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Review

A Bibliometric Analysis of Research Hotspots and Trends in Coastal Building from 1988 to 2023: Based on the Web of Science and CiteSpace

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Abstract: This paper uses CiteSpace R6.1 bibliometric software to construct a knowledge map of coastal building research, analyses research authors, institutions, countries, keyword co-occurrence and keyword clustering, visualises and analyses the relevant literature collected in WOS, summarises the current state of research, research hotspots and research frontiers in the field, and provides a theoretical basis and decision support for relevant research. Specifically, this paper analyses 2067 records from 1988 to 2023. The results show that the impacts of climate change on coastal buildings are a major focus of research, but there are methodological and data limitations that encourage cross-national and interdisciplinary collaboration to address complex issues. Research trends include adaptive strategies, shoreline response and machine learning, and the need to integrate technical, engineering, social, economic, environmental and ethical dimensions to achieve sustainable and inclusive development.

Keywords: bibliometric analysis; research hotspots; trends; coastal building; Web of Science; CiteSpace

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1. Introduction

Coastal areas are commonly defined as transitional zones or interfaces between land and sea, which also encompass expansive inland lakes [1]. Coastal improvement is inevitable, with almost 60% of the population targeted along the shoreline and the developing risk of rising sea levels and improved storms [2]. Sea level rise poses a major challenge to coastal landscapes and communities. Sustainable adaptation to sea level rise has been a growing concern for coastal management authorities, engineers, ecologists, urban planners and designers [3]. The coastal building is of great importance for sustainable and energy development. Coastal building hotspot issues are mainly related to urbanisation, sea level rise, natural disasters and environmental pollution [4], which pose a major challenge to sustainable and energy development and therefore need to be explored in depth.

In 1974, the United Nations Environment Programme (UNEP) launched the Regional Seas Programme [5]. This led the countries in the region to take holistic and explicit action in response to the continuing deterioration of the marine and coastal environments. In 1997, researchers gradually examined the impact of urban development on runoff and infiltration, moving towards water-sensitive urban planning (WSUP) [6]. In 2002, researchers considered the oceans a two-module system consisting of ecosystems and organisational patterns for a more scientific analysis of the characteristics of marine systems [7]. In 2012, predictions of the state of the coastal ocean at different time scales were performed through the validation of remote sensing data, ocean and atmospheric model analysis, which are essential for the welfare of coastal populations and energy, as well as the socio-economic development of the country [8]. In the 2015 UN Climate Conference [9], 90 countries included actions related to reducing emissions from buildings or improving sectoral energy efficiency in their nationally owned contribution targets (NDCs) under the Paris Agreement. The fourth session of the United Nations Environment Assembly 2018 announced the implementation of the Towards a Zero Pollution Planet implementation plan [10]. In the study, ecology is integrated into the framework of coastal infrastructure, and ecologically sensitive design and concrete technology are employed in coastal buildings to enhance the organic and ecological value of their form while also ensuring structural integrity [11]. In 2021, the IOC issued a 10-year plan for sustainable development (2021–2030) [12], which determined the carbon sequestration potential and optimal location of marine protected areas. In 2022, researchers were concerned with integrating mobile configurations to create a smart coastal city [13]. Greater attention has been paid to environmental pollution in coastal areas. Research on controlling and reducing emissions from buildings and industry, as well as enhancing the management and protection of water resources, is vital for achieving sustainable development and energy security in coastal areas.

A search conducted on Web of Science and Scopus using the keywords "coastal building review" revealed a lack of existing studies specifically focusing on "coastal building". The majority of studies found were primarily centred around topics such as coastal erosion, coastal spatial data and coastal management. However, in this paper, the term "coastal building" primarily pertains to coastal structures, coastal building practises and coastal engineering, which include a broad range of constructions beyond traditional buildings. The term "coastal structures" specifically refers to human-made structures like seawalls, breakwaters, and other coastal defence structures that are designed to mitigate coastal erosion, storm surges and flooding.

While factors like coastal erosion and marine data are significant aspects of coastal building research, they are typically examined and assessed in isolation. This paper sets itself apart from existing studies by integrating these factors with other relevant aspects of coastal building research. By adopting a holistic perspective and approach, this paper aims to provide a comprehensive understanding of coastal building trends and challenges, avoiding the limitation of focusing solely on one aspect at the expense of others.

This paper uses data analysis tools to identify hidden trends and patterns more accurately than traditional literature reviews and qualitative research methods. Complex network analysis is an effective way to achieve this due to its powerful data organisation and visualisation capabilities. The Citespace visual analysis used in this study focuses more on the presentation of timelines, allowing for the presentation of time, frequency and centrality as well as phrase clusters simultaneously. Compared to descriptive research, data visualisation provides a more intuitive understanding of the knowledge structure and trends in the field of coastal building research, providing researchers with more comprehensive and objective reference information.

Therefore, an in-depth study of coastal building hotspots better demonstrates the challenges to sustainable energy development in coastal areas, explores effective solutions, and contributes to the achievement of sustainable development and energy security in coastal areas.

To date, the development of coastal buildings has been diverse, moving from a psychological to an ecological to a smart building dimension. The analysis of the existing literature majorly suggests the main authors, institutions, keywords and categories to further explore the possible trends of coastal building. In this study, a bibliometric and visual evaluation of the literature available in the Web of Science core collection database was conducted using the knowledge model created by CiteSpace. This analysis aimed to assess the current state and potential future trends in coastal building development. The database used to be searched for the final thirty-five years (1988–2023) with 'coastal' and 'building' as search topics. This study analysed a dataset consisting of 2067 records, with only one record falling outside the time period of 1988 to 2023. To ensure a comprehensive and inclusive study, no literature was excluded or removed. Mapping and analysis techniques were employed to investigate global hotspots and trends.

2. Data and Method

2.1. Data Source

The scope of this paper is primarily concerned with coastal structures, coastal building and coastal engineering, including but not limited to buildings in the general sense, hence the keyword "coastal building".

The Web of Science search system is recognised as authoritative, and it is a limitation that the Scopus database cannot be used for co-occurrence analysis in academic areas when using the Ciespace visualisation software. Therefore, to ensure the accuracy and comprehensiveness of the data, only the Web of Science database was used in this study.

This study used the Web of Science (including SCIE, SSCI, A&HCL, ESCI, CCR and IC databases) to search for research articles, conference proceedings papers, conference abstracts and review papers from 2023 to 1988 with the themes of "coastal" AND "building". The search date was 16 March 2023. This search includes English publications only.

