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Research Article

Urban morphology and planning from an entropy perspective: A bibliometric evaluation

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ABSTRACT

This study aims to analyze the theoretical and practical reflections of the concept of entropy in the urban studies literature by tracing its conceptual and methodological evolution across two distinct domains. To achieve this, two distinct literature sets retrieved from the Web of Science database Urban Morphology & Entropy (n=56) and Spatial Entropy & Urban Planning (n=643) were comparatively analyzed using bibliometric methods. The analysis was conducted with Bibliometrix and Biblioshiny tools in the RStudio environment, visualizing annual publication output, keyword distributions, citation patterns, thematic maps, collaboration networks, and trend analyses. The findings indicate that China is the most productive country, contributing 35% of the publications within the 'Spatial Entropy & Urban Planning' category, which encompasses broader themes such as environmental sustainability, data analytics, and decision support systems. Frequently used keywords across the literature include 'urban morphology,' 'entropy,' 'spatial metrics,' and 'sustainable development.' While entropy in the urban morphology literature is primarily associated with structural and formal analysis, it is linked to data science, artificial intelligence, and decision-support mechanisms in urban planning contexts. The unique contribution of this study lies in revealing how the concept of entropy is positioned across different theoretical frameworks and how it is operationalized in urban research at a meta-level. By examining two distinct thematic areas with an interdisciplinary approach, the study traces the evolution of entropy-based research in the urban studies field. Based on the results, it is recommended that future studies enhance database diversity, strengthen interdisciplinary collaboration, and deepen spatial modelling applications.

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INTRODUCTION

Urban morphology is an interdisciplinary field that examines the physical form, structural patterns, and spatial organization of cities [1-4]. It is regarded as a fundamental approach to understanding how urban environments are shaped and transformed, as well as the social, economic, and environmental implications of these changes [5]. By analyzing the evolution of cities, their textures, street networks, building configurations, and functional zones,

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urban morphology contributes both theoretically and practically to urban design and planning processes [1,6].

However, scholars have noted persistent challenges in achieving consensus on the conceptual foundations and measurement indicators of urban morphology. For instance, Zhang et al. [7] emphasized the need to incorporate ecological considerations such as natural features and ecosystem health. Similarly, [4] proposed an integrative approach that considers both spatial form and function. In this sense, urban morphology remains a critical discipline for understanding, comparing, and sustainably reshaping the physical structure of cities. With the rise of technological advancements and interdisciplinary perspectives, its role in building more livable and sustainable cities has become increasingly important. Nevertheless, the growing spatial complexity of contemporary urban areas demands more advanced analytical tools than traditional morphological methods can provide [6,8-10]. Formal analyses alone are insufficient to capture and quantify the rising structural complexity, underscoring the need for new tools that can quantitatively measure spatial regularity and disorder.

In this context, entropy has emerged as a powerful analytical concept for evaluating urban disorder and spatial heterogeneity [11,12]. Originally developed in the field of thermodynamics, entropy is a universal metric that assesses the degree of disorder or uncertainty in a system, and it has since been adapted across multiple disciplines, including information theory, statistics, probability, machine learning, and urban planning [13-15]. Notably, Shannon's formulation of entropy [16,17] provided a mathematical framework to compute information density and uncertainty levels within systems. For example, Fagerholm et al. [17] defined entropy as a measure of hidden information in a system, shaped by the observer's limitations. Meanwhile, [15] explored entropy as a tool in planning decision-support systems, particularly for representing spatial heterogeneity, land-use diversity, and the irregularity of spatial distributions.

Entropy has been increasingly adopted in spatial analyses to examine the structural complexity and distributional characteristics of urban areas [11,12,18-20]. In urban morphology, entropy has proven useful for analyzing spatial information density, land-use diversity, and urban compactness [21]. In particular, spatial statistical tools such as Shannon Entropy, Moran's I, and Geary's C have been used to evaluate spatial structure, density, and diversity in urban contexts [22-24]. As Jat et al. [25] argued, entropy provides not only a descriptive function but also a comparative and predictive analytical advantage, particularly when used alongside geospatial techniques and remote sensing data.

Recent studies have expanded the scope of entropy by integrating it into digital planning processes, smart city frameworks, and decision-support systems [26,27]. For example, Xiong et al. [28] applied entropy metrics to assess urban sprawl and land-use efficiency, while Altieri et al. [29] combined entropy with machine learning algorithms to identify spatial anomalies. Despite its growing relevance, however, existing literature remains fragmented, with entropy applied across a wide range of conceptual frameworks and disciplines.

This study aims to address this gap by conducting a comparative bibliometric analysis of two distinct bodies of literature: (1) Urban Morphology & Entropy [n=56]; (2) Spatial Entropy & Urban Planning [n=643].

The primary objective is to evaluate how the concept of entropy has evolved both theoretically and methodologically across these domains. By systematically comparing these two streams, the study reveals the thematic patterns, collaboration networks, and citation structures that shape scholarly discourse. In doing so, it offers both a conceptual mapping of entropy-based urban research and practical insights into its future applications [30-36].

MATERIALS AND METHODS

This study uses bibliometric analysis to analyse academic publications on urban morphology, entropy, spatial Entropy, and urban planning. The Web of Science (WoS) database was selected as the research's data source. WoS is a reliable source of information frequently preferred in the literature due to its comprehensive data and high accuracy rate in academic research [37,38].

Data Collection and Selection Criteria

To analyze the thematic and methodological positioning of entropy in urban research, two separate literature sets were defined using the keyword combinations "Urban Morphology & Entropy" and "Spatial Entropy & Urban Planning". This distinction was made to comparatively examine how entropy is interpreted through different theoretical lenses. The 'Urban Morphology & Entropy' set primarily focuses on morphological and formal analyses of urban structure, while the 'Spatial Entropy & Urban Planning' set reflects a broader planning perspective that includes decision support systems, GIS integration, and technology-oriented methodologies.

To comprehensively investigate developments in the literature, the dataset was constructed using the following keyword combinations:

- (ALL=(urban morphology)) AND ALL=(entropy)
- (ALL=(spatial entropy)) AND ALL=(urban planning)

These combinations were determined to comprehensively capture studies relevant to urban morphology, spatial entropy, and urban planning. The bibliographic search was conducted on 20 February 2025, resulting in 56 documents for Urban Morphology & Entropy and 643 documents for Spatial Entropy & Urban Planning. This dual dataset approach was adopted to reveal how entropy is used differently across disciplinary boundaries and to uncover conceptual overlaps, divergences, and gaps in the literature.

Data Analysis Method

The study used RStudio software to analyse the data obtained, and bibliometric analyses were carried out with the Bibliometrix package and the Biblioshiny visualisation tool. Bibliometrix is a powerful tool that enables the analysis and visualisation of bibliometric data [31]. Biblioshiny, conversely, allows the analysis results to be presented in a more understandable and interpretable form, thanks to its interactive visualisation capabilities.

The bibliometric analysis methods used in the research are as follows [31,34,39-41]:

- Scientific Productivity Trends and Citation Dynamics (annual scientific production, annual citation averages and document types) were analysed.
- Keyword Distribution (Author's Keywords (DE), Word Cloud) and Thematic Trends were analysed.
- Citation Analysis and Co-Citation Networks (Collaboration Network) were analysed.
- Thematic Maps and Trend Analyses (Three-Field Plot, Trend Topic and Factorial Map) were analysed.

Data Processing and Visualisation

The data obtained were pre-processed using R software; missing information was cleaned, and inconsistencies were eliminated. 'Article', 'book', and 'review' categories were included as article types. Only documents written in English were included in the study, and publications in other languages were excluded from the analysis. The study consists of publications between 1992 and 2024. Different spellings of author names were combined, and keyword normalisation was performed. To increase the reliability of the results, the analyses were repeated more than once, and the consistency of the data set was checked.

The visualised analysis results, which are visualised with the Biblioshiny tool in RStudio, are presented using the following techniques:

- Annual Scientific Production and Average Citations per Year graphs were used to analyse the number of publications and average citations per year.
- Changes in keywords over time were visualised with Word Cloud and Trend Topics visuals.
- Citation and academic collaboration networks were analysed using the Co-citation Network and Collaboration Network analyses.
- The relationships between keywords, countries, and institutions were comparatively evaluated with Three-Field Plot analyses.

This methodological framework was meticulously developed to ensure the study's scientific validity and reliability [42,43,41]. The findings obtained through visualisation techniques provide a comprehensive assessment of scientific productivity and thematic developments in urban morphology, entropy, and Spatial Entropy and urban Planning (Fig. 1).

With this method flow, scientific productivity, academic collaborations, and thematic developments in

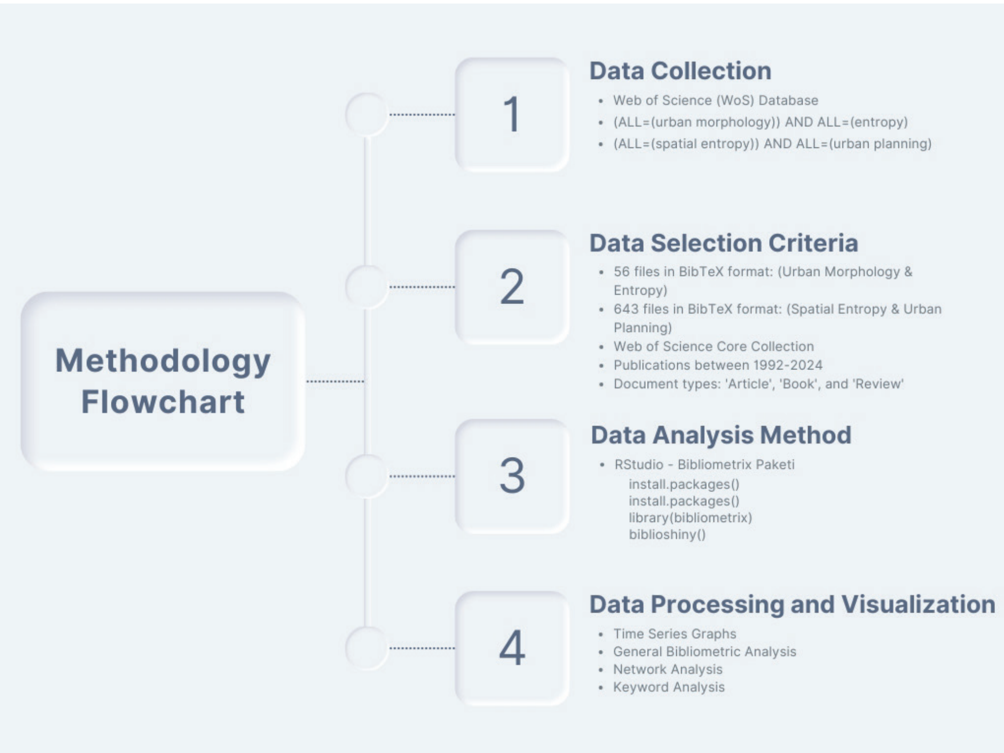

Figure 1. Flowchart of the method.

urban morphology and entropy and Spatial Entropy and urban Planning were analysed in detail. The study's comprehensive data set and visualisation techniques will provide a methodological basis for future bibliometric analyses.

RESULTS AND DISCUSSION

A total of 709 documents were initially retrieved from the Web of Science (WoS) Core Collection. Using the Biblioshiny tool in R, a filtering process was applied to include only English-language publications up to the year 2024. Following this refinement, 619 documents under Spatial Entropy & Urban Planning and 56 documents under Urban Morphology & Entropy were selected for comparative analysis. The results are evaluated under the following subheadings:

Scientific Productivity Trends and Citation Dynamics

Table 1 presents the annual scientific production between 1992 and 2024 for the two literature sets (Urban Morphology & Entropy' and 'Spatial Entropy & Urban Planning), as well as their bibliometric characteristics [34, 42-44].

