, its applications, and the social logic of buildings and cities.

Although the aforementioned publications have made valuable contributions to a greater understanding of space syntax theory and method, developed the field further, and fostered knowledge transfer, little effort has been made to conduct a quantitative systematic review of the space syntax literature to gain an understanding of the current state of space syntax-related research, its main characteristics, trends, scientific collaboration networks, and emerging and declining thematic areas. After nearly five decades of space syntax research, a quantitative systematic review of the field through multiple databases could enable a wide range of researchers and planning professionals to have an informed and factual discussion on the past, present, and future of space syntax.

To the best of our knowledge, there have been two review articles that are related to ours. In their review, Krenz (2022) and Krenz et al. (2019) traced the evolution of conceptual

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systems and concept trajectories in space syntax through conducting quantitative text analysis for a corpus of 1,089 conference papers over 20 years. Our study prolongates prior research by providing a comprehensive review of the landscape of space syntax research through analyzing 4,740 publications over about five decades, focusing on the field's social, intellectual and conceptual structures. The following research questions formed the framework that defined the scope of this study: (a) How does the field of space syntax perform at the individual, institutional, and country levels? (b) What are the major social cores of collaborations for authors, institutions, and countries? (c) Which publications contributed the most to the development of the field? (d) What are the thematic research trends and potential directions for future research?

A bibliometric review (Cobo et al. 2011; Wallin 2005) was subsequently conducted to evaluate the existing knowledge in terms of its main characteristics, intellectual structure, main research themes, and future subject trends. The literature corpus of 4,740 documents (during 1976–2023) drawn from multiple data sources was analyzed to answer the research questions.

The novelty of this study is threefold. First, it provides a systematic descriptive analysis and bibliometric mapping of the field to explore its tendencies and characteristics. Second, we combined data from multiple databases (Scopus, Dimensions, the space syntax network [www.spacesyntax.net], and the Portico preservation archive) to compile the relevant literature, including indexed and non-indexed publications. For the space syntax field in particular, it is important to create a holistic database with indexed and non-indexed literature because key relevant publications were published in non-indexed journals (e.g., the Journal of Space Syntax, which was active during 2010–2017) and conference proceedings (e.g., the proceedings of space syntax symposia before 2013). Collecting scientific literature from different sources made it possible to obtain valid and robust analytical results for interpretation. Third, supported by research evidence, our findings provide rich background knowledge and map out current progress, globally popular issues, and future research directions, thus offering a valuable source for scholars engaging in the field, people new to space syntax research, and practitioners. Perhaps more importantly, this study provides information about establishing and enhancing research network collaborations across countries, authors, and affiliations.

## Methodology

This study was conducted during February–April 2023. Quantitative bibliometric techniques were used to map the main tendencies of space syntax research and analyze its social, intellectual, and conceptual landscapes to identify potential collaborations, research gaps, and future research directions.

A bibliometric analysis allows the quantitative evaluation of the similarities between documents of a knowledge domain based on various metrics (van Eck and Waltman 2020). It aims to portray the landscape of a given discipline to measure and understand its performance and suggest a basis for future research. In bibliometric studies, performance analysis, which
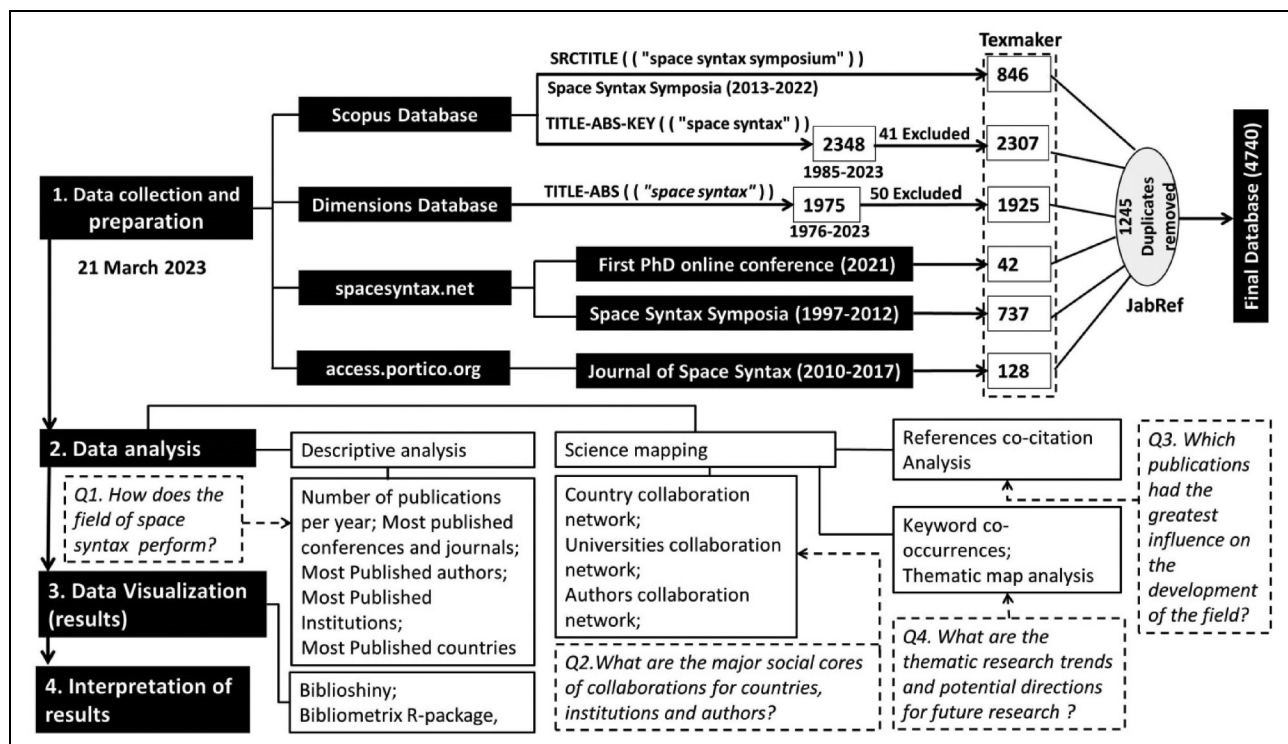


**Figure 1.** Workflow of bibliometric analysis of space syntax studies.

is descriptive in nature, focuses on summarizing the contributions of different research constituents (e.g., authors, journals, and countries) to a given field of study, whereas science mapping accounts for the relationships between research constituents (Donthu et al. 2021).

Based on our guiding questions, this study consisted of four main steps, illustrated in Figure 1 and described in the following subsections. We first describe the scientific database selection process and keyword search used to identify the body of literature considered in the bibliometric analysis. We then conducted a quantitative analysis of the data gathered. We then visualized the results and interpreted the findings.