The dataset contains a total of 2067 records, with all but one falling within the period of 1988 to 2023. Most of the records are proceedings papers, with a total of 1627. There are also four hundred and thirty-nine articles and proceedings papers and two meeting abstracts included in the dataset. This study encompassed all areas related to coastal building, and therefore no deletions were made to the literature to ensure that the study was comprehensive and inclusive. Deletions from the literature may have resulted in under-research of certain sub-fields or specific topics, thus compromising the accuracy and completeness of this study.

2.2. Method

CiteSpace R6.1 (hereafter referred to as CiteSpace) is a software tool developed by Chao-Mei Chen for identifying scientific literature and visualising trends and dynamics in citation networks, enabling further analysis and exploration [14]. CiteSpace utilises cluster evaluation as its underlying algorithm to generate multi-perspective visualisations of literature co-citation analysis, enhancing the interpretability of author co-citation and literature co-citation networks [15,16].

CiteSpace is based on several algorithms and principles to achieve these goals:

- Kuhn's theory of paradigm shifts in scientific revolutions: the concept that scientific advancement is driven by ongoing scientific revolutions. In CiteSpace, this theory is reflected in the clustering of literature data by time period to reflect the rise, fall and alternation of different paradigms [17].
- Burt's structural hole theory: This theory examines the relationship between the position of individuals in a social network in terms of network position and the quality of opinions/ideas. In CiteSpace, this theory is reflected in the search for nodes with high mediated centrality [18].
- Optimal information foraging theory by Pirolli: CiteSpace applies optimal information foraging theory to explain the way researchers make decisions in information search. This theory is used to help researchers find the most relevant and valuable research topics and hotspots in the vast literature [19].
- Kleinberg's algorithm for detecting frequency surges: CiteSpace uses Kleinberg's algorithm for detecting frequency surges, which is used to detect sudden increases in the frequency of citations. When the citation frequency of a paper increases dramatically over a certain period of time, this often indicates that the paper is making an impact in a key position in the academic field [20].
- Structural Variation Theory: CiteSpace uses structural variation theory to measure the degree of modularity of networks and the impact of local structural changes on the overall structure, revealing important structural changes in academic fields [21,22].

In this paper, we use the Cosine method in CiteSpace to calculate the connection strength of the network as follows [23]:

$$Cosine\left(c_{ij}, s_i,\ s_j\right) = \frac{c_{ij}}{\sqrt{s_i s_j}} \tag{1}$$

In Equation (1):
c_{ij}—Number of co-occurrences of s_i and s_j
s_j—Frequency of occurrence of j
Centrality can be used as a measure of the importance of a node in the network and is used by CiteSpace to discover and measure the importance of documents, which are labelled with purple circles. Centrality is calculated using the following formula [23,24].

$$BC_i = \sum\nolimits_{s \neq i \neq t} \frac{n_{st}^i}{g_{st}} \tag{2}$$

In Equation (2):
g_{st}—The number of shortest paths from node s to node t
n_{st}^i—Number of shortest paths through node i out of the g_{st} shortest paths from node s to node t.
The higher the intermediary centrality, the greater the importance of the node.
Feature vector centrality (also known as feature centrality) is a measure of a node's influence in a network. It is calculated as follows:

$$x_i = c \sum\nolimits_{j=1}^{N} a_{ij} x_j \tag{3}$$

In Equation (3):
C—Constants
$(A = a_{ij})$—Adjacency matrix of the network.
$(A = a_{ij})$ also counted as $x = [x_1 x_2 \cdots x_n]^T$, i.e.,

$$x = cAx \tag{4}$$

In Equation (4):
x is the eigenvector corresponding to the matrix A with eigenvalue $c - 1$, so this algorithm is called eigenvector centrality [23].
The keyword co-occurrence study in this paper refers to the higher-than-accidental frequency of two terms appearing side-by-side with each other in a particular order in a text corpus [25]. By analysing co-occurring keywords, we can identify correlations between different keywords and better understand and explore the knowledge structure and research dynamics of a particular field.
The clustering labels were extracted using the LLR (Log Likelihood Ratio) algorithm, which is a statistical method used to calculate the co-occurrence of associations between two items (keywords, words or entities) in a given data set [26]. The LLR algorithm can assess the significance of co-occurrence associations more accurately than other algorithms.

$$LLR = log \frac{p\left(C_j \backslash V_{ij}\right)}{p\left(\overline{C_j} \backslash V_{ij}\right)} \tag{5}$$

In the Equation (5):
LLR—Log-likelihood ratio of word W_i for category C_j
$p\left(C_j \backslash V_{ij}\right)$-Density functions in the category C_j
$p\left(\overline{C_j} \backslash V_{ij}\right)$—Density function in the category $\overline{C_j}$
The analysis flow based on the above algorithm and principles is shown in Figure 1. Network scaling in CiteSpace refers to the process of pruning a network to reduce the number of links while retaining the most salient ones. One specific approach to network

scaling is called Pathfinder network scaling. It involves creating a Pathfinder network, which is the combination of all the minimum spanning trees of the original network [27]. The use of network scaling, such as Pathfinder network scaling, in CiteSpace allows researchers to address the issue of excessive links in a network, especially when the total number of links is high [28,29]. By pruning the network, the most significant and relevant connections are retained, providing a compromise between a network with too many links and a potentially arbitrary minimum spanning tree [30]. In summary, through network pruning, we retain only the most important and relevant links, resulting in a clearer and more comprehensible representation of relationships in the literature. This approach allows for a better understanding of the significant connections and influences in the literature.

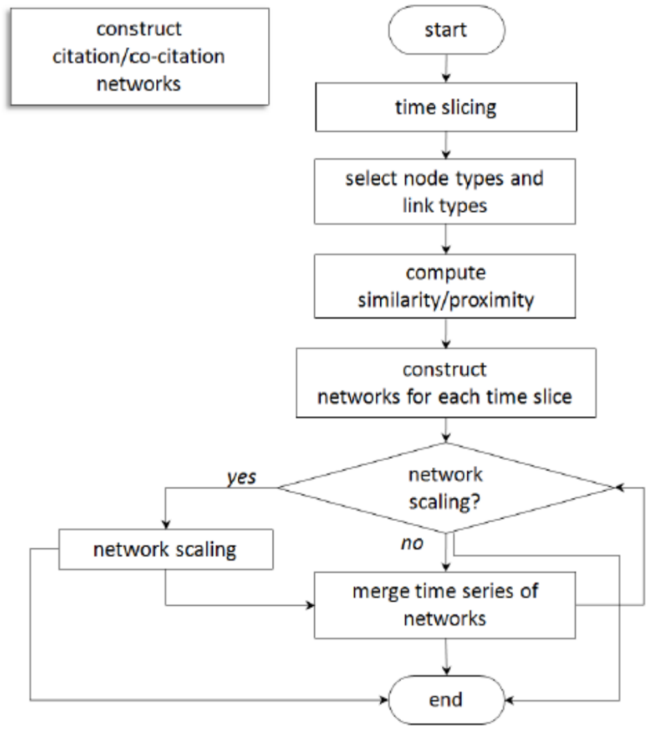

Figure 1. CiteSpace's analysis flow chart [31,32].