According to the findings, the field of 'Spatial Entropy & Urban Planning' is significantly superior to the field of 'Urban Morphology & Entropy' (47 documents, 5.76% growth), both quantitatively and in terms of development rate, with a total of 619 documents and an annual growth rate of 16.4%. In terms of the average number of citations, 'Spatial Entropy & Urban Planning' produced a higher impact (21.72) and also exhibited a richer literature structure in terms of total sources (246), total references (28.310) and keyword diversity (2264 Author's Keywords). However, the 'Urban Morphology & Entropy' field has more global partnerships with 31.91% international collaboration level and presents a more specific, thematically concentrated literature. These findings show that urban planning addresses spatial entropy in a multifaceted and interdisciplinary manner. In contrast, the relationship between urban morphology and entropy has developed within a narrower but deeper academic framework (Table 1).

The results also provide insight into the academic depth and collaboration networks of each literature set. Interestingly, the Urban Morphology & Entropy literature has shown a resurgence in recent years, while Spatial Entropy & Urban Planning—despite drawing significant attention in the past—has experienced a relative decline in publication and citation activity [34,45].

The analyses presented in Figure 2 and Figure 3 show the distribution of the average annual number of citations in 'Urban Morphology & Entropy' and 'Spatial Entropy & Urban Planning' between 1992 and 2024. These analyses reveal that Urban Morphology & Entropy has been rising again recently. In contrast, the field of Spatial Entropy & Urban Planning has attracted much attention in the previous years but has recently decreased [44].

In the 'Urban Morphology & Entropy' field, although the annual average number of citations decreased in certain years after 1992, it peaked in 2015. It showed a relatively steady upward trend in the following years. This shows that the academic impact of some pioneering publications has increased over time and produced remarkable outputs in specific periods (Fig. 2).

In Figure 3, high fluctuations in the annual average citation numbers in the field of 'Spatial Entropy & Urban Planning' are observed in earlier years (especially between

Table 1. Comparative bibliometric summary of the urban morphology & entropy and spatial entropy & urban planning literature sets (1992–2024)

	Urban Morphology & Entropy	**Spatial Entropy & Urban Planning**
Timespan	1992:2024	1992:2024
Total Sources	44	246
Total Documents	47	619
Annual Growth Rate	%5.76	%16.4
Document Average Age	7.34	4.8
Average citations per doc	18.17	21.72
Total References	2343	28310
International co-authorships	%31.91	%24.72
Document Type		
Article	43	568
Proceedings Paper	4	38
Other (Book, Book Review, Review)	-	13
Keywords Plus (ID)	179	1160
Author's Keywords (DE)	153	2264

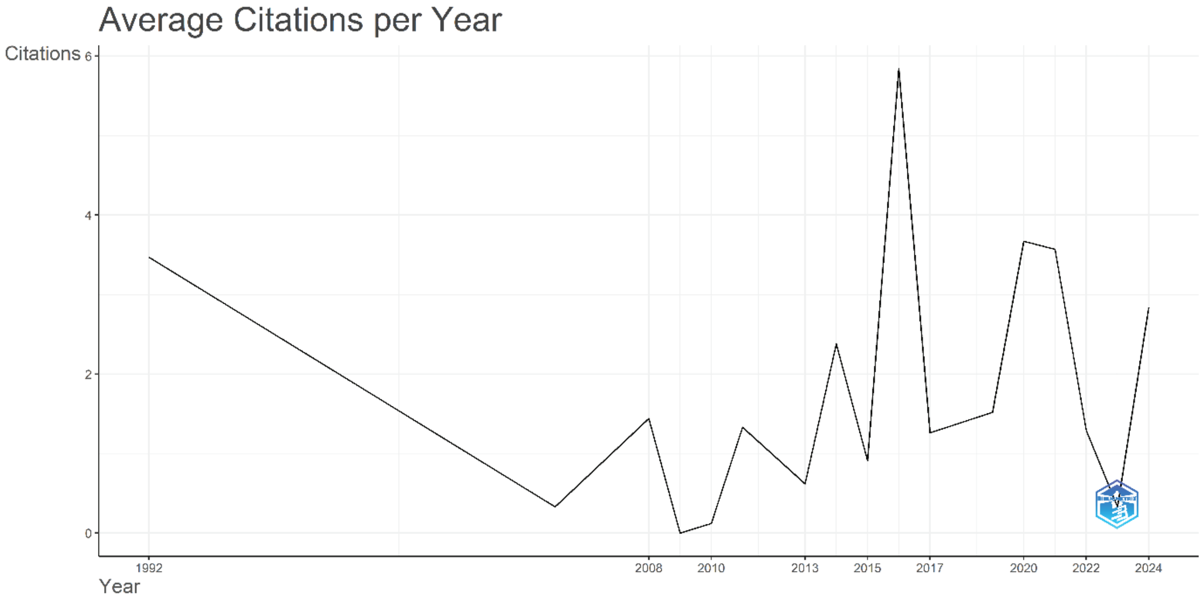

Figure 2. Annual average citation trends in the 'Urban Morphology & Entropy' literature (1992–2024), indicating periods of academic influence and thematic growth**.**

2000 and 2004), indicating that publications in this field have a broader and earlier academic resonance. However, the decline after 2015 suggests that the distribution of citation activity may be more heterogeneous despite the intensive publication production in the field. This suggests that the field is becoming increasingly saturated or that newer topics are attracting interest. The annual citation trends and metrics in the figures show that spatial entropy and urban planning are emerging as a more dynamic and influential research area [34] (Fig. 3).

In comparative terms, 'Urban Morphology & Entropy' shows a trend of later development but steadier citation growth. Meanwhile, 'Spatial Entropy & Urban Planning' was heavily cited earlier, but this effect has diminished over time. This reveals that the two fields have different academic visibility and sustainable impact dynamics.

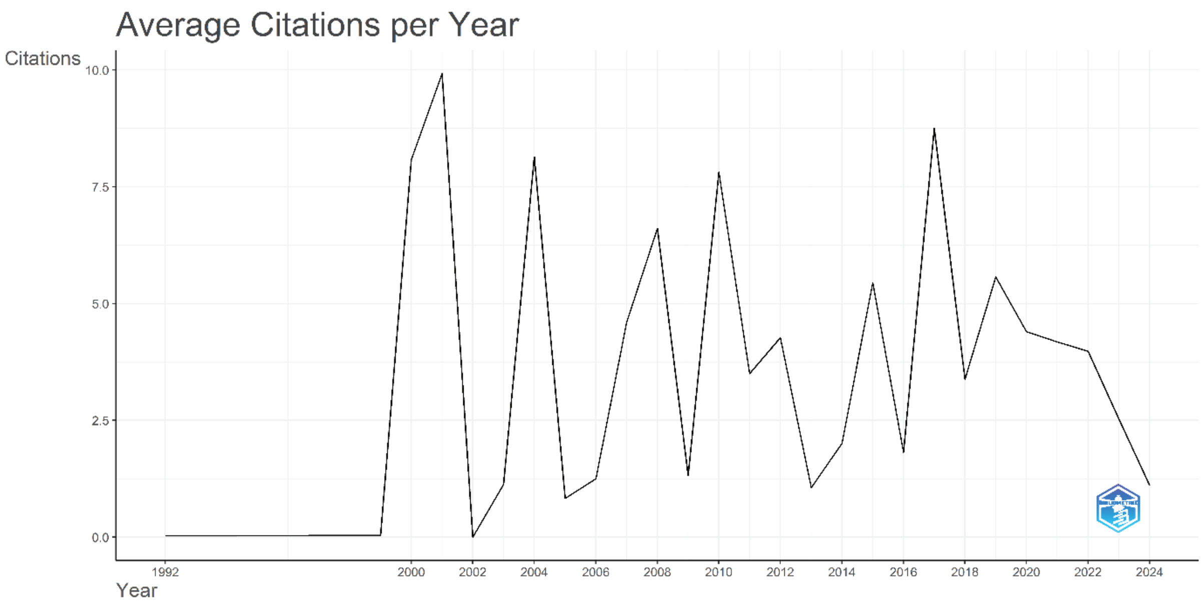

Figure 3. Annual average citation trends in the Spatial Entropy & Urban Planning' literature (1992–2024), indicating periods of academic influence and thematic growth.

According to the annual scientific production graphs presented in Figure 4 and Figure 5, different levels of publication growth are observed over time in the fields of 'Urban Morphology & Entropy' and 'Spatial Entropy & Urban Planning' [34,44].

This figure illustrates the average number of citations per year within the Spatial Entropy & Urban Planning literature. The increasing trend after 2016 indicates a growing scientific interest and methodological diversification in this field.

Annual production in 'Urban Morphology & Entropy' increased especially after 2015 and gained a remarkable momentum after 2020. However, the total production in this field is still limited, and the number of studies has rarely exceeded 6 per year. This situation shows that this field is mainly limited to original and in-depth research (Fig. 4).

The course of scientific production in the fields of 'Spatial Entropy & Urban Planning' shows a much more pronounced upward trend; this rise, which accelerated especially after 2017, continues with a dramatic increase

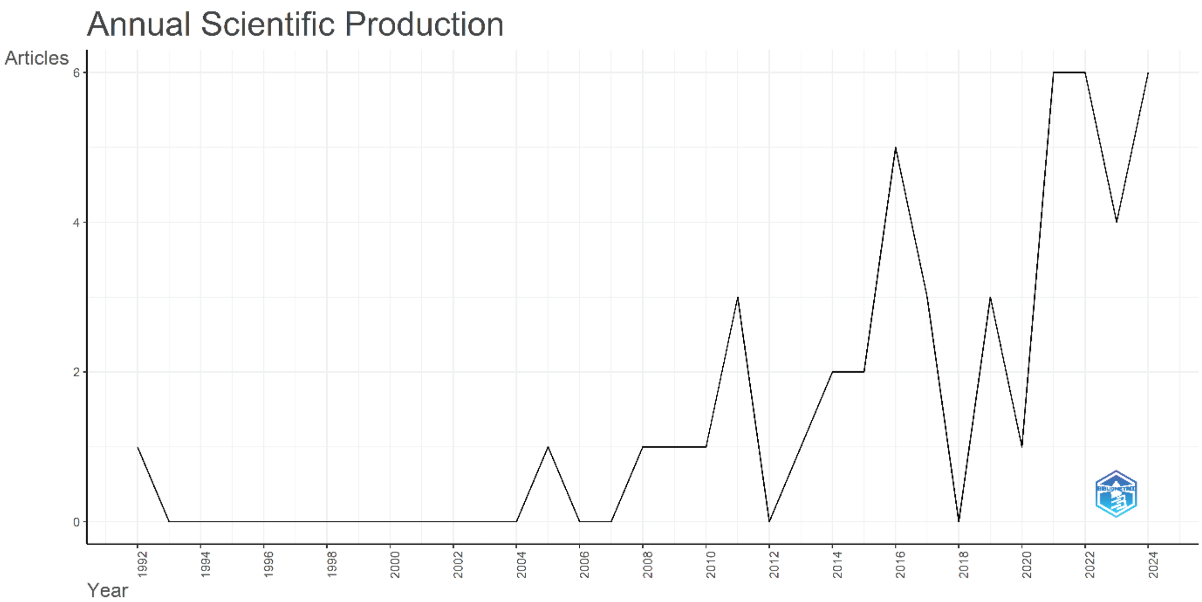

Figure 4. Annual scientific production in urban morphology & entropy (1992-2024).