## Data Collection and Preparation

*Data sources.* Collecting the corpus of relevant literature on space syntax was an important and sensitive phase because it could significantly impact the analysis results (Peris, Meijers, and van Ham 2018). Numerous studies have compared different academic databases, including the Web of Science (WoS), Scopus, and Dimensions, in terms of article coverage and the completeness and accuracy of the extracted metadata (Guerrero-Bote et al. 2021; Singh et al. 2021). The results of these studies reveal that Dimensions has the most exhaustive journal coverage, followed by Scopus and then WoS (Singh et al. 2021). However, Dimensions and Scopus metadata are characterized by lower quality than WoS metadata (Sedita, Caloffi, and Lazzeretti 2020; Singh et al. 202). Specifically, affiliation information is usually missing in a significant fraction of documents in Dimensions (Singh et al. 2021), and cited references are not standardized in Scopus, so intensive data cleaning is needed to match citation records (Sedita, Caloffi, and Lazzeretti 2020). Despite these limitations and others discussed in the literature, Scopus and Dimensions were chosen for use in this study to compile the relevant indexed literature because both provide broader publication coverage than other databases (Mongeon and Paul-Hus 2016). We also used the Space Syntax Network (https://www.spacesyntax.net/symposia/) and the Portico preservation archive (http://access.portico.org/stable?cs = ISSN_20447507_1392) to obtain the non-indexed proceedings of Space Syntax Symposia (1997–2012) and the publications of the Journal of Space Syntax (2010–2017), respectively.

*Data extraction and cleaning.* This research has employed different approaches to extract relevant indexed and non-indexed literature. First, a query of a reasonable choice of keywords is essential for literature extraction. Because not all morphological studies are related to space syntax analysis and vice versa, we used the term "space syntax," which is common in literature, to demonstrate the relevance of the extracted publications. To ensure that our search captures a wide range of articles, and it is not biased toward the aforementioned term, we have also searched for other keywords. For example, searching for "spatial syntax" in the Scopus database gives only 169 publications about half of which have already been captured by the search term "space syntax."

Importantly, due to the settings of search engines, Scopus and Dimensions were searched using slightly different ways. Specifically, we conducted a literature search on 21 March 2023 using the title, abstract, and keywords search in Scopus; and the title and abstract search in Dimensions to extract relevant documents covering the period between December 1976 and March 2023. Although space syntax officially dates back to the early 1970s, when Bill Hillier and his colleagues established a master's degree program in Advanced Architectural Studies at the University College London's School of Environmental Studies (now part of the Bartlett School of Architecture) (Penn 2021), our analysis began with the year 1976, as no publications are indexed in the selected databases prior to that year. Second, to extract the full records of indexed proceedings of space syntax symposia (2013–2022), we searched Scopus using the keyword "space syntax symposium" within the source title. Our searches in Scopus and Dimensions databases yielded a total of 5,169 documents. In the next step, non-peer-reviewed documents (i.e., preprints) and less important documents (i.e., letters, retracted, notes, erratum, data papers, and conference reviews) were excluded to strike a balance between precision and comprehension (Figure 2). This filtering process yielded 5,078 publications. We then used Texmaker, a free LaTEX editor, to input manually missing Dimensions metadata, such as affiliations and keywords.

In parallel, we used the PDF files available on Space Syntax Network and the Portico preservation archive to create BibTeX bibliographies of the proceedings of non-indexed Space Syntax Symposia (1997–2012), the proceedings of the First International Space Syntax PhD Conference (2021), and issues of the Journal of Space Syntax (2010–2017). Each record included the following fields: authors, paper title, abstract and keywords, year of publication, document type, affiliation, and references.

We then combined all entries of detected and created datasets using Texmaker and used the free software JabRef to identify and remove duplicates. Our final database included 4,740 publications (2,346 journal articles, 2,117 conference papers, 244 book chapters, 25 books, and eight book reviews) published in 1,298 sources (e.g., journals, conferences, book series, books).

To improve the efficiency of the analysis, we performed data cleaning in which individual keywords with similar meanings (such as "spatial syntax" and "space syntax" and "road network" and "street network") or with variations of the same term in the database (e.g., Geographic Information Systems versus GIS) were replaced with defined labels. Similarly, we aggregated different affiliation variants (e.g., Istanbul Technical University versus ITU) in the database. We also checked authors with the same surname but different initials (e.g., Ruth Conroy Dalton versus Ruth Dalton, and Claudia van der Laag Yamu versus Claudia Yamu), and standardized cited references (e.g., Hillier 1996b, space is the machine,
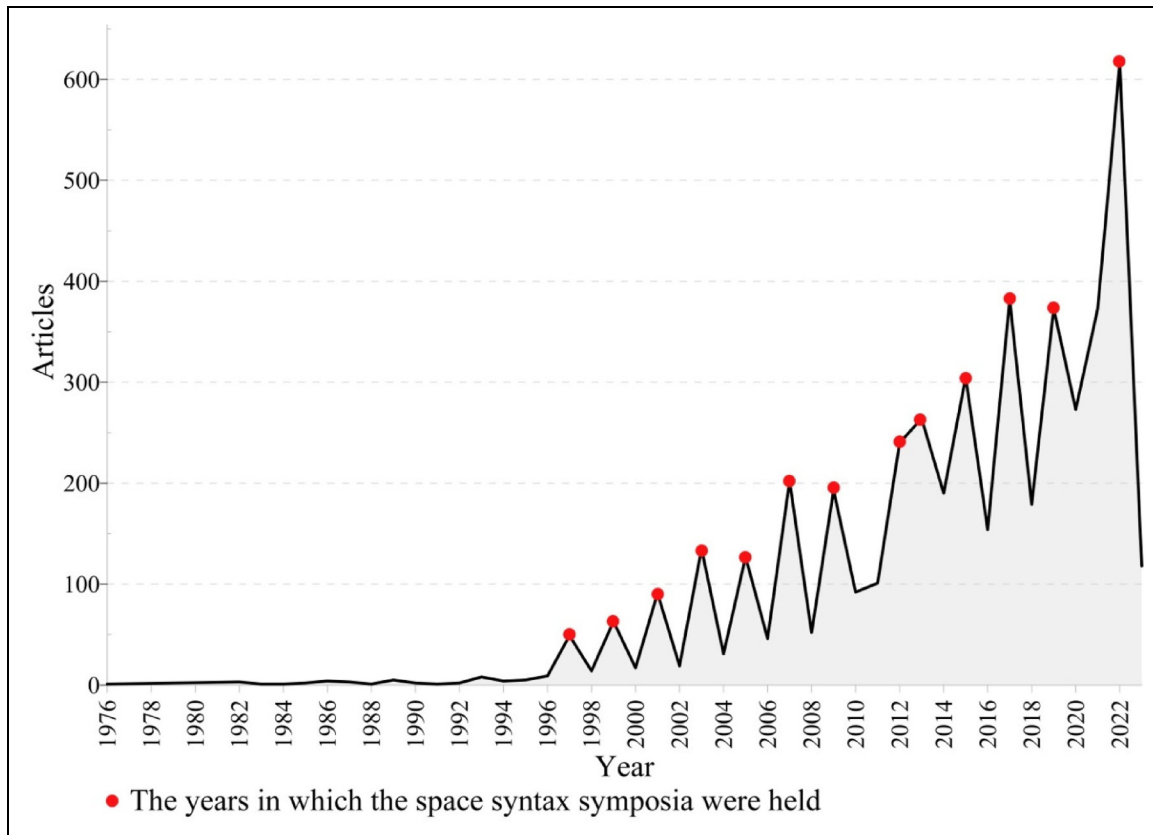
**Figure 2.** Annual scientific production by year (1976–March 2023) (*n* = 4,740)

Cambridge, UK: Cambridge University Press versus Hillier (1996b) space is the machine, Cambridge University Press, Cambridge) (for more details, see van Eck and Waltman 2020).