In this paper, the collected data is first formatted. The literature section adopted the de-duplication function in CiteSpace. The time slice was one year, and clustering was performed using the LLR algorithm. Timeline and cluster views were employed for this study. After unduplicated access to standard format data, CiteSpace was used to visualise and analyse 2067 documents from the Web of Science core collection in the discipline of coastal building. The methodology summarises the common occurrence of main research countries and institutions, main authors, main journals and keywords worldwide.

Overall, the methodology provides a series of metrics and analytical tools that are important for the quantitative analysis and evaluation of this paper, helping us to identify key research topics and thus grasp the evolution of research hotspots, which is very useful in guiding our research and planning.

3. Results and Analysis

3.1. Current Situation

To analyse the vitality and potential of research in the field of coastal building, a bibliometric and visual analysis of the literature in the Web of Science Core Collection database was carried out to determine the distribution of articles in terms of frequency of citation and frequency of publication by year, covering the period 1988 to 2023. As shown in Figure 2.

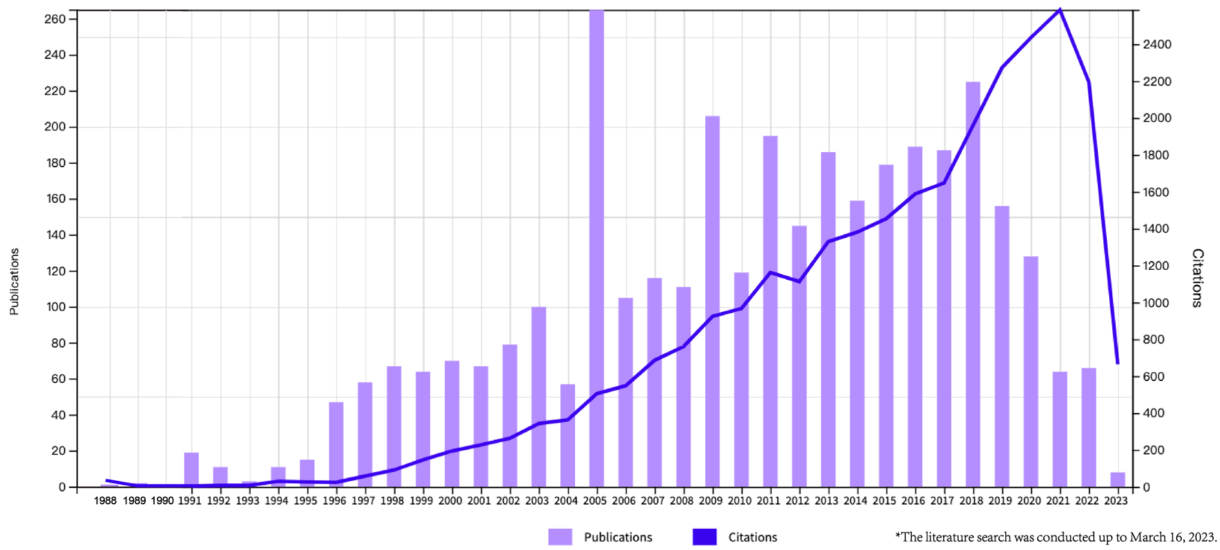

Figure 2. Graph of the number of articles and citations for the topic "Coastal building" generated from the Web of Science database.

3.1.1. Coastal Building Topic Publication Volume

Figure 2 reveals a gradual increase in the number of papers published from 1998 to 2009 and 2011, followed by a rapid increase from 2015 to 2019, followed by a gradual decrease, which would coincide with the "Philippine Green Building [33]". This may be related to the promulgation of the Paris Agreement under the United Nations Framework Convention on Climate Change (Abbreviated as UNFCCC) in 2015, commonly referred to as the CODE (Conference of the Parties to the UNFCCC), and the UN Climate Conference in 2015 [9], which emphasised the reduction of emissions in the building sector or the improvement of energy efficiency in the sector, and the increasing research on green building design adapted to the natural climate environment attributed to the clearer standardisation and policy support for green buildings. The COVID-19 epidemic had a huge global impact in 2020, leading to the closure or restriction of many research institutes, laboratories and universities. Delays in research projects, restrictions on researchers and the unavailability of laboratory equipment may have led to a reduction in the number of new research results and papers. According to a report by the European Association for International Education (EAIE), a study of 805 people in 38 countries highlighted concerns about the short- and long-term impact of the outbreak crisis in various areas, including contingency measures, long-term planning, partnership management, student mobility, management of technical aspects and effective communication with stakeholders. The impact of the outbreak on research output is felt in a number of ways. In addition, researchers may need to shift to COVID-19-related research in order to respond to the immediate needs of the outbreak [34]. This is therefore one of the reasons for the decline in research related to coastal building in 2020 and beyond. However, there is still an overall emphasis on tackling climate change, so the literature related to climate change appears most frequently. And the observed decrease in the number of works from 2022 to 2023 can be attributed to the search period ending on 16 March 2023, which limited the inclusion of recently published works.

3.1.2. Main Research Countries and Institutions

The author-country network map generated in CiteSpace, shown in Figure 3, yielded 813 country nodes and 1527 collaborative links between countries. The size of a node in the network corresponds to the volume of articles published by a particular country, with larger nodes indicating a higher publication volume. The first author is usually considered to be the main representative of the country or region to which the paper relates. This approach allows the affiliation of authors to be determined and facilitates the analysis of patterns of collaboration at the national level. A graph of trends in the main posting countries generated from the literature data is depicted in Figure 3. A statistical summary of the literature about coastal building over the final thirty-five years has yielded the top ten countries in the number of papers published. These include the USA (342), China (292), Italy (160), Indonesia (140), France (95), England (86) and Australia (77). China has published the most papers in the field of coastal building in the last 10 years, accounting for 17.4% of the total number of papers.