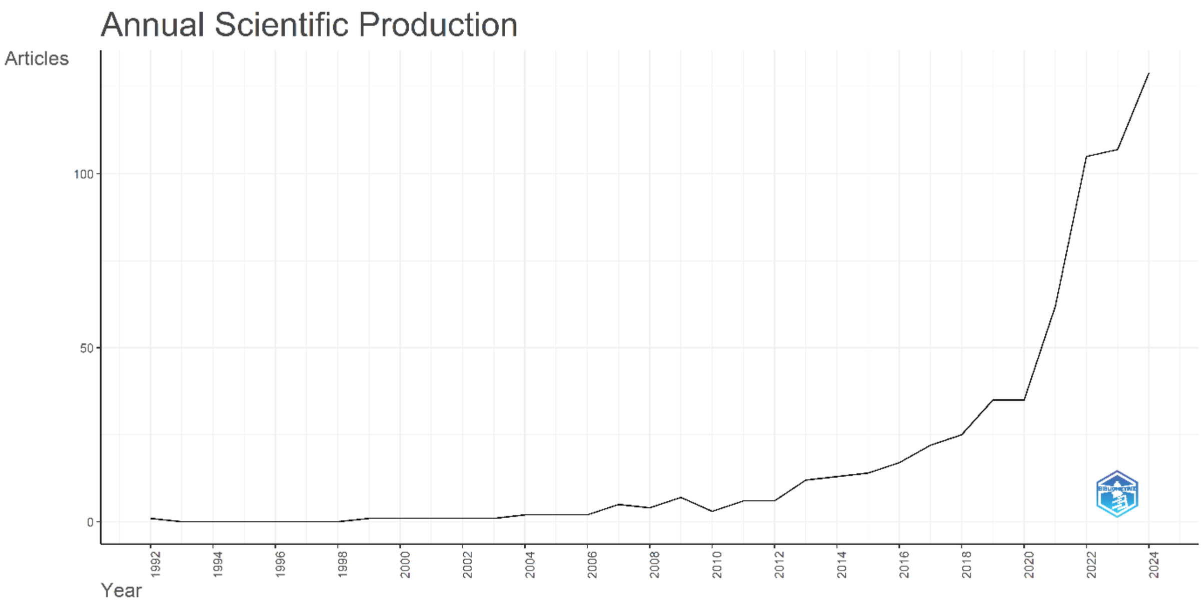

Figure 5. Annual scientific production in spatial entropy & urban planning (1992-2024).

from 2020 onwards. As of 2023, the annual number of articles in this field has exceeded 130. This shows that spatial entropy is increasingly used in urban planning literature and that this field is becoming increasingly attractive for interdisciplinary research. This difference in production between the two fields reveals that 'Urban Morphology & Entropy' corresponds to a more specific area of expertise. At the same time, 'Spatial Entropy & Urban Planning' is associated with wider-scale applications (Fig. 5).

These analyses show that Urban Morphology & Entropy remains a more specific and niche field, whereas Spatial Entropy & Urban Planning has a broader interdisciplinary impact [41,46]. When the differences between the two fields are evaluated in the context of scientific productivity, citation dynamics, international collaboration rates, and keyword distributions, they provide essential clues for interdisciplinary integration and thematic diversity in future research.

These figures compare the annual scientific output of the two literature sets. While Urban Morphology & Entropy demonstrates a steady but limited production, Spatial Entropy & Urban Planning shows a notable increase in publications after 2017, reflecting a shift toward more applied and interdisciplinary studies.

Keyword Distribution and Thematic Trends

Figures 6 and 7 visualise the most frequently used keywords in Urban Morphology & Entropy and Spatial Entropy & Urban Planning as a word cloud. This word cloud analysis visually reveals the thematic foci and common keywords of the Urban Morphology & Entropy and Spatial Entropy & Urban Planning topics, providing a comparative assessment of research trends in both fields. Keyword analysis shows that different research trends have emerged in both subjects [46].

According to the WordCloud analysis, the most prominent themes in Urban Morphology & Entropy are 'urban morphology', 'entropy', 'morphology', 'urban', 'spatial metrics', and 'sustainability'. These expressions reveal how urban morphology is associated with the concepts of spatial disorder and entropy and how these relationships gain meaning in terms of sustainable urban structures. The density of keywords indicates that the studies focus more on theoretical and morphological analyses (Fig. 6).

It is noteworthy that more applied, technical and geographical components such as 'entropy', 'urban sprawl', 'GIS', 'China', 'land use', 'urbanisation' and 'remote sensing' come to the forefront in the studies on Spatial Entropy & Urban Planning. This indicates that spatial entropy is primarily addressed through geographic information systems, land use planning, and remote sensing technologies. In addition, advanced analysis methods such as 'machine learning', 'deep learning', and 'topsis' reveal the methodological diversity and technical depth of research in this field (Fig. 7).

As a result, although 'entropy' stands out as the basic concept in both fields, theoretical orientation is dominant in urban morphology and entropy studies, while applied and technical orientation is dominant in Spatial Entropy and urban Planning studies. This difference reflects the thematic orientation of the literature and the diversity in the research paradigms of the two fields.

The keyword association networks presented in Figure 8 and Figure 9 reveal the thematic structures and conceptual clusters in the literature on urban morphology, entropy, spatial Entropy, and urban Planning [33,34].

Figure 6. Keyword WordCloud analysis on urban morphology & entropy.

Figure 7. Keyword WordCloud analysis on spatial entropy & urban planning.

These visualizations highlight the most frequently used thematic keywords. The Urban Morphology set emphasizes concepts like "urban form" and "spatial structure", indicating a theoretical orientation. In contrast, the Spatial Entropy set includes terms such as "remote sensing", "planning", and "AI", suggesting a more technical and practical approach.

In the field of Urban Morphology & Entropy, the concepts of 'urban', 'entropy', and 'morphology' have a high frequency and central position. These three keywords have strong relationships, indicating that publications in this field focus more on applying entropy theory in morphological analyses. Supporting concepts such as 'spatial metrics', 'Shannon's entropy', 'land cover', and 'form' are grouped around this central axis. The division of the network structure into limited and distinct clusters shows that the studies in this field have a more focused structure with a clear theoretical framework (Fig. 8).

The network in the Spatial Entropy & Urban Planning field exhibits a more dispersed and polycentric structure. While terms such as 'entropy', 'urban sprawl', 'GIS', and 'remote sensing' are central, various sub-clusters have formed around these concepts, such as 'urbanisation', 'land use', 'spatial analysis', and 'China', which include both theoretical and applied topics. This shows that the planning literature has a wider conceptual diversity and focuses on different research questions. Furthermore, the interdisciplinary nature of the network and the emphasis on technical tools (Geographic Information Systems (GIS), Remote Sensing) suggest that the field is more practice-oriented and data-driven (Fig. 9).

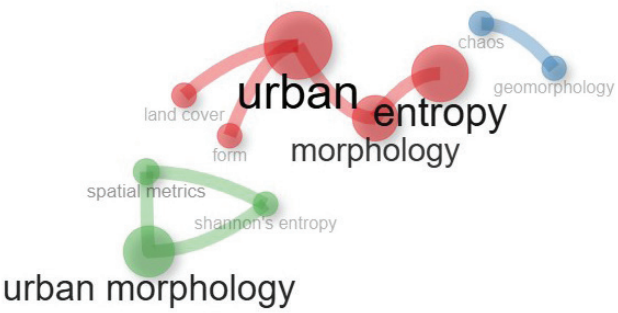

Figure 8. Keyword association network for urban morphology & entropy**.**

According to the results of the analyses, although the concept of 'entropy' constitutes the central axis in both network analyses, the Urban Morphology & Entropy field is shaped around more limited conceptual clusters and theoretical approaches. In contrast, the Spatial Entropy & Urban Planning field opens to more widespread, diverse, and multidisciplinary themes [47]. This difference distinguishes the priorities and methodological orientations of the research agendas of the two fields.

The keyword co-occurrence networks reveal how central concepts cluster within each literature. The Urban Morphology set presents compact thematic groupings focused on spatial form, whereas the Spatial Entropy literature shows a more dispersed and interdisciplinary structure.

The time series analyses in Figure 10 and Figure 11 show the cumulative usage frequencies of the most frequently used keywords in Urban Morphology & Entropy and Spatial Entropy & Urban Planning over the years. These findings provide important clues about the literature development dynamics of both fields [34,46].

According to the graph in Figure 10, it is observed that terms such as 'entropy', 'urban morphology', 'morphology', and 'sustainability' in the Urban Morphology & Entropy literature have increased significantly after 2015. After 2020, the rise in these terms has accelerated even more. In

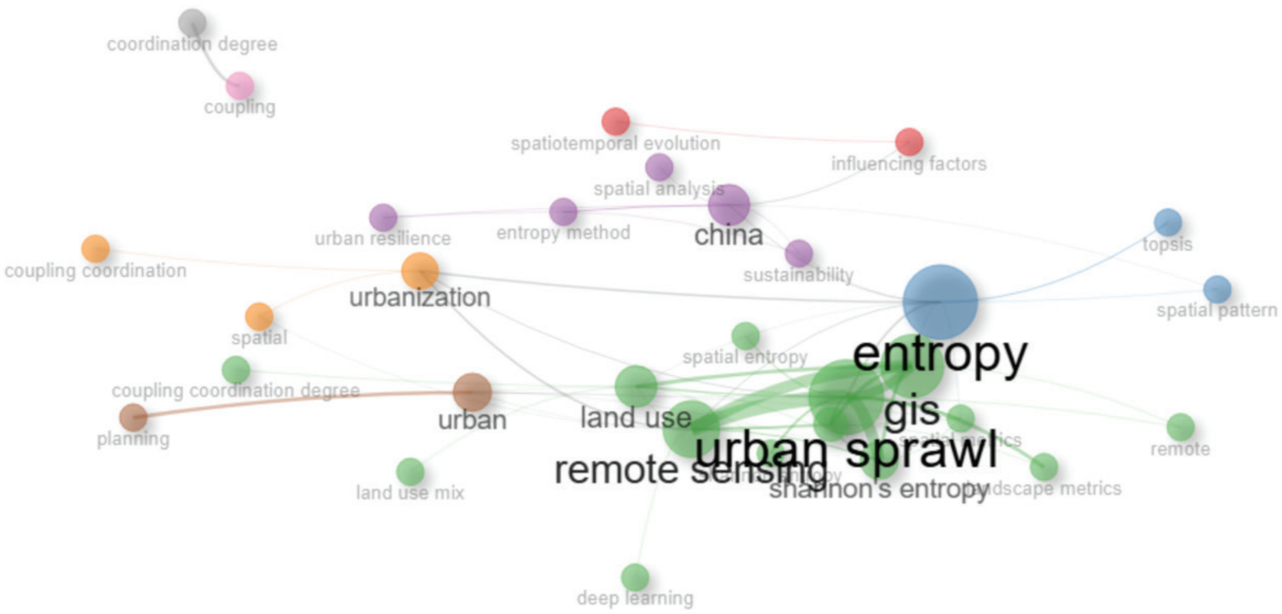

Figure 9. Keyword association network for spatial entropy & urban planning.