## Data Analysis

Descriptive analysis and science mapping are traditionally implemented in bibliometric studies. We employed both techniques to answer our research questions.

First, we conducted descriptive analyses at the individual, institutional, and country levels. Specifically, we mapped the number of publications per year and the distribution of publications among different authors. On the community or organizational levels, we explored the productivity levels of journals and institutions. On a global level, we identified the most published countries based on the volume of "authors' appearances by country affiliations"; put differently, each document was associated with the countries of all of its co-authors based on their affiliations rather than citizenship. Second, using science mapping, we performed co-authorship analysis to determine the social patterns of collaborations for countries, organizations, and authors. These collaborative patterns are determined by the number of co-authored articles between countries, institutions, and/or authors. Identifying the core collaboration networks of authors and organizations can help find potential scientific hubs for invitations to collaborate. Third, co-citation analysis

by cited references, which reveals the hierarchical pattern of the importance and influence of academic works based on the number of times they are cited together, was carried out to identify influential publications that shaped the intellectual landscape of the field.

Fourth, keyword co-occurrence analysis, which identifies the collective interconnection of keywords based on the number of articles in which they occur together, was conducted to identify clusters of the main themes. Finally, we conducted a thematic map analysis to identify major, basic, highly specialized, and emerging and declining themes. This analysis involved working with a graph-based network logic to highlight the relative importance of keywords/themes based on their degree of centrality (i.e., connections between different clusters in the network) and density (connections within a cluster) (Cobo et al. 2011). A thematic map classifies drawn clusters of keywords/themes based on their density and centrality scores.

## Data Visualization

We used the R-based Biblioshiny, a Shiny app providing a web interface for non-coders, to perform a descriptive data analysis. The free Bibliometrix R package (Aria and Cuccurullo 2017), which supports creating network maps, was used to conduct and visualize the main science mapping analysis results,

including the collaboration network analysis, co-citation analysis, and keyword co-occurrence analysis.

### Interpretation of Results

In this step, we examined the key findings concerning the main research tendencies, collaborative patterns, and future research directions in space syntax from 1976 to 2023. Having described the four workflow steps, we present the results in the next section.

## Descriptive and Collaboration Network Analyses

### Annual Trend of Publications and Prominent Conferences and Journals

Figure 2 presents the annual scientific production in the field of space syntax by year between 1976 and 2023. The annual growth rate of publications was 12.03 percent. In 1976, the first article containing the term "space syntax" was published in *Environment and Planning B: Planning and Design (currently known as Environment and Planning B: Urban Analytics and City Science)*. It addressed the social logic of spatial orders and proposed a syntactic theory of human space organization (Hillier et al. 1976). Subsequently, 195 documents were published on this theme between 1976 and 2000. Globally, the interest in the space syntax approach increased at the start of the new millennium. Between 2001 and 2010, the number of publications quintupled compared to the previous periods. The growth in the number of publications has been remarkable over the past decade (between 2011 and 2023), during which 3,568 papers were published, i.e., 75.27% of all publications for the entire analysis period. Overall, the trend of scientific production followed and coincided with the organization of the biennial International Space Syntax Symposia (https://www.spacesyntax.net/symposia/), which started in 1997. Clear drops in the number of publications between two consecutive symposia can be observed. Put differently, there was an increasing trend with a strong biennial pattern. There was a drop in 2011 because *the 8th International Space Syntax Symposium* was postponed to 2012. It is important to note that the number of articles in 2023 is significantly lower than that in 2022 because our analysis period ended in March 2023.

Interestingly, 33.40 percent (*n* = 1,583) of the documents in our collection were published in space syntax symposia. The other most relevant conferences were the *IOP Conference Series: Earth and Environmental Science* (52), *The International Conference on Education and Research in Computer-Aided Architectural Design in Europe* (45), and *Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)* (29). The five journals with the highest numbers of publications were the *Journal of Space Syntax* (128), *Environment and Planning B: Urban Analytics and Cities Science* (103), *Sustainability* (Switzerland) (72), the *Journal of Asian Architecture and Building Engineering* (52), and *URBAN DESIGN International* (41).

### Author Co-Authorship Analysis

We identified 5,578 authors responsible for the 4,740 documents. On average, each document was written by two authors (2.42). The top 15 most productive authors are identified in Supplemental Figure S1, in which each line is dedicated to an author's timeline (see Supplemental Materials 01). A node in a given year means that a given author published at least one article in that year. The node size is proportional to the number of articles a given author published in that year. As the Supplemental Figure shows, the most prolific author was Alan Penn of University College London, with 107 publications. Second with 93 publications was Akkelies van Nes of the Western Norway University of Applied Sciences (previously associated with Delft University of Technology). Bill Hillier (1937–2019) from University College London was third with 85 publications. The leading authors during 1976–1995 were Bill Hillier, Julienne Hanson (who retired in 2014), John Peponis, Alan Penn, and Frederico de Holanda. The distribution of the publications in relation to the authors indicates a significant increase in the diversity of authors after the turn of the millennium.

Revealing the core social structure of leading authors is a fundamental step toward enhancing scientific cooperation. The collaboration network among authors in space syntax studies is shown in Figure 3, which was produced using the Bibliometrix R package. In the collaboration map, each author is represented by a node. The node size is proportional to the number of publications, and the links/lines show co-authorships among authors. The main collaboration clusters have different colors. The red, dark green, and purple clusters, corresponding to Alan Penn, Laura Vaughan (University College London), and John Peponis (Georgia Institute of Technology), respectively, are the most dominant groups, with higher scientific cooperation than other clusters, since they have stronger co-authorship links than others. In contrast, the light green and light salmon-colored clusters, corresponding to Valerio Cutini (University of Pisa) and Mohammad Javad Koohsari (Japan Advanced Institute of Science and Technology; Waseda University) have no connections with other clusters, which suggests that the authors in these two clusters have the lowest scientific collaboration with the wider space syntax community.