The literature was statistically summarised, and the institutions with the highest number of published articles were obtained. The top five research institutions with the most published papers were the Chinese Academy of Sciences (China, twenty articles), Diponegoro University (Indonesia, sixteen articles), Consiglio Nazionale delle Ricerche (CNR) (Italy, fifteen articles), Delft University of Technology (Netherlands, fourteen articles), and Tianjin University (China, eight articles). These institutions have been major centres of coastal building research since at least 1988. Emerging institutions in 2019 comprise the Indian Institutes of Technology (India), Universitas Gadjah Mada (Indonesia), Bogor Agricultural University (Indonesia) and Auburn University (USA).

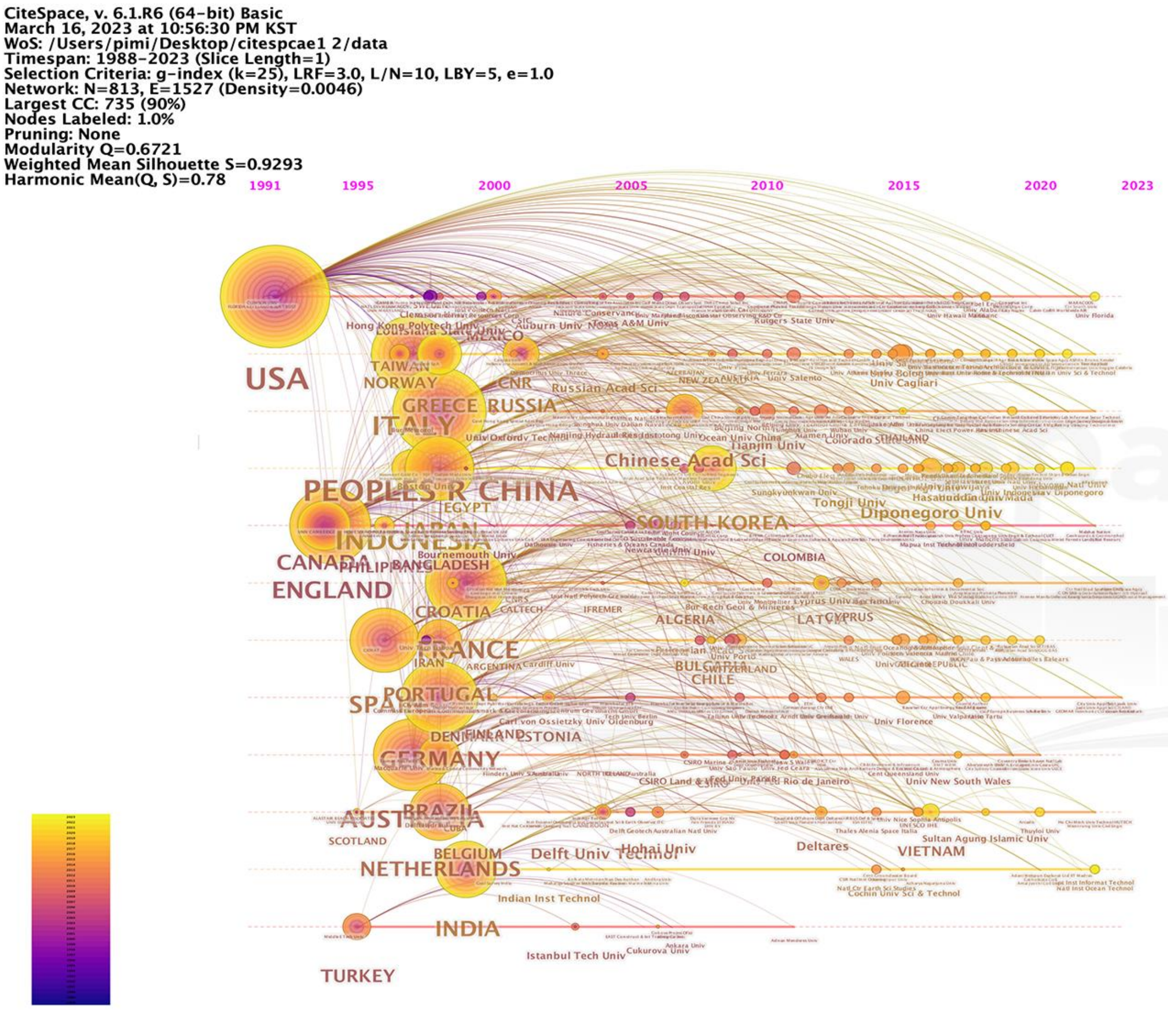

Figure 3. Timeline mapping of the main published countries generated by CiteSpace.

3.1.3. Main Research Direction and Field

Table 1 demonstrates that the main research directions for the coastal building theme include Environmental Sciences (466 articles), Geosciences Multidisciplinary (325 articles), Engineering Civil (306 articles), Water Resources (242 articles), Remote Sensing (195 articles), Oceanography (192 articles), Geography Physical (189 articles), Engineering Environmental (157 articles), Engineering Electrical Electronic(153 articles) and Engineering Ocean (153 articles).

Table 1. Main types of research based on the Web of Science database.

Web of Science Category	Records	2068 Percentile
Environmental Sciences	466	22.534%
Geosciences Multidisciplinary	325	15.716%
Engineering Civil	306	14.797%
Water Resources	242	11.702%
Remote Sensing	195	9.429%
Oceanography	192	9.284%
Geography Physical	189	9.139%
Engineering Environmental	157	7.592%
Engineering Electrical Electronic	153	7.398%
Engineering Ocean	153	7.398%

The literature about coastal buildings has the highest number of publications in the direction of Environmental Sciences, accounting for 22.534% of the total publications. This indicates the growing interest of researchers from different countries in the field of coastal environments, which can be attributed to the expanding development of commercial and residential areas, agriculture, animal husbandry, and soil and sediment erosion in coastal regions [35].

Therefore, the dimensions of environmental problems in the coastal zone [36], the state of coastal research, specific modelling needs, the analysis and management of pollution problems, and the state of research funding should be researched [37]. Moreover, research areas such as coastal marine environmental management and governance, novel applications of geoprocessing and Geographic Information System (Hereinafter referred to as GIS) technology, beach management, and water quality assessment are all important subjects within the realm of environmental science [38].