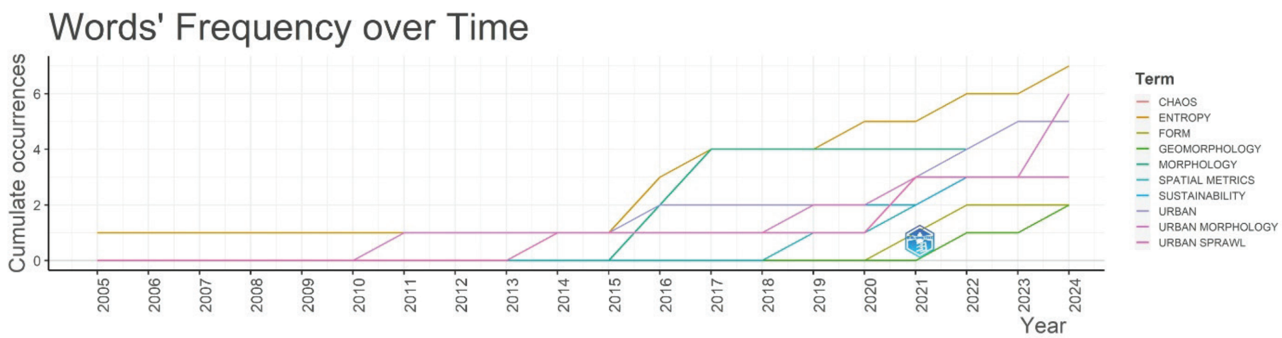

Figure 10. Frequency distribution of keywords in urban morphology and entropy over time.

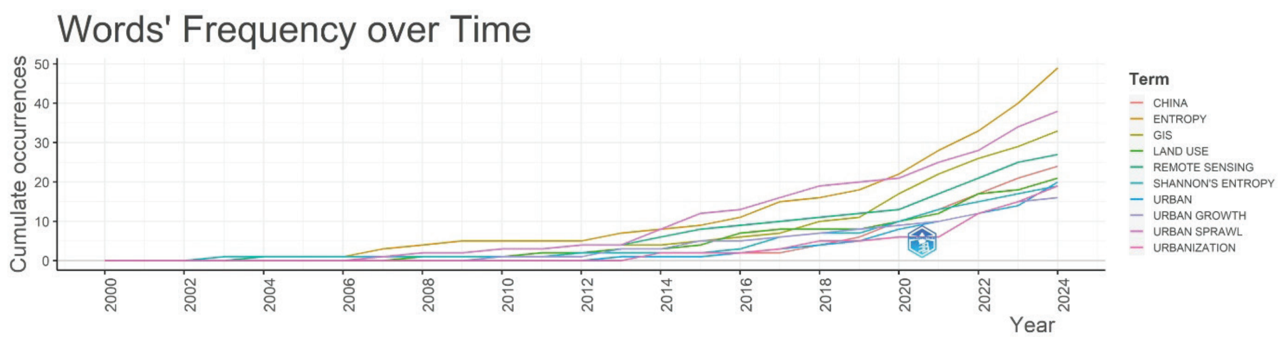

Figure 11. Frequency distribution of keywords in spatial entropy & urban planning over time.

particular, the parallel increase in the terms 'entropy' and 'urban morphology' shows that the studies in which these two concepts are handled together are increasingly intensifying. On the other hand, concepts such as 'chaos' and 'form' follow a relatively more limited usage curve, indicating that such themes are addressed in narrower studies.

The data in Figure 11 reveals that the terms in the Spatial Entropy & Urban Planning literature have increased more widely and continuously. It is evident that terms such as 'entropy', 'urbanisation', 'urban sprawl', 'land use', 'GIS', and 'remote sensing' exhibit a regular and significant upward trend, particularly since 2016. This trend shows that spatial entropy has found a wider application area, primarily through its integration with geographic information systems and urbanisation studies. In addition, the prominence of the term 'China' reveals that a significant portion of the research in this field is China-centred.

Overall, urban morphology and entropy have developed more limitedly and theoretically, whereas Spatial Entropy and urban Planning have grown more comprehensively, appliedly, and interdisciplinarily. This reveals that the two fields differ in academic interest, geographical density, and methodological diversity [41].

These figures illustrate the temporal evolution of key concepts. The Urban Morphology literature shows consistent usage of a few core terms, while the Spatial Entropy field reflects thematic expansion and adaptation to contemporary planning challenges.

Citation Analysis and Co-Citation Networks

The co-citation network analyses presented in Figure 12 and Figure 13 visualise the scholarly interactions between prominent journals, studies, and research clusters in Urban Morphology & Entropy and Spatial Entropy & Urban

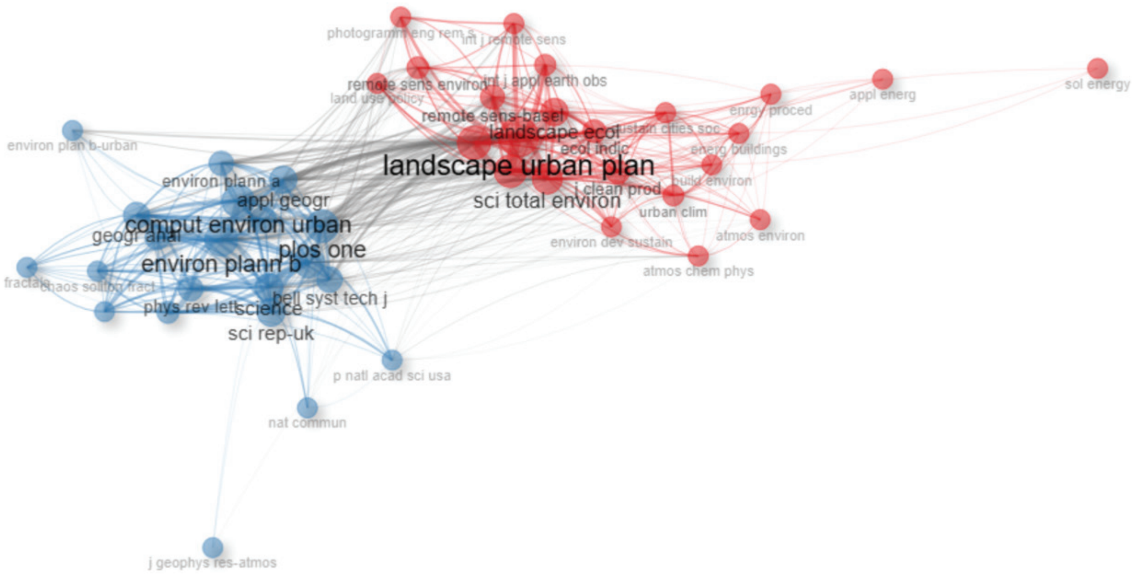

Figure 12. Co-Citation network on urban morphology & entropy.

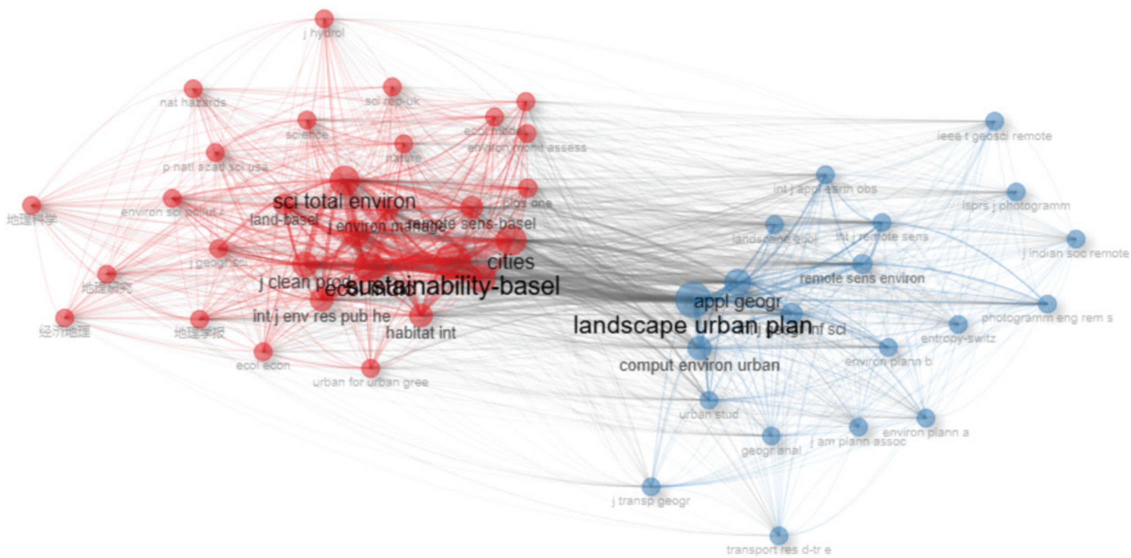

Figure 13. Co-citation network on spatial entropy & urban planning.

Planning. These analyses provide information about structural differences and thematic densities in the literature [47].

When the citation network on Urban Morphology & Entropy in Figure 12 is examined, it is seen that the network is divided into two distinct clusters. The red cluster is concentrated around journals such as “Landscape Urban Plan”, “Sci Total Environ”, and “Remote Sens Environ”, indicating that environmental planning and land use themes are prominent. The blue cluster is more centred around “Environ Plan B” and “Comput Environ Urban” journals. It focuses on urban morphology, geographic information systems, and computational modelling. This segregation reveals that Urban Morphology & Entropy is addressed from environmental and structural-theoretical planning perspectives.

In the network on Spatial Entropy & Urban Planning presented in Figure 13, a more dense and polycentric structure stands out. Journals such as “Sustainability-Basel”, “Cities”, “Sci Total Environ”, and “Land Use Policy” stand out as highly interactive nodes. While sustainability, urbanisation, and environmental policy themes dominate in the red cluster, remote sensing, geographical analysis, and modeling are concentrated in the blue cluster. The journal “Landscape Urban Plan” bridges both clusters and is at the centre of interdisciplinary interaction. This network structure shows that Spatial Entropy & Urban Planning has a broad, multidisciplinary literature base.

These findings suggest that the field of Urban Morphology & Entropy has a more focused, theoretical core. In contrast, Spatial Entropy & Urban Planning has a more applied and multidimensional research focus. Moreover, the centrality of the journal “Landscape and Urban Planning” in both fields suggests that this journal plays a decisive role in spreading knowledge across fields. These results confirm the structural differentiation of thematic densities and academic interactions in the literature [46,47].

These networks visualize intellectual linkages between cited sources. The Urban Morphology literature forms distinct clusters around morphological analysis and spatial structure, whereas the Spatial Entropy field exhibits diverse clusters related to environmental planning, remote sensing, and AI applications.

The citation network analyses in Figure 14 and Figure 15 reveal the citation relationships between prominent researchers in Urban Morphology & Entropy and Spatial Entropy & Urban Planning and the intellectual structure of these fields [46].

The citation network for Urban Morphology & Entropy, presented in Figure 14, points to three distinct clusters. First, the green cluster, where names such as Batty M. and Clark C. are highly cited, constitutes the core of the literature on urban growth, morphological structure, and modelling. In contrast, the blue cluster, which includes theoretical names such as Shannon C.E., is based on the statistical and information-theoretic origins of entropy theory. Authors such as Galster G. have emerged in the red cluster, clustered around themes such as urban sprawl, land use, and spatial inequality. This structure shows that the field of Urban Morphology & Entropy has developed on two principal axes, both theoretically and practically.