### Institution Co-Authorship Analysis

The top 15 most productive institutions in space syntax, identified using Biblioshiny, are listed in Supplemental Table S1. The most productive institutions were in the United Kingdom, Turkey, the Netherlands, the United States, Sweden, and Brazil. As expected, affiliations belonging to University College London in the United Kingdom are at the top of the list, with 787 publications. Istanbul Technical University and Delft University of Technology were second and third, respectively.
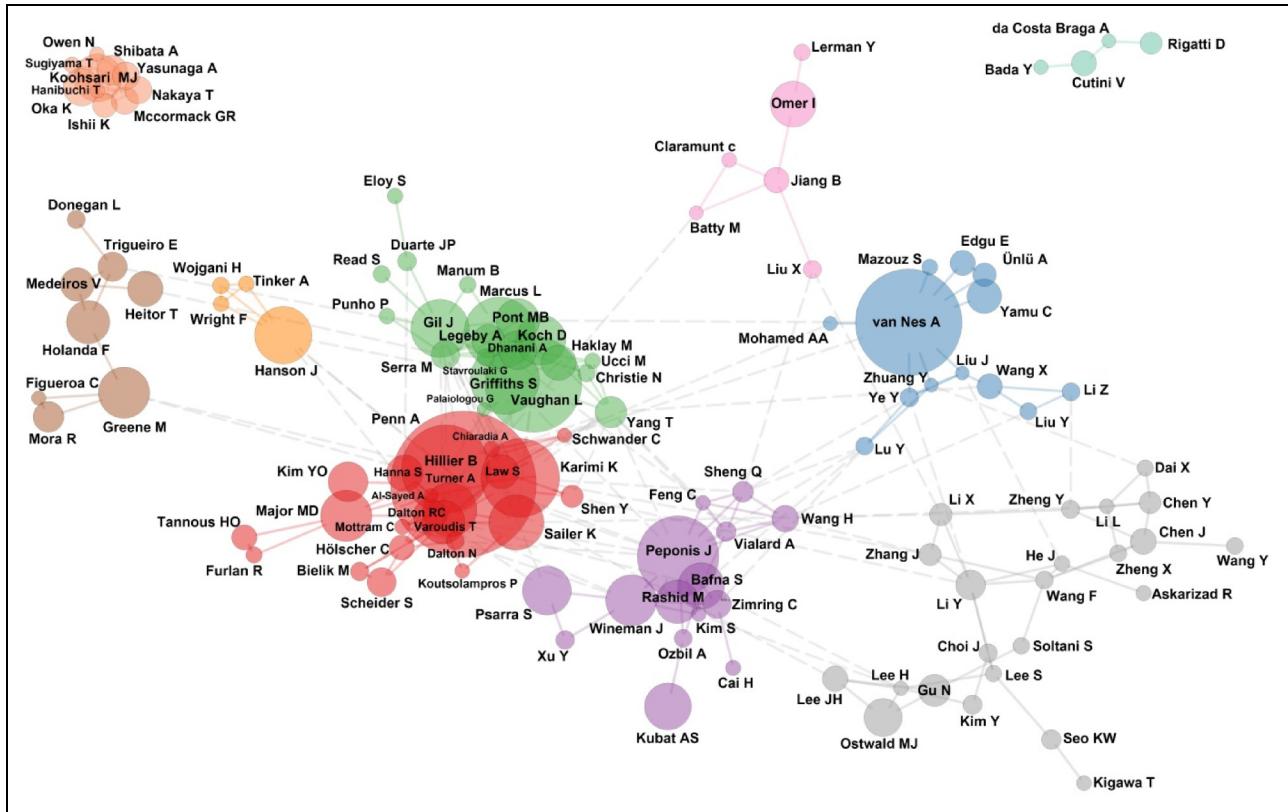
**Figure 3.** Authors' collaboration network in space syntax studies. Each collaboration cluster is represented by a color. For color illustrations, please refer to the electronic version of the article.
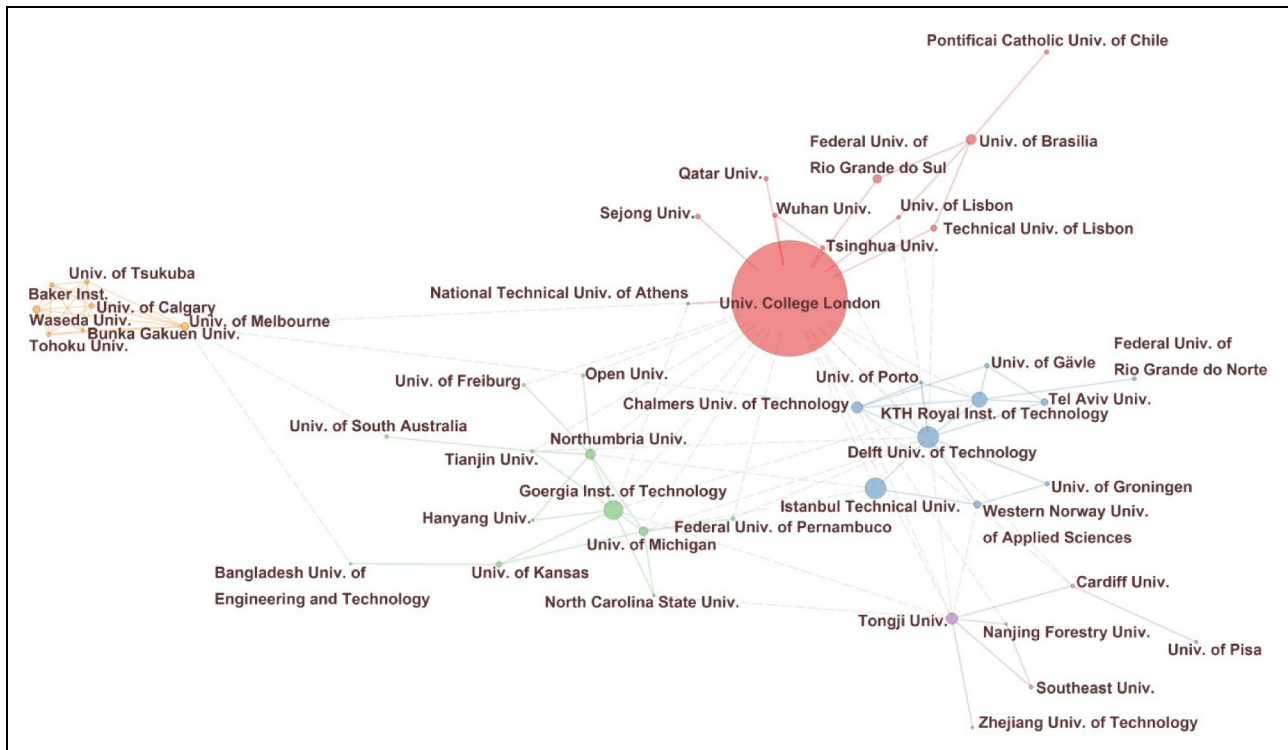


**Figure 4.** Institutions' collaboration network in space syntax studies. The node size is proportional to the volume of publications. Each collaboration cluster is represented by a color. For color illustrations, please refer to the electronic version of the article.

The collaboration network among organizations in space syntax studies is shown in Figure 4. In the graph, the node size reveals the number of publications for each institution, and stronger links indicate more collaboration between the nodes. Consistent with Supplemental Table S1, University College London, Istanbul Technical University, Delft University of Technology, and Georgia Institute of Technology are the most productive institutions. Interestingly, five major clusters can be identified. These include red (head: University College London), blue (head: Istanbul Technical University), green (head: Georgia Institute of Technology), purple (head: Tongji University), and brown (head: the University of Melbourne) clusters.

## Country Co-Authorship Analysis

Identifying the most active countries provides helpful information for researchers and organizations to collaborate effectively with other research bodies on a global scale. Supplemental Table S2 highlights the top 15 most productive countries based on the number of publications by country affiliations. Supplemental Table S2 shows that the United Kingdom, China, the United States, Brazil, Turkey, Korea, and Sweden have been key contributors to space syntax research. Specifically, the United Kingdom is the leading country, with 1,215 publications. China is ranked the second most productive country, with 938 articles. The United States and Brazil are third and fourth, respectively.