3.1.4. Main Journal Sources and Researchers

After the number of publications in the 2067 annotated documents was counted, the main journal sources and related information were summarised. The main literature journals are the Journal of Coastal Research (105 articles) and the IOP Conference Series: Earth and Environmental Science (85 articles), Oceans IEEE (79 articles) and Proceedings of SPIE (67 articles).

The authors with the highest number of publications retrieved by Web of Science mainly include Li Yue (Case Western Reserve University, nine articles), Chen Jie (Tongji University, six articles), Robertson Ian N. (University of Hawaii Manoa, six articles), and Zhang Yong (State Grid Corporation of China, six articles). The statistics imply that the most active researchers in the final thirty-five years are concentrated at the Centre National de la Recherche Scientifique (CNRS) in France and the Chinese Academy of Sciences (Abbreviated as CAS) in China.

The author collaboration analysis generated from the Coastal building citation is shown in Figure 4. The analysis of collaboration patterns and networks between authors reveals the dynamics of collaboration and cooperative relationships in the research field. The network consists of 855 nodes and 585 links, with the nodes representing the corresponding authors and the links indicating the existence of a collaborative relationship between two authors. The density statistic represents the proportion of possible relationships that actually exist in the network and takes values from zero to one [39]. When the network density is close to one, there are a large number of connections between the nodes in the network, and the network is very dense; when the network density is close to zero, the nodes in the network are sparsely connected to each other, and the network is loose. The network density is 0.0016, which indicates that the author collaboration network is very loose and that the collaboration between authors needs to be strengthened. Modularity (Q) is an evaluation metric for the modularity of the network, with Q > 0.3 implying that the structure of the obtained network associations is significant. The network density of the graph is 0.9575, indicating that the network has a good association structure and suggesting that good collaborative networks have been established between some of the authors. The average Silhouette (S) is a measure of network homogeneity, and the closer it is to one, the higher the homogeneity of the network. The average Silhouette value of one indicates that the collaboration patterns among the authors are very consistent and similar, with no significant differences and a focus on a specific research area.

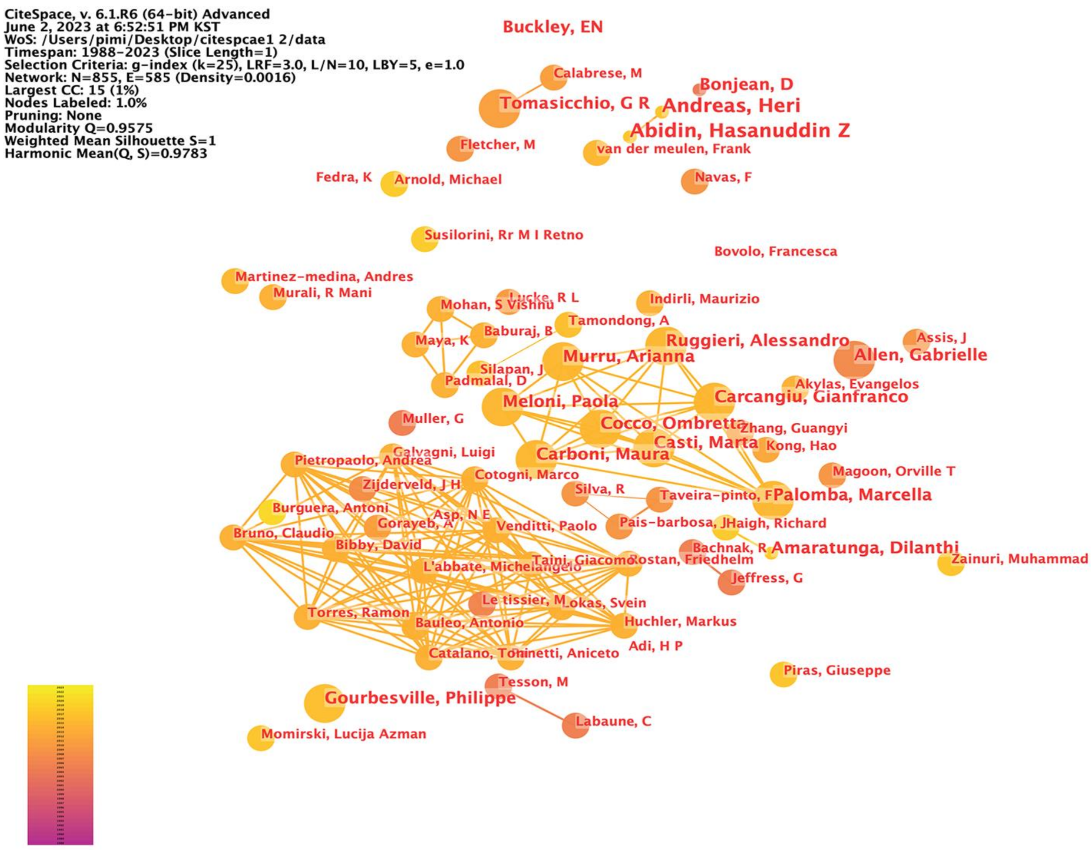

Figure 4. Author collaboration analysis graphs generated from the cited literature.

Prof. Bibby David of the European Space Agency, Prof. Rostan Friedhelm of Airbus Defence and Space GmbH, Prof. Lokas Svein of the European Space Agency, and Prof. L'abbate_Michelangelo of Thales Alenia Space Prof. L'abbate_Michelangelo of Italia and more than ten other professors have worked on projects such as the Copernicus Sentinel-1 Earth Radar Observatory for global mapping and route monitoring of land and coastal areas [40]. The geotechnical materials and decay forms of coastal towers have been studied by Prof. Gianfranco Carcangiu of the Italian National Research Council in collaboration with Prof. Meloni Paola, Prof. Ombretta Cocco and others from the University of Cagliari [41]. Collaborative research between Professor Vishnu Mohan S of the University of Kerala and Professor kk Maya of the Centre for Earth Science Studies reveals the impact of heavy rainfall in river catchments and early to mid-Holocene sea level rise on the development of deltaic regions [42]. The collaboration between Prof. Heri Andreas of the Institute of Technology Bandung and Prof. Hasanuddin Z. Abidin of the Institut Teknologi Bandung is evident in their joint article, "Land subsidence of Jakarta (Indonesia) and its relation with urban development," published in 2011. In this work, they proposed for the first time that the spatial and temporal variation of ground subsidence depends on the corresponding changes in groundwater extraction as well as on the characteristics of the sedimentary layers and the building loads above them. The close relationship between ground subsidence and urban development activities in Jakarta was demonstrated [43]. The study has been cited 386 times and has had a wide impact on the fields of geology and coastal civil engineering.