The citation network for Spatial Entropy & Urban Planning in Figure 15 indicates a broader and multicenter structure. Here, China-based researchers such as Wang Hui, Jiang Ruidan, and Liu stand out, suggesting that the field is geographically concentrated in academic circles in Asia. Other clusters, including Zhang, Guo Renze, and He Biao, are related to more topical issues such as remote sensing, machine learning, and urban sustainability. This structure

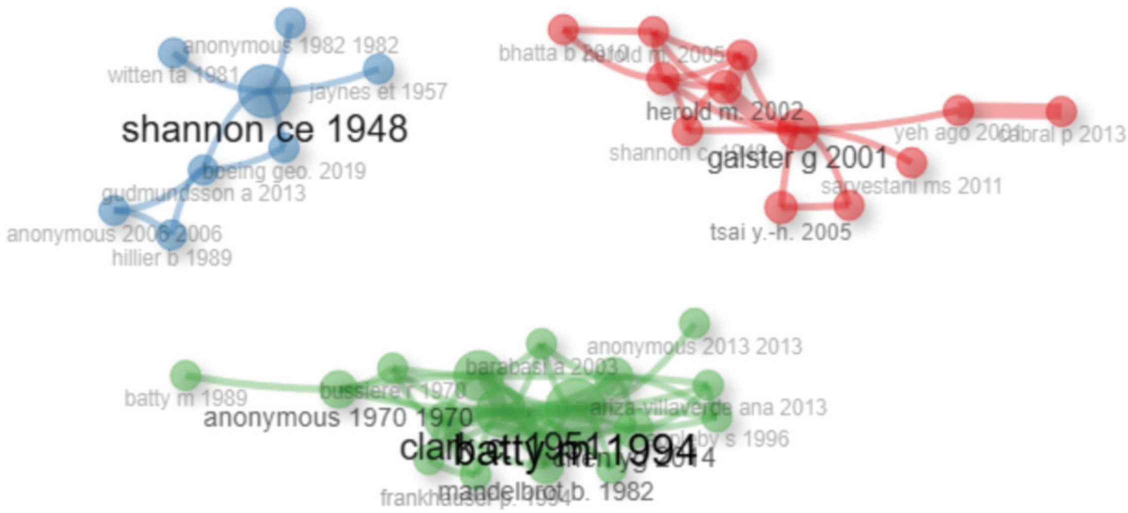

Figure 14. Citation networks in urban morphology & entropy.

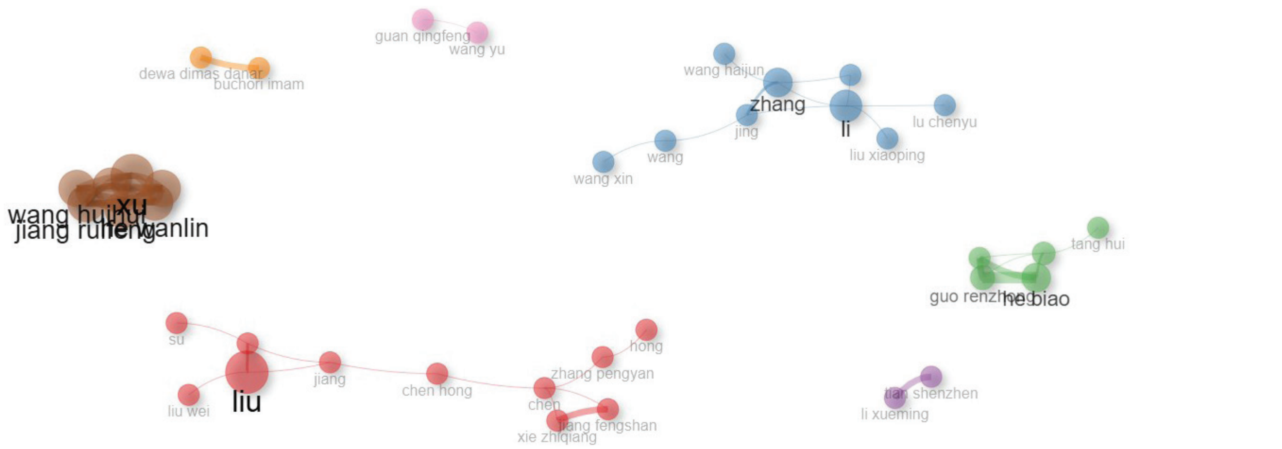

Figure 15. Citation networks in spatial entropy & urban planning.

shows that the Spatial Entropy & Urban Planning literature has diversified rapidly, especially in the last decade, shifting towards a more technical, multidisciplinary, and data-driven research axis.

These findings reveal that urban morphology and entropy are based on more classical theoretical studies. In contrast, Spatial Entropy and urban Planning are more contemporary, technology-based, and open to global research collaborations. The pioneers of both fields provide an essential reference point for future research, guiding the study's contributions to the literature.

These graphs identify influential authors and their citation relationships. Classical theorists dominate the Urban Morphology network, focused on spatial form. At the same time, the Spatial Entropy domain is driven by contemporary authors from China and other countries with expertise in data-driven urban planning.

Figures 16 and 17 present the global impact of the most cited studies in Urban Morphology & Entropy and Spatial Entropy & Urban Planning. These visualizations are essential in showing which publications have been leading in the literature in both fields [31,48].

The most cited study in Urban Morphology & Entropy, as shown in Figure 16, is the article by Mohajeri published in Renewable Energy, which received 165 citations in total. This is followed by Batty's classic work published in Urban Studies, which provides the basis for urban growth and morphological analyses (118 citations). Other highly cited

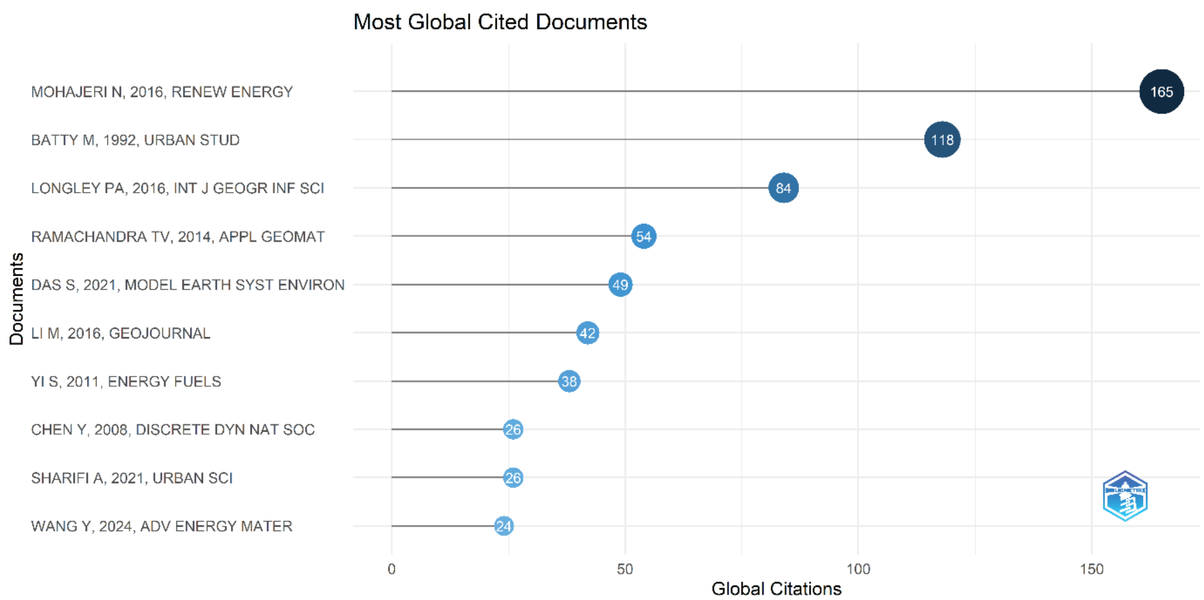

Figure 16. Most cited studies in urban morphology & entropy.

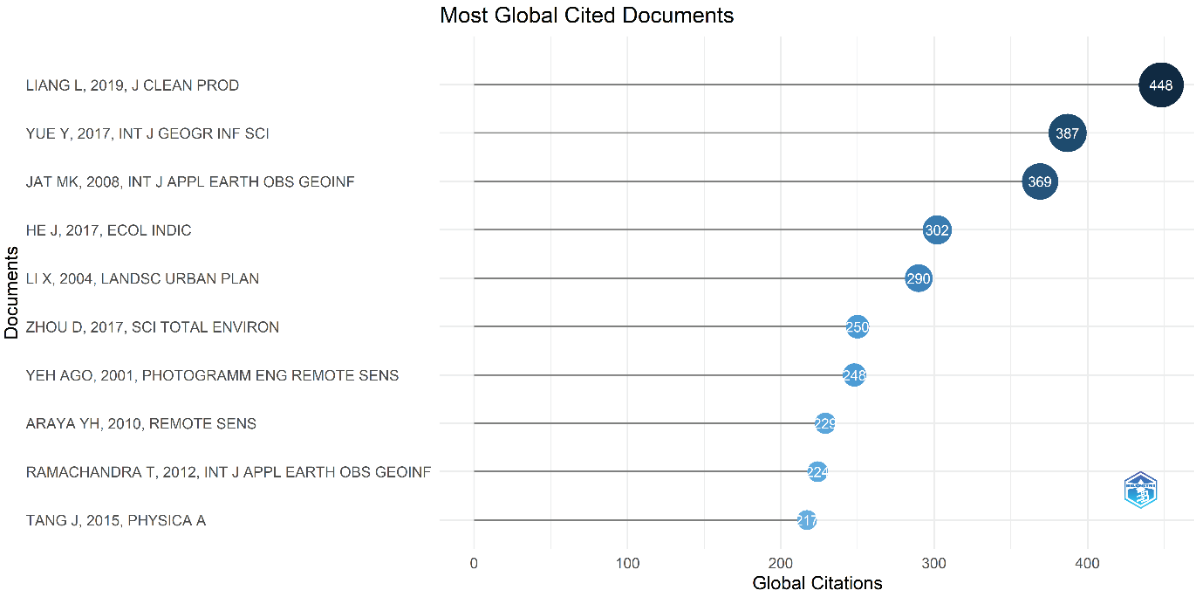

Figure 17. Most cited studies in spatial entropy & urban planning.

studies include spatial statistics, entropic modelling, and energy planning. This shows that entropy is associated with spatial structure in the context of urban morphology and interdisciplinary fields such as sustainability and energy.

Figure 17 reveals the existence of many more highly cited publications in Spatial Entropy & Urban Planning. The most remarkable study is the article published by Liang in the Journal of Cleaner Production, which is by far the most cited source in the field with 448 citations. It is followed by Yue (387 citations) and Jat (2008) (369 citations). These articles particularly focus on environmental planning, Geographic Information Systems (GIS), and spatial modelling. In this context, it is observed that the literature in the field of Spatial Entropy & Urban Planning has a more up-to-date, environmentally sensitive, and decision support systems-oriented development line.

These findings reveal that Urban Morphology & Entropy is more theoretically and historically grounded. In contrast, Spatial Entropy & Urban Planning is more applied, focusing on environmental planning and technology-oriented approaches. Furthermore, the latter field is more widely cited in the literature, indicating that it is becoming a more dynamic and rapidly developing field in the global research community. At the same time, this analysis shows that the Spatial Entropy & Urban Planning field appeals to a broader readership and has an interdisciplinary impact. In contrast, the Urban Morphology & Entropy field focuses on more niche and specific topics. These differences emphasise the importance of the comparative framework provided by the bibliometric analysis [31,41,46].

These bar charts display the most cited studies in each field. Urban Morphology is characterized by foundational theoretical work, while Spatial Entropy emphasizes recent, high-impact studies related to sustainability and thoughtful planning.

Thematic Maps and Trend Analyses

Figure 18 and Figure 19 show the trending topics over time in Urban Morphology & Entropy and Spatial Entropy & Urban Planning, respectively. These analyses provide important clues to understand research trends by revealing the thematic evolution in the respective fields [31,48].

In Figure 18, urban morphology', 'urban', 'entropy', and 'morphology' are among the prominent trending terms in Urban Morphology & Entropy. The fact that these terms are trending shows that this field focuses more on structural morphology and entropic distribution models at the conceptual level. However, in terms of period, these terms seem to be concentrated for a limited number of years and remain largely up to date. This reveals a conceptual continuity in the literature, but the diversity of applications remains limited.