Co-authorship analysis by country was used to reveal collaboration networks among countries. In Figure 5, each node is

dedicated to a country. The node size is proportional to the volume of publications, and the lines reveal collaborations among countries. Consistent with Table S2, the United Kingdom, China, the United States, and Brazil are the most active countries in the network. In contrast, some countries have made fewer contributions; for example, Poland and Finland had only 33 and 11 publications, respectively. A potential explanation is the lack of local experts in space syntax that would support potential researchers ready to carry out such studies. This explanation is consistent with Lamprecht (2022), who argues that space syntax is largely marginalized in Poland because of the relative complexity of its methodology, which requires the support of a space syntax expert.

In our collaboration map, there are five major co-authorship clusters: red (head: United Kingdom), blue (head: China), green (head: Brazil), orange (head: Iran), and purple (head: Algeria). The global collaboration links among countries are influenced largely by geographical proximity but also by shared historic cooperation. Furthermore, the link count indicates that British researchers are highly cooperative with researchers from other countries, especially with those from the United States (42 links), China (24 links), and Germany (24 links). Similarly, the strong connections between China and the United States (28 links) reflect their close collaboration. In contrast, authors from Russia and countries in Eastern Europe have weak scientific cooperation with scholars from other countries. Given these patterns of cooperation among nations, greater scientific collaboration is needed to expand the space syntax community to underrepresented countries.
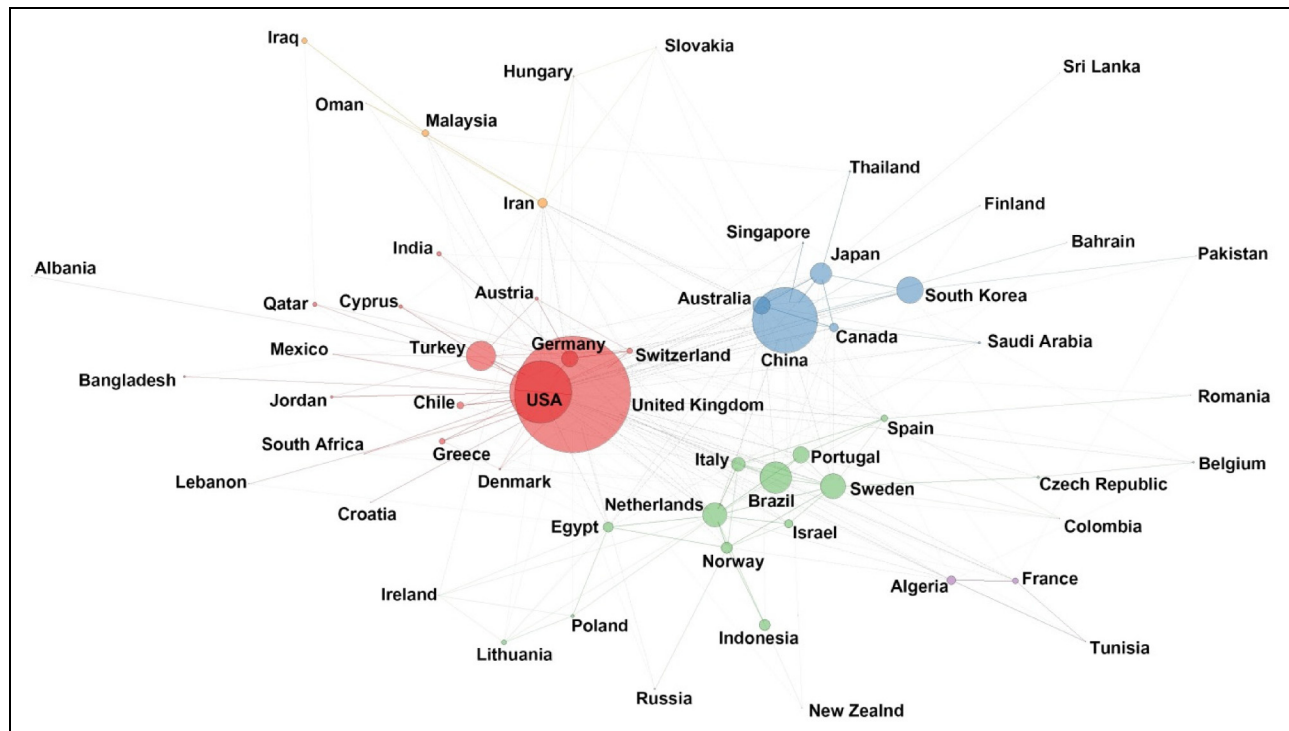


**Figure 5.** Countries' collaboration network in space syntax studies. Each collaboration cluster is represented by a color. For color illustrations, please refer to the electronic version of the article.
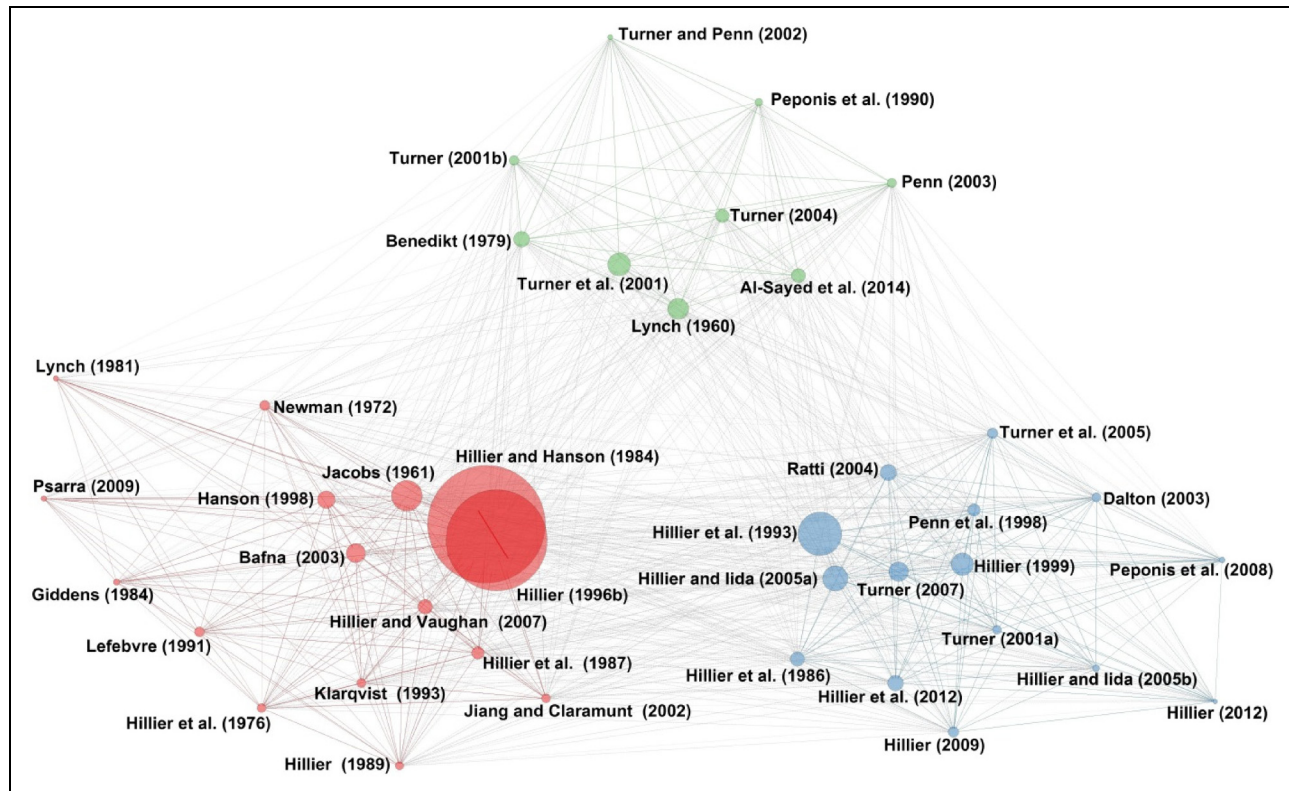
**Figure 6.** Results of co-citation analysis based on cited references. For color illustrations, please refer to the electronic version of the article.