In summary, the collaboration patterns among authors primarily involve individuals within the same disciplinary fields, institutions, and countries, encompassing diverse domains such as aerospace technology, earth sciences and geotechnical engineering. While scholars have actively collaborated within their respective fields, the absence of interdisciplinary collaboration may hinder the capacity to address complex problems in an integrated manner. Consequently, fostering interdisciplinary collaboration, transcending disciplinary boundaries, facilitating resource sharing, and cultivating interdisciplinary researchers emerge as vital avenues to drive the advancement and innovation of academic research.

The higher number of citations usually reflects the degree of influence and contribution of an author in the academic community. To explore the main core authors in the field of coastal building, we calculated author co-citation relationships, as shown in Figure 5. Two or more authors are said to constitute a co-citation relationship if they are cited in one or more papers at the same time. The calculation is shown in Figure 5. Only first-author co-citations are considered when calculating author co-citations in CiteSpace software, and the same author is cited more than once in the same paper.

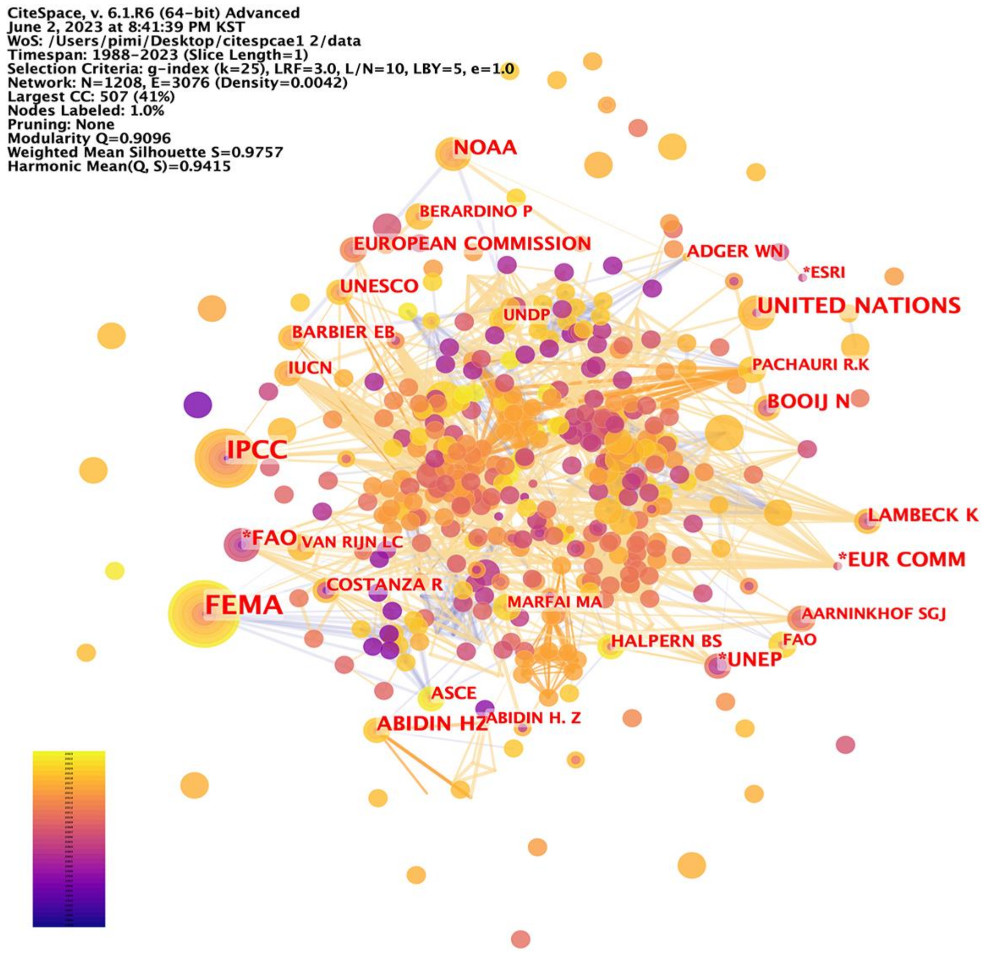

Figure 5. Author co-citation relationships calculated with CiteSpace. (Symbols '*' represent abbreviated terms).

In summary, we can identify the core authors in the field of coastal building according to their total number of citations. At number one is the Federal Emergency Management

Agency, with twenty-two citations. Number two is the Intergovernmental Panel on Climate Change, with eighteen citations. Number three is the United Nations, with twelve citations. Number four is the Food and Agriculture Organisation of the United Nations, with ten citations. Number five is the European Commission, with nine citations. These major co-cited authors are all important international organisations or institutions, indicating that their research and work are influential in the development and decision-making in the field of coastal construction. They have been influential in a wide range of disciplines, including emergency management, climate change, international cooperation, food security and policy development. However, the lack of participation from individual authors in academia can lead to specific academic research and innovations being overlooked or underexplored in the development of the field.

3.2. Coastal Building Hotspots

Keywords can provide a high level of summarization of the content and ideas of a study. Therefore, the keyword clustering co-occurrence analysis is performed to reflect the hotspots and find the keywords with the highest overlap. The data were imported into CiteSpace software, and the nodes were analysed using the Minimum Spanning Tree algorithm, with a time span of 1988–2023, a time partition of 1 year, a node type of keyword, and a threshold of TOPN = 50. The Pathfinder algorithm was used to crop the composite time slices, resulting in a keyword co-occurrence map with 1163 nodes and 3681 lines, as exhibited in Figure 6.