Figure 19 shows that the thematic development in Spatial Entropy & Urban Planning is much more diverse, dynamic, and application-oriented. Here, concepts such as 'entropy', 'urban sprawl', 'GIS', 'urbanisation', 'remote sensing', 'landscape metrics', and 'machine learning' come to the forefront; this shows that spatial entropy issues are addressed in a broad interdisciplinary context. Especially in the post-2019 period, the rise of concepts such as 'coupling coordination', 'urban resilience', 'topsis', 'information entropy', 'driving factors', and 'deep learning' reveals that methodological diversification and planning-oriented applications in this field have increased.

These findings show that urban morphology and entropy are based on basic concepts and theoretical frameworks.

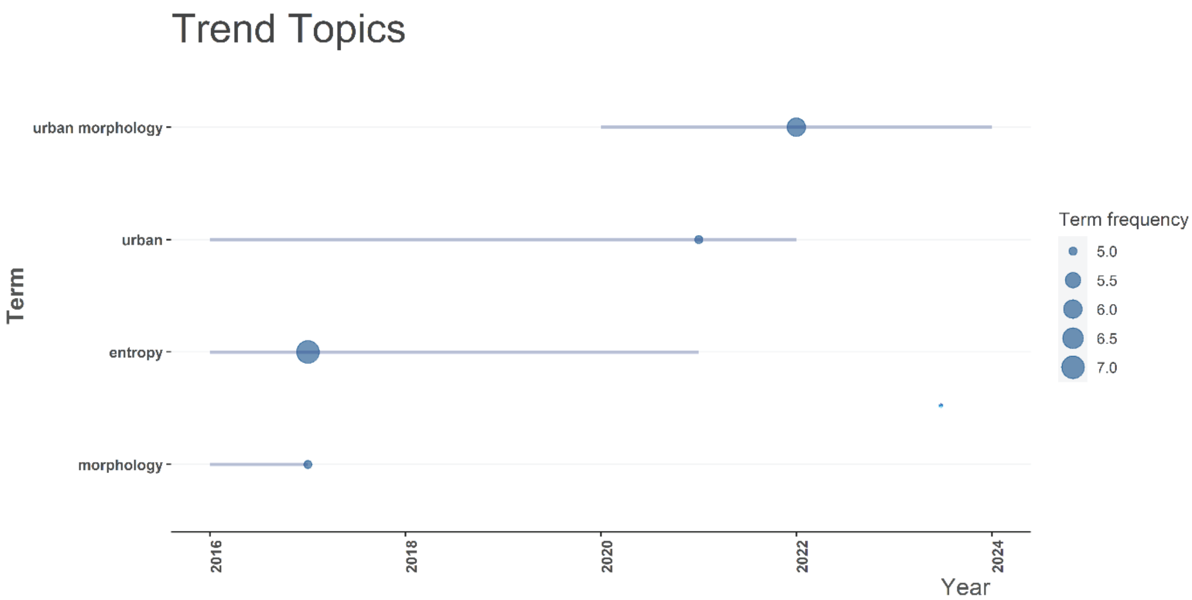

Figure 18. Distribution of trending topics in urban morphology & entropy research areas over time.

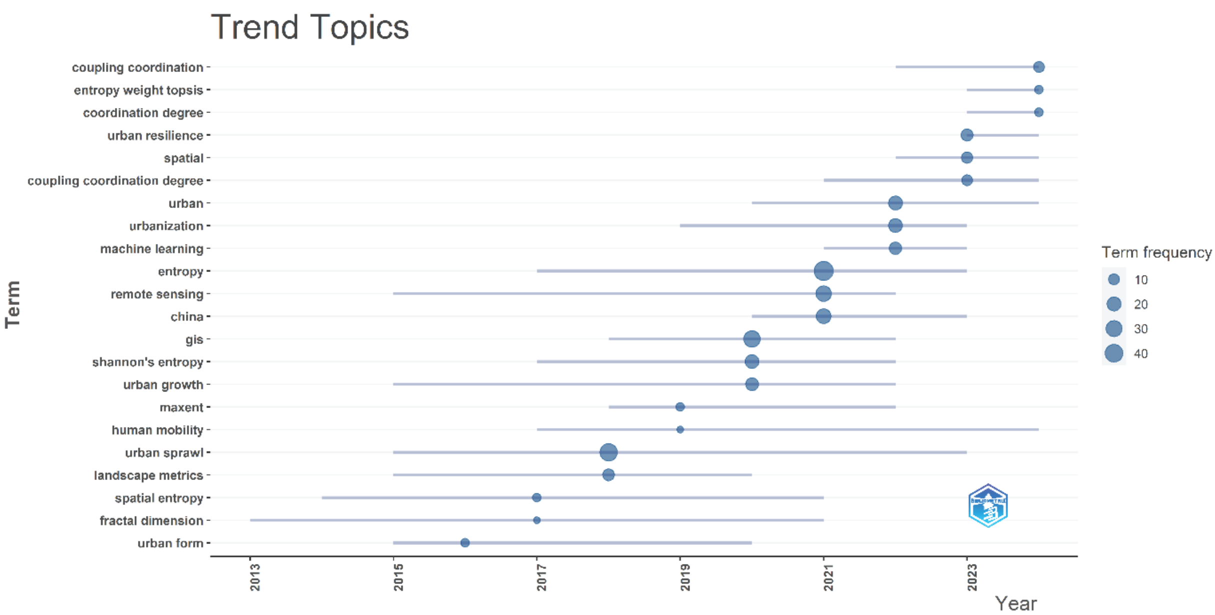

Figure 19. Distribution of trending topics in spatial entropy & urban planning research areas over time.

In contrast, Spatial Entropy and urban Planning are more up-to-date, technology-integrated, data-based, and practice-oriented. Thus, these analyses provide a comparative assessment of the development axes of the two fields over time and reinforce the methodological power of the bibliometric approach [48].

These visuals demonstrate how popular research topics have evolved. Urban Morphology maintains focus on stable theoretical themes, whereas Spatial Entropy exhibits growing attention to emerging technologies and planning tools.

Figures 20 and 21 show a Three-Field Plot analysis that analyses the scientific production on urban morphology and entropy at three primary levels: publishing countries (AU_CO), institutions (AU_UN), and most frequently used keywords (DE). This analysis visualises the relationships between the prolific actors in the literature and the research themes, detailing the geographical and institutional distribution of the discipline [31,45].

According to Figure 20, China, the USA, Poland, Brazil, and Japan stand out among the most productive countries

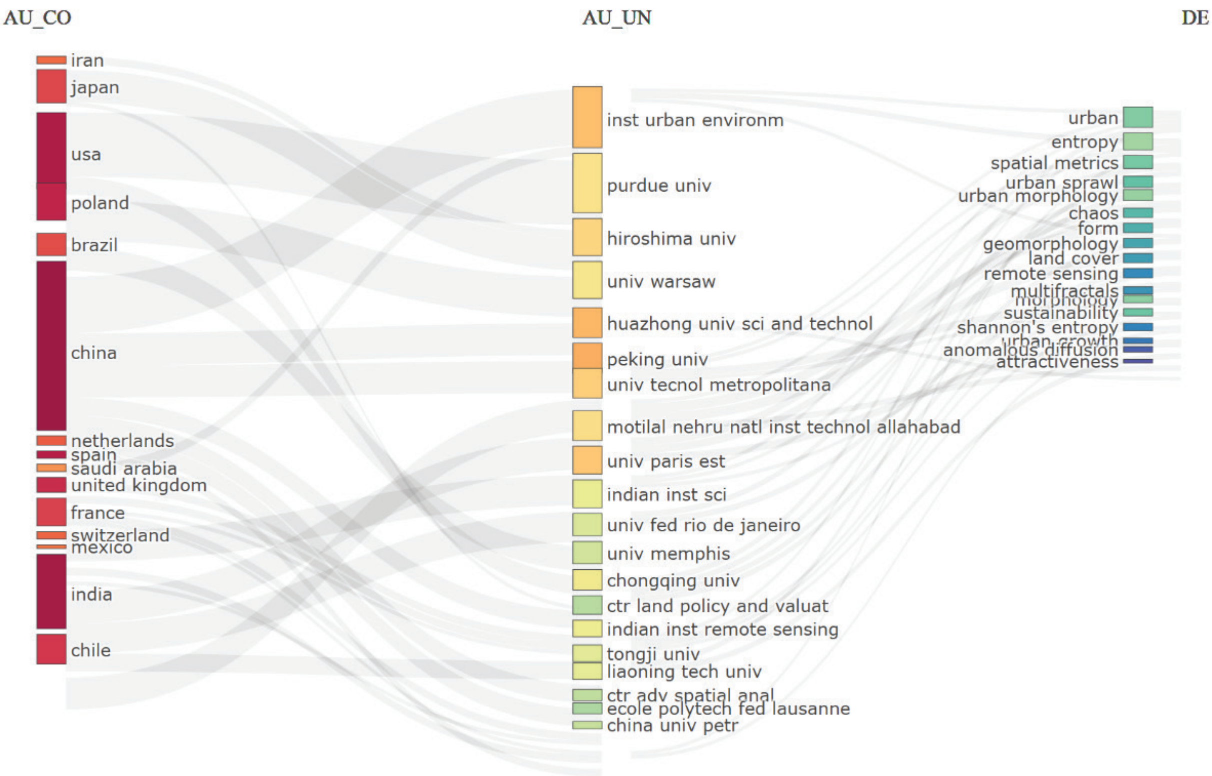

Figure 20. Three-field plot analysis on urban morphology & entropy.

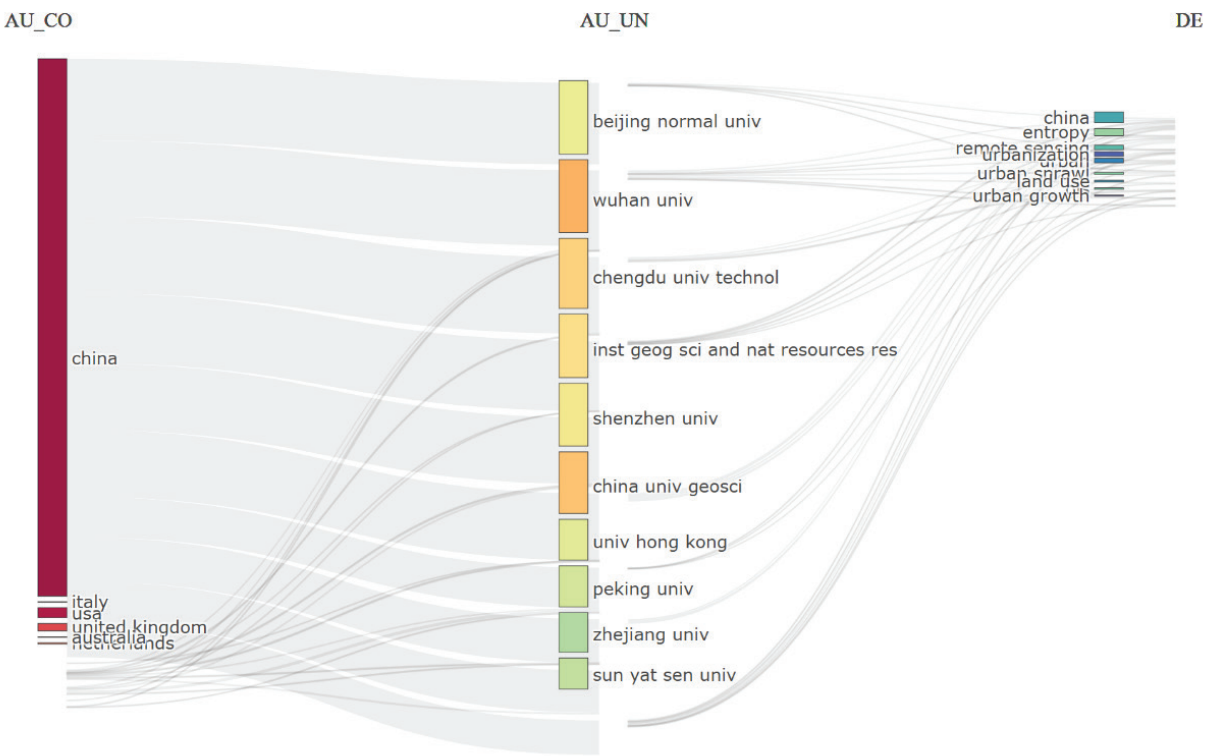

Figure 21. Three-field plot analysis on spatial entropy & urban planning.

in this field. In particular, China is at the forefront of studies related to various keywords through many organisations. This indicates that China has become a central actor in the research on theoretical and applied urban morphology and entropy.