## Intellectual Structure in Space Syntax Studies

We identified the most influential references in space syntax based on the number of co-citations. The co-citation analysis was performed based on cited references. The results highlight the top 40 most co-cited references (represented by their authors). The co-citation network map of references is shown in three main divisions (Figure 6). Supplemental Table S3 shows the influential publications in each cluster. This set of highly cited articles has shaped the field's intellectual foundations. The results indicate a greater interest in those articles published before 2010, not only because they contributed to developing and refining existing concepts and methods but also because they have been available longer to receive citations. Specifically, Hillier and Hanson's (1984) book *The Social Logic of Space*, which first launched the space syntax theory and method, was the most influential work. Hillier subsequently developed this paradigm in his book *Space is the Machine: A Configurational Theory of Architecture* (Hillier 1996b). These two books represent the theoretical foundations of the field. In more detail, fundamental intellectual clusters of space syntax references are as follows:

- Cluster 1 (Red): Spatial configuration and social processes

This cluster mainly includes studies on face-to-face interaction in a built environment, and how configurative properties of settlements condition street life. Antony Giddens (1984) acknowledges the role of space in structuring social integration, which involves the reciprocity of practices between face-to-face connections. Insights on co-presence in urban space can be seen in Jane Jacobs's (1961) and Oscar Newman's (1972) perspectives. Jacobs (1961) argued that accessible urban environments with high density and multi-functional land use are more likely to encourage the co-presence of inhabitants and strangers in public streets and, in turn, enhance the feeling of safety. In contrast, Newman (1972) suggests the concept of "defensible space" by separating inhabitants from outsiders by creating local territories of semi-private inaccessible spaces that foster community cohesiveness. However, Hillier (2004) criticized Newman's notion of urban territoriality but acknowledged that while a stranger's presence in a public space is natural and essential for safety, it would be unusual and potentially dangerous in semi-private streets.

According to space syntax theory, the likelihood of encountering a physical co-presence is largely determined by spatial configuration—what Henri Lefebvre (1991) might refer to as "spatial practice" (*perceived space*). The core of Lefebvre's dialects of material space is what he calls spatial trait. This trait includes three moments with triple interactions to keep social relations united. These moments are the *perceived space* (the observable physical space), the *conceived space* (the mental or imagined space), and the *lived space* (the space experienced in everyday life) (Lefebvre 1991). Accordingly, the lived or representational space is an instrumental element that theoretically integrates the other two spaces. However, this dialectical insight is confusing and ends at the stage of

philosophy, as it cannot objectively measure how an urban environment influences social life and vice versa.

The novelty of space syntax theory is that it formatively connects space and potential users at an abstract level. It confirms a measurable association between spatial configuration and potential patterns of co-presences. Space syntax provides a new way of describing and analyzing spatial configurations of buildings and towns to better understand how they are shaped, used, and perceived (Hanson 1998; Hillier 1996b; Hillier and Hanson 1984; Hillier et al. 1976) and how different activities seek different volumes of movement and co-presence (Hillier and Vaughan 2007).

- Cluster 2 (Blue): Urban movement and centrality

This cluster mainly includes studies on the relationship between space and activity and the role of street configuration in the distribution of pedestrian movement and possibilities for services. Earlier space syntax studies have found that when other spatial conditions (e.g., land use and density) remain equal, street configuration first naturally generates urban movement flows (Hillier 1996b; Hillier and Iida 2005; Hillier et al. 1993; Penn et al. 1998), which then attract economic activities and other movement seeking functions, and these, in turn, are likely to generate "multiplier effects" on pedestrian volumes with further influence on land use choices (Hillier 1996a). This interrelation between spatial configuration, pedestrian movement, and attraction (i.e., functional dimension) is what Hillier (1996a) has conceptualized as the theory of the "movement economy" that has been recently extended by adding physical structure (i.e., conditions) and urban area type to the model (Lerman and Omer 2016). The movement economy process helps us understand how urban centers and sub-centers—or the concentration of functional uses and activities in certain locations—are generated and sustained (Hillier 1999). Importantly, space syntax analysis shifted from axial line to line segment in 2000, with the introduction of angular segment analysis (Turner 2000, 2001a; Turner, Penn, and Hillier 2005), which established through-movement measures by considering an angle and metric-weighted graph. Previous research on vehicular movement found that angular segment analysis has a stronger association with observed movement than standard axial analysis (Turner 2007). Based on the new angular analysis, Hillier, Yang, and Turner (2012) introduced and applied normalized least angular choice (NACH) and normalized least angular integration (NAIN) to better understand the spatial structures of cities and their functioning.

- Cluster 3 (Green): Wayfinding and spatial cognition

This cluster mainly includes studies on visual perception, wayfinding, and spatial cognition. Kevin Lynch (1960) identified five city elements comprising the mental image of citizens: paths, edges, nodes, landmarks, and districts. The perception of these elements depends primarily on the interaction between an observer and his environment. Space syntax provides analytical techniques to study the effects of configuration

on route choice decisions (Dalton 2003; Penn 2003)—or the way people move around architectural and urban spaces. Hillier and Hanson (1984) formulated and developed the spatial units that are used in space syntax: (a) axial line as the longest sightline indicating movement, (b) convex space, in which all corners of space are visible from each other when people interact, and (c) an isovist field, which reflects the field of vision from a given vantage point in space, based on the works of Tandy (1967) and Benedikt (1979). Hillier invented the "axial map" as the minimal set of "axial lines" for a network (van Nes and Yamu 2021). Put differently, with the introduction of the axial map, the entire length of a street is considered a node in the planar graph (Penn 2021). In 1996, Ruth Conroy Dalton developed a computer application for the isovist camera, coined IsoCam, to represent three-dimensional (3D) isovists (Dalton and Dalton 2015). In 1998, Alasdair Turner (1969–2011) created the computer application DepthMap for simple isovist processing (UCL Space Syntax 2022). Subsequently, isovist analysis developed into visibility graph analysis (Turner 2001b; Turner et al. 2001). Turner and Penn (2002) developed behavioral models based on Gibson's principles of affordance (Gibson 1979) to encode human movement patterns. Moreover, Van Bilsen and Stolk (2007) proposed a methodology for 3D isovist-based visibility analysis. Later, 3D angular openness measures were developed based on 3D isovist capture in urban space using measurement data from remote sensors (Kim et al. 2019).