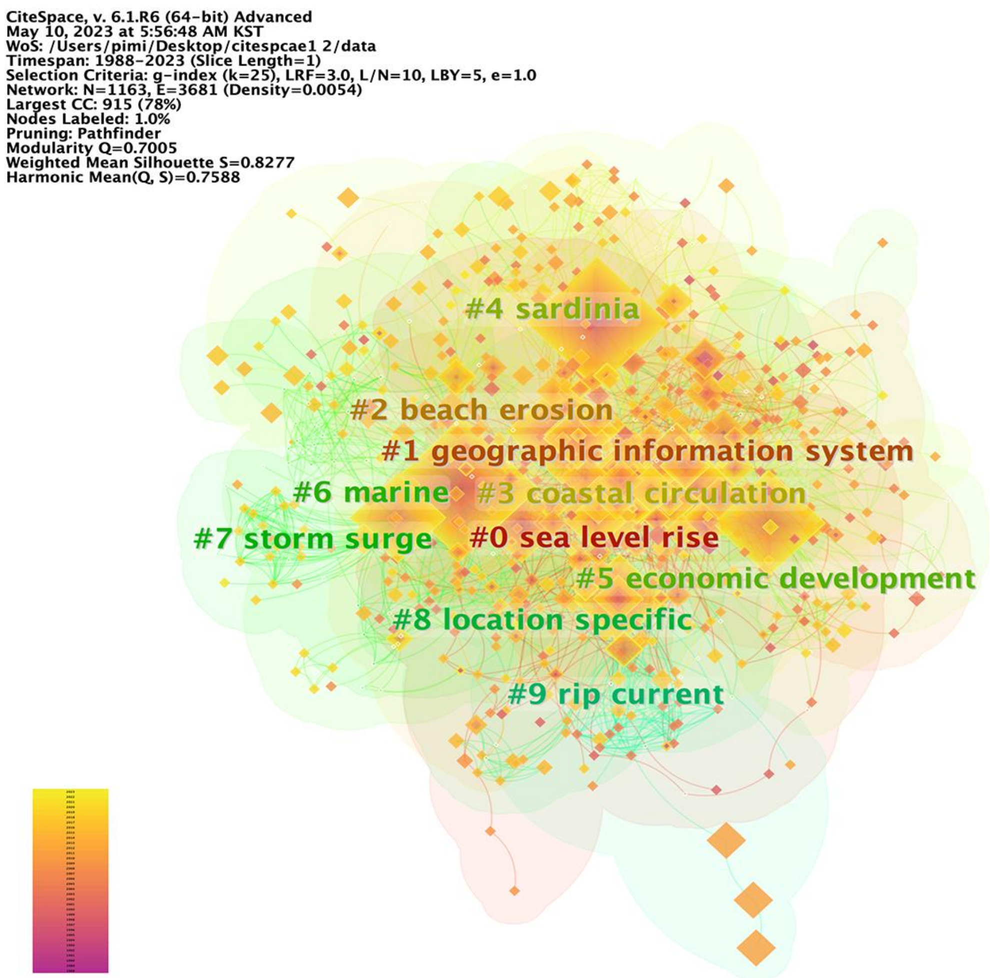

Figure 6. Keyword co-occurrence and clustering diagrams in the field of coastal building research.

In this figure, each keyword is represented by a circular node; the larger the circle, the more frequently the keyword appears in the research field, that is, a high-frequency keyword. The node with the purple circle is the most crucial since it represents a keyword with a high degree of centrality, indicating a high degree of association with other keywords.

The keyword clustering, excluding the topic itself, is mainly reflected in sea level rise, geographic information systems, beach erosion, coastal circulation, Sardinia and economic development. With the most frequent keywords as criteria, the keywords are clustered in the earliest years that contain dates, as these keywords are also grouped into years of occurrence in subsequent applications.

High-frequency keywords are listed in Table 2. Specifically, the high-frequency keywords for coastal building are organised according to their centrality. Apart from the topics themselves, the main keywords are coastal cities, climate change, sustainable development, coastal environment and sea level height. The top 10 high-frequency keywords are mainly related to a wide range of coastal areas, characterised by their early appearance and the general similarity of the high-frequency studies found in the final thirty-five years, as well as the absence of specific implementation strategies and technologies for coastal building in the content of the keywords. Thus, this needs more in-depth discussion.

Table 2. Top 10 high-frequency keywords (by centrality).

Serial Number	Frequency	Centrality	Average Year of Keyword Occurrence	Keywords
1	371	0.19	1992	coastal area
2	162	0.15	1996	coastal zone
3	112	0.12	1994	coastal region
4	101	0.08	1996	climate change
5	89	0.11	1998	sustainable development
6	67	0.09	2002	coastal city
7	60	0.09	1998	coastal water
8	56	0.03	2004	coastal community
9	53	0.09	1998	coastal environment
10	46	0.05	1996	sea level rise

The top ten keyword clusters calculated based on the LLR (Log-Likelihood Ratio algorithm) are described in Table 3. The keyword co-occurrence clusters were sorted and ordered from largest to smallest, resulting in the following 10 clusters: sea level rise, integrated coastal management, coastal structure, upper semi-arid sub-catchment, land subsidence, coastal ocean, coastal area, building scale, marine infrastructure, and geographical information system.

Table 3. Keyword co-occurrence clustering (based on the LLR algorithm).

Cluster ID	Size	Silhouette	Label (LLR)	Average Year
0	122	0.707	sea level rise	2009
1	94	0.759	integrated coastal management	2008
2	94	0.814	coastal structure	2008
3	92	0.806	upper semi-arid sub-catchment	2012
4	88	0.89	land subsidence	2009
5	83	0.78	coastal ocean	2009
6	77	0.837	coastal area	2007
7	66	0.859	building scale	2015
8	49	0.823	marine infrastructure	2010
9	40	0.928	geographical information system	2009

As a result, the construction of coastal buildings has been more widely discussed in relation to the effects of global climate change than economic development, with issues such as coastal erosion induced by sea level rise becoming a priority for coastal buildings. There has been an increase in research related to the upper semi-arid sub-basins since the last decade (around 2012). In that area, the planning of buildings and infrastructure must consider the scarcity of water resources and the risk of land subsidence. In this context, GIS data and analyses should be considered to reveal the impact of factors such as land subsidence and shoreline change on buildings and infrastructure. By around 2015, the discussion of the different characteristics of the coastal zone had been refined in the studies on the scale of construction in the coastal zone.

Figure 7 presents the keyword co-occurrence timeline mapping. By clustering the terms, 14 main clusters were identified, and a timeline map was generated. The longest-lasting cluster was 'marine' (1990–2022), which was present throughout most of the study period. This was important in that it underpins the entire field of coastal building research. Early terminology for the cluster included terms of a broad nature, such as coastal modelling [44,45] slam and desalination. In the medium term (upswing), specific strategies such as application systems, dynamic data, neural networks and coastal aquifers are attracting attention. The focus on climate change is present throughout the timeline. "Sea level rise" (1995–2021) is the term selected in this paper to describe the largest cluster according to the objectives of this study. It emerged earlier and has also been developed as a new research area in recent years. "Geographic Information Systems" (1996–2020) is the second largest keyword cluster in the field of coastal construction. It appears early in the literature and is very actively researched, indicating its importance and the frequency and prominence of research in the field. The aim of the cluster is to enhance the climate resilience of coastal buildings by applying, for example, coastal management strategies to best adapt to these observed and potential future impacts [44]. "Economic development" (1992–2023), "beach erosion" (1995–2021), "storm surge" (2001–2022) and "geographic information" (1995–2020) are four vital clusters with a growing number of related research strategies.