Institutions such as the Institute for Urban Environment, Purdue University, Hiroshima University, and the University of Warsaw stand out at the institutional level. Their research activities are most frequently centred around the keywords 'urban', 'entropy', 'urban morphology', and 'spatial metrics'. This situation shows that specific institutional centres influence the entropic analysis of urban structures and are shaped around specific thematic foci.

Concepts such as 'urban morphology', 'entropy', 'spatial metrics', 'urban sprawl', 'form', and 'land cover' are frequently used at the keyword level. This shows that the formal analysis of spatial structures, urban sprawl, and the evaluation of complexity with entropic metrics are among the prioritised research themes in this literature.

In general, this tripartite structure has allowed the analysis of geographical diversity, institutional activity, and thematic concentrations in the literature together, thus providing a holistic view of the scientific ecosystem of Urban Morphology & Entropy [49].

Figure 21 presents a Three-Field Plot analysis visualising the studies on Spatial Entropy and urban Planning in terms of countries (AU_CO), institutions (AU_UN), and keywords (DE).

The most important finding in Figure 21 is the apparent hegemonic position of China in this research area. China is far ahead in the number of publications at the national and institutional levels. In particular, institutions such as Beijing Normal University, Wuhan University, Chengdu University of Technology, Shenzhen University and the Institute of Geographic Sciences and Natural Resources Research realize a large part of the production in this field. This shows China has become a global centre for spatial entropy and urban planning studies.

At the keyword level, concepts such as 'entropy', 'China', 'remote sensing', 'urbanization', 'land use' and 'urban growth' come to the fore. This shows that spatial entropy is considered together with urban growth, land use and remote sensing techniques, and entropy is integrated into urban planning decisions through these parameters. It reveals that the Spatial Entropy & Urban Planning literature is primarily centred in China, with research themes focusing on rapid urbanization and land use supported by technological tools (especially remote sensing). This is an important indicator for understanding the regional concentration in the field and how entropy is addressed in practical planning contexts.

These figures map the relationships among countries, institutions, and keywords. The Spatial Entropy literature prominently features China as a dominant contributor, reflecting its central role in the global discourse on data-driven urban planning.

Figures 22 and 23 present the conceptual structure of the Urban Morphology & Entropy and Spatial Entropy & Urban Planning literature, visualized using the Factorial Map method. This analysis reveals the thematic clustering of terms and their positions on two basic dimensions (Dimension 1 and Dimension 2), revealing the contextual affinities of subheadings in the literature [31,49]. This map, created by the factor analysis method, shows the spatial relationships and thematic groups of the concept clusters prominent in the literature. The concepts on the two-dimensional plane allow for analyzing thematic diversity and research trends [31].

Figure 22 presents a Factorial Map visualization analyzing the distribution of conceptual constructs in the Urban Morphology & Entropy research area. Phrases such as 'adsorption', 'mechanism', 'composite hydrogel' and 'thermodynamic parameters' in the upper section reveal the interdisciplinary aspect of this field and represent studies where entropy is associated with physical-chemical processes. This shows that entropy in urban morphology is addressed through spatial structure and energy and material cycle-based approaches. Concepts such as 'decision making model', 'deployment planning' and 'temporal mismatch' in the lower right area show the applied use of entropy in decision making, planning processes and time-space mismatches. This points to entropy-based spatial planning approaches. Concepts such as 'urban geography', 'geo-temporal demographics' and 'twitter' in the lower left area represent the new generation of research areas where the relationship between social media, spatial demography and entropy is evaluated. Concepts such as 'urban function', 'spatial interaction probability', 'attractiveness', and 'typical urban unit cluster', which are concentrated in the centre, show that entropy-based spatial analyses are carried out through functional distributions and attractiveness within the city.

Overall, this analysis shows that the urban morphology and entropy literature is multidimensional, encompassing physical environment, energy-based approaches, and social-spatial analyses. Furthermore, this thematic map observes current trends in which different data sources (social media, location-based service (LBS) data) and models are integrated with entropy analysis in an interdisciplinary synthesis (Fig. 22).

Figure 23 presents a Factorial Map visualization analyzing the distribution of conceptual constructs in the Spatial Entropy & Urban Planning research area. Keywords such as 'analysis', 'maxent', 'ecosystem services', 'remote', 'landscape metrics' and 'deep learning', which are in the upper left part of the map, indicate that this field is heavily associated with the assessment of environmental services, remote sensing technologies and artificial intelligence-assisted analysis techniques. These concepts are especially prominent in studies on modelling natural resources, determining sustainability criteria, and analyzing spatial data.

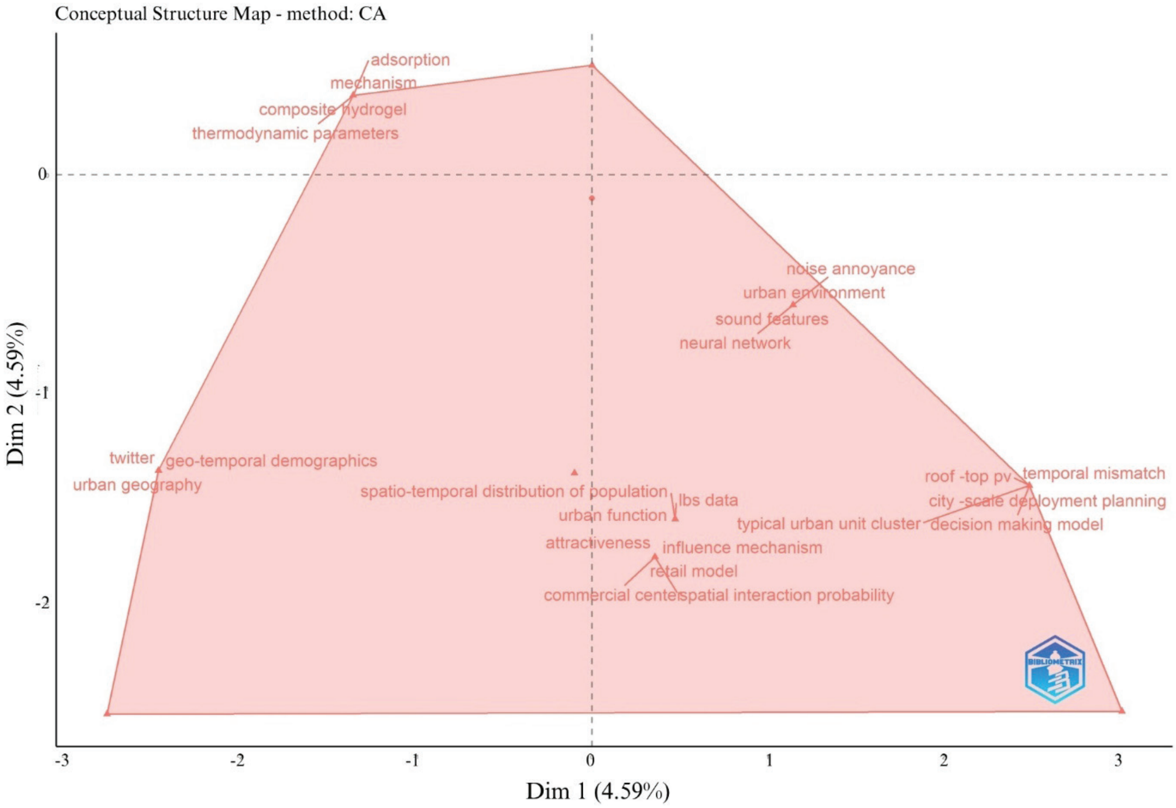

Figure 22. Factorial map analysis on urban morphology & entropy.

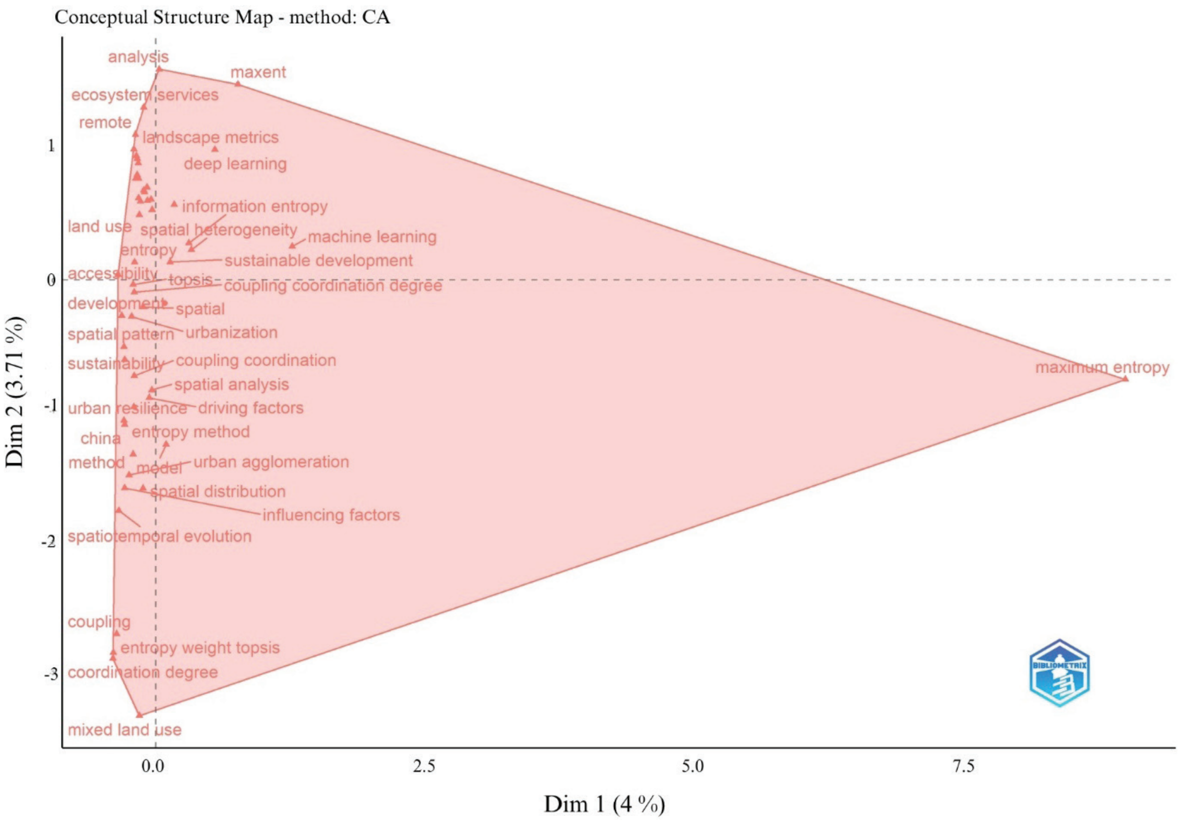

Figure 23. Factorial map analysis on spatial entropy & urban planning.