## Conceptual Structure in Space Syntax Studies

The keywords co-occurrence analysis provided insights into major thematic clusters, gaps in space syntax research, and potential avenues for future research for the overall period. The lowest allowable frequency of a keyword was experimentally set to 15 to convey meaningful visualization and classification of themes representing the conceptual structure. The results identified a total of 106 author keywords. The 30 most frequently co-occurring keywords are listed in Supplemental Table S4. The most used keywords are "space syntax" (2,160 times), "spatial configuration" (355 times), "urban morphology" (175 times), "accessibility" (157 times), and "GIS" (119 times).

The results of the keyword co-occurrence analysis are shown in Figure 7. In the graph, the node sizes are proportional to the co-occurrence frequencies of the keywords. The closer the nodes appear on the network plot, the more frequently they co-occur. The output highlights theoretical- and technical-focused terms. Furthermore, the most frequently mentioned keywords of space syntax research highlight sub-topics related to the empirical evidence that space syntax gathers, including keywords such as "human behavior," "social interaction," and "crime." Overall, the captured keywords are classified into five distinct clusters. These co-word clusters are as follows:
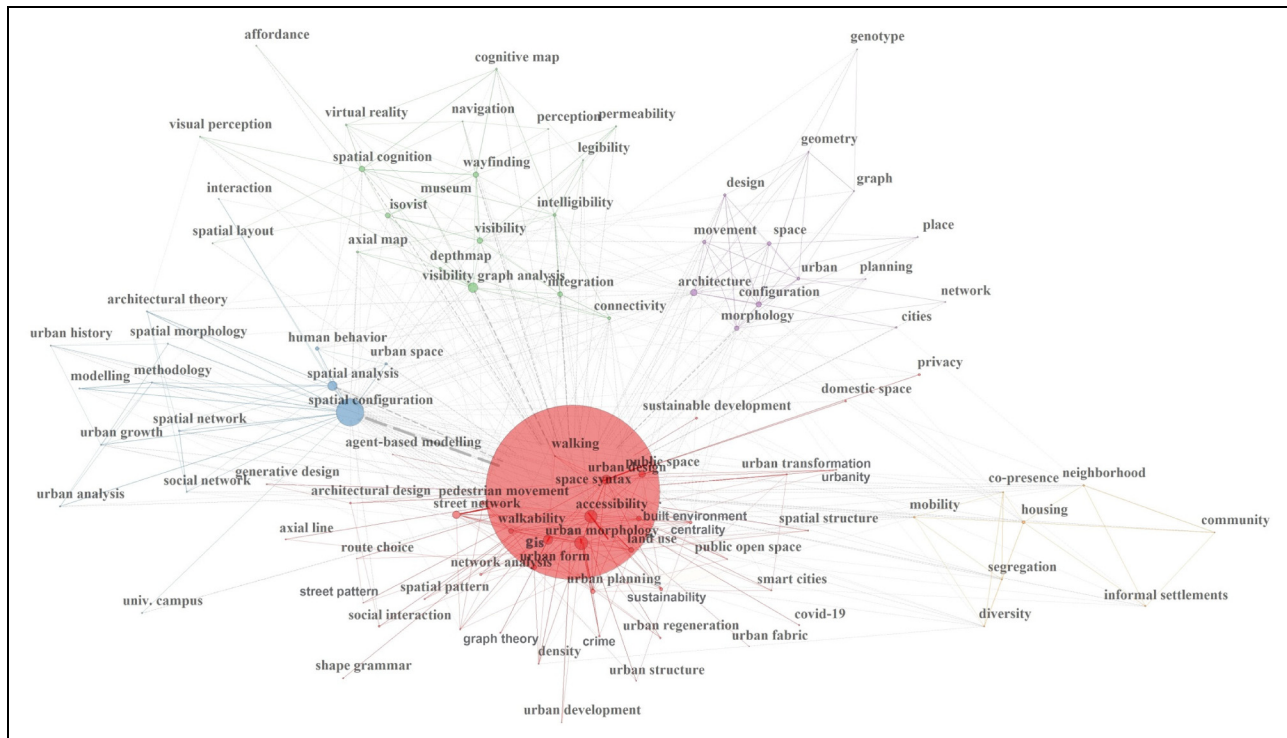
**Figure 7.** Keyword co-occurrence map with a threshold of 15 co-occurrences.

- Cluster 1 (Red): Space syntax and urban design

This cluster is the largest and represents most of the research effort. Studies in this cluster address topics related to space syntax and urban form factors. Urban sustainability and walking encouragement depend on some "built environment" characteristics. Several studies used space syntax measures to examine how street network "accessibility" and "land use" intensity and diversity contribute to "walkability" and "sustainability" (Bielik et al. 2018; Dhanani et al. 2017). Srirangam et al. (2023) developed a toolkit based on integrating land use with street network connectivity to make cities sustainable. Also, Rybarczyk et al. (2023) employed space syntax to analyze children's walking behavior to school. They found that walkability had no influence on children's route choice decisions. A space syntax walkability index was developed and examined against the full walkability index (Koohsari et al. 2016). Based on space syntax, various generative approaches can be taken to test different design proposals and interventions (Richard 2022). This cluster also includes studies that examined the relationship between spatial design and crime (e.g., van Nes and López 2010). Topics addressed recently (within the last decade) included "COVID-19," "smart cities," and "urbanity." As expected, the strength values of these keywords are still obviously low.

- Cluster 2 (Blue): Spatial configuration and spatial analysis

The second cluster marks advances in space syntax methods, indicated by keywords such as "spatial analysis," "urban analysis," "modeling," and "methodology." Over years of refinements, several scholars and countless doctoral students have developed "tools to think with" (Penn 2021), thus prompting architectural computing development. For instance, Dalton and Dalton (2001) developed an isovist-generating software called OmniVista. Ståhle et al. (2005) created and developed the Place Syntax Tool (PST). Later, multiple plug-ins for geographic information systems, including the QGIS space syntax plug-in (Gil et al. 2015), sDNA (spatial design network analysis) (Cooper et al. 2016), and the QGIS PST plug-in (Marcus et al. 2019), were released. The consolidation of open-access publications and increasing computational power enhanced the accessibility to knowledge, thus promoting global interest and discoveries that yielded new ideas and evidence (Yamu et al. 2021).

- Cluster 3 (Green): Wayfinding and spatial cognition

The third cluster focuses on themes related to "wayfinding," "spatial cognition," and "virtual reality." From a methods perspective, studies in this cluster used visibility graph analysis (Turner et al. 2001), agent simulation (Turner and Penn 2002), and/or multi-agent simulation (Tang 2018) to examine the effects of architectural and urban layouts on navigation performance within the built environment (e.g., Dalton 2003). Some other studies in this cluster explored the relationship

between legible and intelligible urban environments (Long and Baran 2012; Peponis, 2016).

- Cluster 4 (Purple): Architectural morphology

Studies in this cluster explore morphological architectural features of topological (accessibility, visibility) and geometrical (position, shape, size) natures. For example, Kamelnia et al. (2022) analyzed the spatial configurations of old courtyard houses in Toon, a historical city in Iran, to better understand the relationship between housing design and changing lifestyle and cultural conditions. Similarly, Umbelino (2017) employed configurational analysis to explore the relationship between conversions in the accessibility and visibility of floor plans of Brazilian homes and sociocultural changes. Based on the space syntax framework, Psarra (2022) discussed the analogy between architecture and language in terms of morphosyntactic and morphosemantic relations. She argued that space syntax rests on both types of relations. In other words, buildings and cities represent not only the socio-spatial fabric of society but also its conceptual, discursive, and semantic patterns (Psarra 2022).