The cluster in the central region includes terms such as 'entropy', 'land use', 'sustainability', 'urbanization', 'information entropy', 'spatial pattern', 'coupling coordination degree' and 'accessibility'. These terms reveal how spatial entropy is used to measure the complexity of urbanization processes, support sustainable planning practices, and explain land use dynamics. In particular, terms such as 'coupling coordination degree' and 'information entropy' reflect trends in interdisciplinary studies towards integrated assessment of complex systems. Concepts such as 'coordination degree', 'entropy weight topsis', 'spatiotemporal evolution' and 'urban agglomeration' in the lower left region show that multi-criteria decision-making methods and temporal-spatial modelling are intensively used. It is understood that these analyses are used to optimize planning decision processes.

In the upper right part of the map, the concept of 'maximum entropy', which is positioned alone, draws attention. Although this term shows less commonality with other concepts in the conceptual map, it is an important focal point at the theoretical level. The maximum entropy approach is integrated into planning models as a mathematical method for optimal information extraction, especially under uncertainty. The Spatial Entropy & Urban Planning field generally shows an interdisciplinary structure, where remote sensing, artificial intelligence, sustainability, urbanization and decision support systems are intertwined with entropy-based analyses. It can be said that this structure reflects in detail how entropy is positioned not only as a theoretical but also as an applied tool in the urban planning literature (Fig. 23).

These two analyses demonstrate that urban morphology and entropy are more effectively integrated with spatial analysis techniques. Spatial Entropy and urban Planning deal with wider interdisciplinary interaction and technical diversity. These findings clearly illustrate the intersection of the theoretical frameworks of the two fields and the differences in their fields of application [49].

These factorial maps depict the conceptual structure of each literature. Urban Morphology literature clusters around physical form and spatial analysis, while Spatial Entropy integrates themes like sustainability, simulation, and machine learning.

This study takes a comparative approach to the bibliometric analyses conducted under the titles 'Urban Morphology & Entropy' and 'Spatial Entropy & Urban Planning' to understand the evolution of the concept of entropy in the urban studies literature. By examining how entropy is interpreted and used in different contexts, this study reveals the place of entropy-based spatial analyses in urban morphology and planning literature. It analyses thematic relationships and methodological divergences often overlooked in previous studies. In this context, elements of scientific productivity, keyword networks, thematic developments, and intellectual structure are visualized and interpreted for two separate sets of literature [31,44].

The study's methodological framework is based on analyzing the data obtained from the Web of Science (WoS) database using the Bibliometrix package and the Biblioshiny visualization tool in the RStudio environment. This approach is in line with the bibliometric analysis methods used by researchers such as Aria et al. [31,44], and [41]. In the literature, WoS and Scopus databases are among the most common sources for conducting bibliometric studies, and Xu et al. [50], Aria et al. [31], and Zhang et al. [38] are examples of studies that use these databases effectively. Yilmaz et al. [34] visualized earthquake research in Turkey using the WoS database in bibliometric analyses; this study is based on WoS data in entropy and urban morphology-based analyses. In this study, the primary justification for the WoS database's preference was the dataset's comprehensiveness and high academic visibility [51,47,48]. In addition, studies such as Aristovnik et al. [52], Liu et al. [53] and Matsler et al. [43] used the Scopus database; [33] analyzed both databases comparatively and found a high level of correlation [51,54]. These findings indicate no significant content difference between WoS and Scopus databases.

The Bibliometrix package used in the RStudio environment offers advanced analysis techniques such as Two-Field Plot, Three-Field Plot, Thematic Map, Factorial Map, and Dendrogram, which are frequently used in bibliometric analyses [49]. These types of analyses have been previously applied in various studies by Cobo et al. [30], Song et al. [55], Aria et al. [31] and Gonçalves et al. [48]. However, the unique aspect of this research is that it deals with the concept of entropy comparatively through two different sets of literature. The analyses conducted under the titles of 'Urban Morphology & Entropy' and 'Spatial Entropy & Urban Planning' evaluate both thematic developments and the scientific productivity, intellectual structure, and interdisciplinary relations of these two fields from a holistic perspective. In this context, the study is based on the analysis of academic studies on integrating entropy in urban morphology and urban planning.

Many studies use entropy to analyze urban morphology Nazarnia et al. [56], Brigatti et al. [2] or to model issues such as urban sprawl and sustainability in spatial planning [29,57]. Altieri et al. [29] assessed the irregularity in the sprawl patterns of European cities using spatial entropy. Similarly, Brigatti et al. [2] analyzed cities with different morphological structures using entropy-based clustering methods. However, these studies deal with entropy only in a single context and do not cover its multidisciplinary interactions or thematic diversity. Aladag et al. [36] adopted the scoping review method to identify the uses of artificial intelligence applications in project management processes, proposing a theoretical basis for future research. Similarly, this study uses bibliometric analysis to evaluate the place of entropy-based spatial approaches in urban planning and morphological interpretation. Al-Shamayleh et al. [58] emphasize the importance of using integrated software to support decision-making processes in urban infrastructure management. Similarly, this research systematically addresses the relationship between urban morphology and entropy at the literature level, demonstrating the potential of multi-data and interdisciplinary analysis approaches to contribute to planning. In their study, Yilmaz et al. [34] presented the academic publications after the 6 February earthquakes through bibliometric analyses. However, this study individually evaluated two literatures (Urban Morphology & Entropy and Spatial Entropy & Urban Planning).

At this point, one of the most important contributions of this study is that it reveals how entropy is interpreted in different ways in urban morphology and planning. While the 'Urban Morphology & Entropy' literature is more theoretically oriented and focuses on the physical structure of urban form, the 'Spatial Entropy & Urban Planning' literature provides a more applied framework by incorporating themes such as machine learning, sustainability, climate policies, and decision support systems [15,59,60]. This differentiation is also confirmed by prior studies, including [57] and [17]. It is clearly illustrated in the Factorial Map and Thematic Map analyses, which highlight the thematic affinities and divergences between the two literature sets.

For example, Batty and Galster applied entropy in more conventional morphological contexts, examining urban growth and spatial distribution patterns. In contrast, more recent studies by He & Chen (2024) have incorporated entropy into AI-driven planning and decision-support frameworks, reflecting a methodological evolution in the field.

This growing trend underscores that entropy is no longer confined to structural analysis; instead, it has become a multidisciplinary, data-driven tool widely used in contemporary urban planning practices [29,59].

In the publications titled Urban Morphology & Entropy, it has been observed that concepts such as 'urban morphology', 'spatial metrics', and 'configuration' come to the forefront, and the studies proceed within a narrower thematic framework [56,61]. On the other hand, Spatial Entropy & Urban Planning literature offers a wide range of content with interdisciplinary concepts such as 'machine learning', 'urban resilience', 'maximum entropy', and 'landscape metrics', and associates entropy with decision support mechanisms [62,27,59,15]. This is a critical point where this study differs from the previous literature.

Furthermore, bibliometric analyses show that China has a high level of scientific productivity, especially in the Spatial Entropy & Urban Planning literature, and that most of the publications in this field are produced by China-based institutions. This finding, in line with studies such as [38] and [53], shows that China is leading entropy-based spatial analyses at the global level. The study also provides a methodological contribution to previous studies with different analysis techniques. For example, using bibliometric methods proposed by [30] and [31], analysis tools such as Three-Field Plot, Factorial Map, and Co-Citation Network visualize intellectual clusters and research relationships. In particular, these analyses have made evident how entropy is integrated with decision support systems in urban planning and spatial structure criteria in morphological analysis.

Another important finding of the study is that entropy is becoming not only a theoretical concept that defines spatial complexity, but also a tool that can be integrated with data-based analyses, artificial intelligence, and geographic information systems in urban planning [23,53]. In this context, spatial entropy may assume more strategic roles in the future in areas such as urban sustainability, spatial distribution of inequalities, and climate adaptation.

This study fills an important gap in the literature and redefines the theoretical position of entropy-based studies in urban research with an interdisciplinary approach. Unlike previous studies on different datasets, this study directly compares two different sets of literature and simultaneously analyzes the theoretical evolution, methodological use, and thematic diversity of entropy. In this respect, the study provides an important framework for how entropy-based spatial analyses can be developed in urban planning and morphological interpretation in the future.

CONCLUSION

This study evaluated the theoretical and practical development of the concept of entropy in urban research by conducting a comparative bibliometric analysis of academic publications under the themes of Urban Morphology & Entropy and Spatial Entropy & Urban Planning. The findings demonstrate that entropy constitutes a central conceptual framework in both fields; however, its applications and research priorities vary significantly. While the Urban Morphology & Entropy literature primarily focuses on the regularity of spatial forms and morphological structures, the Spatial Entropy & Urban Planning literature integrates entropy with data science, sustainability, environmental planning, and artificial intelligence. This divergence illustrates the interdisciplinary evolution of entropy-based analyses and underlines the increasing importance of cross-disciplinary approaches in urban research. Furthermore, the prominence of China in spatial entropy-themed publications signals a shift in the global centers of scientific productivity in this field.

The bibliometric methods employed, such as thematic mapping, three-field plots, collaboration networks, and citation analysis, effectively revealed the structural components, research gaps, and intellectual trends within the literature. In doing so, the study not only provided a systematic assessment of current scholarships but also opened a theoretical discussion about the role of entropy in urban planning and morphological analysis.

From a theoretical standpoint, the findings also contribute to urban systems theory and complexity science by demonstrating how entropy serves as a framework to understand spatial irregularities. In this regard, future bibliometric evaluations are encouraged to explore emerging directions such as the integration of altimetric or social media-based data to capture broader scholarly and societal impact.

Future research should strengthen the interdisciplinary perspective by integrating entropy not only with urban form analysis but also with themes such as spatial justice, disaster resilience, and environmental sustainability. To further explore the intersection of Urban Morphology & Entropy and Spatial Entropy & Urban Planning, incorporating advanced computational tools like machine learning and big data analytics is highly encouraged.

To broaden bibliometric scope and enhance analytical depth, future studies should consider including additional databases such as Scopus and Google Scholar alongside Web of Science. This would help provide a more comprehensive and diversified understanding of academic contributions across disciplines.

In terms of methodological development, the use of advanced techniques such as spatial regression, simulation modeling, and artificial intelligence can facilitate a deeper understanding of urban complexity. Researchers are also encouraged to apply more sophisticated bibliometric methods, including network analysis, systematic mapping, and meta-analysis, to capture evolving thematic trends with greater precision.

From an applied planning perspective, entropy-based indicators should be more actively utilized within decision-support systems of municipalities and planning offices. These metrics can support data-driven decisions in areas such as green infrastructure planning, spatial equity, and resource allocation, thereby enhancing the functional effectiveness of urban interventions.

Finally, it is recommended that theoretical research continue to deepen the role of entropy not merely as a quantitative tool, but also as a conceptual framework for interpreting the complexity and dynamism of urban systems. Viewing entropy as a way of thinking, rather than solely as a metric, can lead to more nuanced and integrated models of urban analysis and governance.

These conclusions underscore that entropy-based analyses can play both a diagnostic and a guiding role in the disciplines of urban morphology and urban planning. Thus, this study contributes not only to the current literature but also offers a robust conceptual and methodological foundation for future research in entropy-informed spatial studies.

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AUTHORSHIP CONTRIBUTIONS

Authors equally contributed to this work.

DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

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

STATEMENT ON THE USE OF ARTIFICIAL INTELLIGENCE

Artificial intelligence was not used in the preparation of the article.

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