- Cluster 5 (Orange): Housing and segregation

The smallest cluster covers themes related to the role of spatial "connectivity" in shaping "mobility," potential "co-presence," and "diversity" (e.g., Sun et al. 2017; Vaughan 2007). This cluster also includes studies that focused on aspects of urbanization and informal settlements (e.g., Hillier et al. 2000; Mohamed et al. 2022).

Following the generation of the keywords co-occurrence map, we classified the themes based on their centrality and density measures in greater detail. Supplemental Figure S2 illustrates the space syntax thematic map developed from the authors' keywords. In this diagram, the node size is proportional to the number of documents covering each theme.

As Figure S2 shows, "spatial analysis" is highlighted as motor themes (driving themes), which are well developed and of central importance to the construction of the discipline of space syntax (Cobo et al. 2011), in the upper right quadrant. In addition, "space syntax," sandwiched between the upper right quadrant and the lower right quadrant, was a motor theme because some of its components have been foundational in advancing space syntax research. Both "spatial analysis" and "space syntax" exhibit high centrality and density values. These themes primarily delved into the formative concepts and methods of the space syntax approach. They covered aspects of novel analytical techniques (Turner 2001a, 2007; Turner et al. 2001) for modeling urban environments. Importantly, the space syntax approach has been closely integrated with GIS to understand urban issues better (Jiang and Claramunt 2002).

Themes such as "spatial cognition" and "pedestrian movement" are basic and transversal themes, shown in the lower right quadrant with high centrality and low density. Finally,

"housing" emerged as a declining theme in the lower left quadrant with relatively weak external and internal connections (Cobo et al. 2011).

## Implications and Future Research

Space syntax studies can be divided into two main categories: theoretical and technical advances in the field and space syntax-based applications (Figures 6–7).

The available literature shows that space syntax has been extensively adopted in urban planning, urban design, and architecture. Current research highlights the role of the spatial configuration of street network accessibility as a key determinant of urban mobility and, in turn, land use patterns (Hillier 1996b). Although the application of space syntax on built environment performance evaluation has been widely studied, its translation into the decision-making process is still fairly limited (van Nes and Yamu 2021) (Figure 7).

The fields of regional planning and urban forestry have been underrepresented within our database. Also, only a few studies on livability, thermal comfort, urban policy, ecosystem services, ecological networks, and spatial resilience have been found in the available literature. But this cannot be asserted based only on bibliometric analysis, as publications and citations on a particular topic would depend on how pertinent space syntax is for studying these fields. Finally, the results show that context-dependent issues such as place identity and meaning are completely missing in space syntax studies since such issues and the like cannot be interpreted using the descriptive and analytical space syntax approach. Accordingly, future research should address the aforementioned understudied topics and data–decision-making–policy interactions.

## Conclusions

Space syntax has been widely applied in urban planning, urban design, and architecture. Although there have been numerous literature reviews on space syntax theory and methods, there was an evident lack of an in-depth bibliometric analysis. To fill this gap, a quantitative review of both indexed and non-indexed literature on space syntax from December 1976 to March 2023 was conducted in this study. We used various bibliometric techniques to identify space syntax research trends based on annual scientific publications, the most productive journals and conferences, prominent authors, leading institutions, geographic distributions, scientific cooperation, influential publications, research themes, implications, gaps, and future research directions.

Beginning in 1997, the annual volume of scientific production in space syntax increased rapidly and exhibited a biennial pattern related to the organization of the biennial International Space Syntax Symposia, as well as advances in space syntax concepts and techniques. Pockets of high-productivity institutions and countries were identified. Researchers affiliated with University College London were the most active in the space syntax field. Accordingly, the United Kingdom had the highest number of publications. China and the United States were the next countries

with the most articles after the United Kingdom. Although the geographical coverage of space syntax research has increased over time, there has been little space syntax research in Poland, Finland, Russia, Argentina, or Nigeria, possibly because of the unavailability of local-skilled researchers who can provide technical support in the field in such countries.

The analysis of co-citations by references helped to identify influential publications that represented the intellectual framework of space syntax studies. Early works conducted by Bill Hillier and Alasdair Turner and their colleagues were amongst the most co-cited publications. On the other hand, author keyword analysis allowed us to detect the existing research mainstream while at the same time identifying knowledge gaps and future research directions. Our findings showed a higher diversity of topics covered during the study period. The results of the keyword distribution and co-citation analyses showed that space syntax studies can be classified into two main groups: theoretical and technical advances in the field and space syntax-based applications. The new trends in space syntax development include the integration of space syntax into GIS and machine learning for generating design solutions. The literature on space syntax-based applications is mainly related to the themes of urban design, spatial analysis, spatial cognition, architecture, and housing.

Our bibliometric analysis, however, has some limitations that should be considered in choosing future research directions. First, this study relied primarily on the Scopus and Dimensions databases. Future research might consider other scientific sources, such as WoS, ScienceDirect, and Google Scholar. Second, as is common with other systematic reviews, we acknowledge that there is a possibility that our search query has omitted some important papers related to space syntax. Put differently, the relevant literature on space syntax does not always mention "space syntax" in publications' titles, abstracts, or keywords, thus indicating that the present study might not cover all publications on space syntax. Nevertheless, considering the large volume and variety of documents that we have analyzed, we believe that this study does not suffer from significant bias; it is largely representative of the current trends in this discipline, and it presents a relatively comprehensive picture of the state of the art. Third, in the word co-occurrence analysis, articles without any similarity relationship with the other articles in the selected literature were ignored when research themes were extracted. Other text mining techniques, such as probabilistic topic modeling, which is an unsupervised machine learning tool that algorithmically and meaningfully extracts the topics discussed in large corpora (Blei and Lafferty 2006), might yield better results. Fourth, this study did not examine the conceptual evolution of space syntax themes. Other future research might analyze keywords in greater detail over different time periods to better understand how the conceptual structure of space syntax studies evolved. Furthermore, future work might review other characteristics of publications (e.g., geographical coverage of case studies and research themes, and the types of spatial analyses applied). Finally, future studies might compare space

syntax methods with other tools related to urban morphology and network analysis.

In summary, this study's findings are important for research scholars in space syntax and configurative analysis and provide a baseline for future research directions and research collaboration across authors, affiliations, and countries. The landscape of space syntax research suggests that future studies should attempt to address as yet understudied or unexplored issues. Nevertheless, this study itself is a contribution that recognizes space syntax as an established field of research. Finally, this quantitative study complements the existing more qualitative reviews of space syntax research.

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AAM: Conceptualization, writing—original draft, writing—review and editing, methodology, data curation, formal analysis, visualization, software, funding acquisition; CY: Conceptualization, methodology, writing—review and editing, funding acquisition.

## Declaration of Interests

The authors declare that they have no known competing financial interests or personal relationships that could appear to have influenced the work reported in this paper.

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## Supplemental Material

Supplemental material for this article is available online.

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