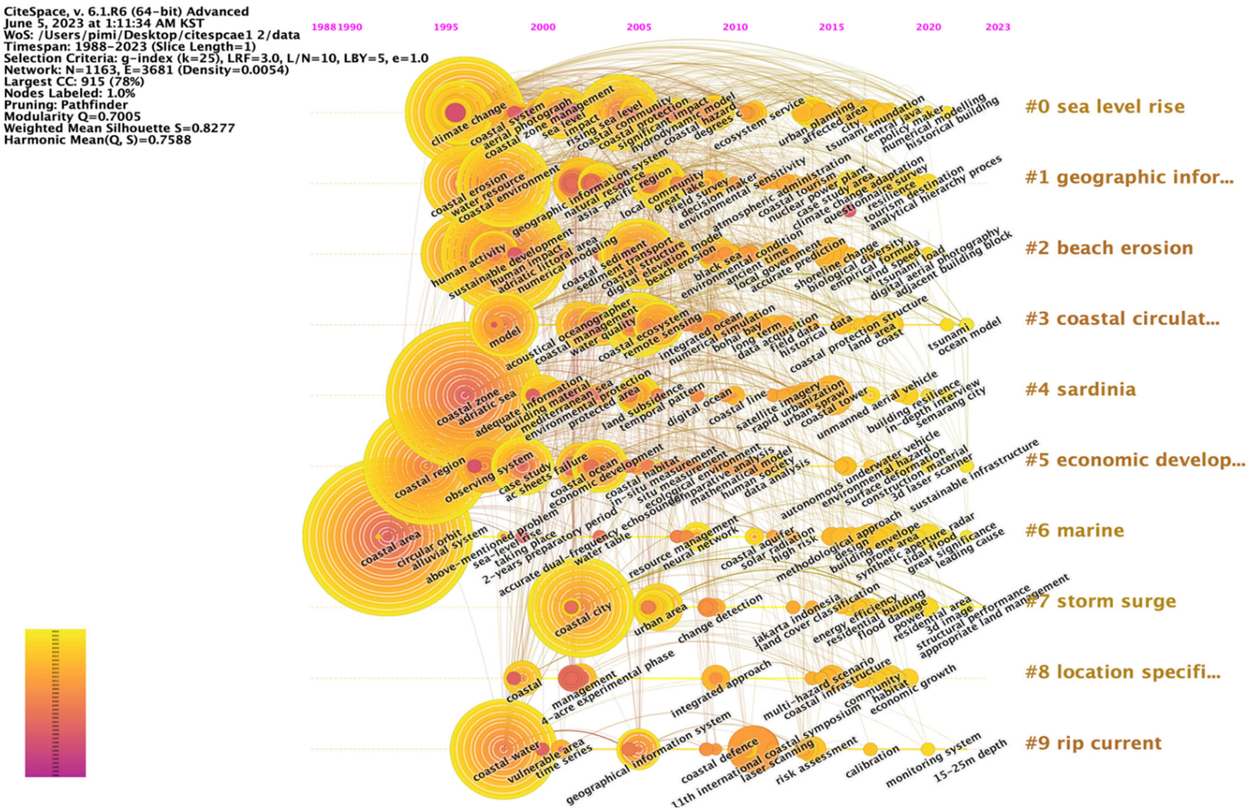

Figure 7. Keyword co-occurrence timeline mapping.

3.2.1. Sea Level Rise Projections and Strategies

In 1996, Jallow et al. utilised aerial video-assisted vulnerability analysis (Abbreviated as AVVA) techniques to assess the vulnerability of coastal areas to sea level rise and identified adaptation strategies consisting of sand management, construction and rehabilitation of berms, public outreach and awareness, building codes, wetland protection and mitigation, and the development of coastal zone management plans [45]. In 2009, Sales Jr. et al. proposed a local framework for integrating adaptation strategies and actions into integrated coastal management (abbreviated as ICM) planning [46].

In 2016, Pintado et al. emphasised the importance of scale and resolution and the use of accurate and local regional datasets when dealing with coastal systems. The need to understand the spatial and temporal variability and non-linear responses of coastal protection services when developing coastal and marine management strategies was also highlighted [47]. In 2017, Matthew Jurjonas and Erin Seekamp presented the Rural Coastal Community Resilience (RCCR) framework, which suggests that local priorities include sustaining rural livelihoods, creating jobs and addressing highly vulnerable groups [48]. In 2018, Rizzo et al. provided detailed marine flooding predictions for 2100 and developed a new inundation prediction model based on predicted spatio–temporal coastal changes to support coastal management under sea level rise conditions in the coming decades. It was demonstrated that sea level rise can lead to associated morphological changes on the investigated coasts, with a maximum beach retreat of 27 m and land loss of 7400 m, impacting architectural integrity and human safety [49]. In 2019, Kuhl et al. proposed a global context identifying potential areas of underinvestment in coastal adaptation in developing countries, while no recommendations were made for coastal building development. The study stressed the need to address climate change and development priorities by coordinating a broad range of adaptive capacities [50]. In 2020, Hai et al. created flood maps caused by strong typhoons under three different scenarios for the coastal area of Khanh An County, Vietnam, using MIKE and ArcGis [51].

In 2021, Chávez et al. used finite element modelling to estimate the performance of buildings. This numerical simulation-based analysis provides researchers with a means of assessing the behaviour of buildings under seismic and other external loads. Such an approach could provide guidance for the design of more resilient and adaptive buildings [52]. In 2022, Yang et al. explored the possibility of creating zero-carbon zones in the ocean by reviewing existing research papers on floating cities and carbon neutrality and finally proposing alternative energy sources and design approaches for ocean cities [53].

To sum up, first, there is a significant relationship between coastal building and sea level rise. The value of accurate dynamic data collection, monitoring and modelling of coastal areas is noticeable. In recent years, climate hazards such as coastal flooding have become an essential area of prediction.

3.2.2. Geographic Information Systems

In 1996, Werner K. Illenberger of the University of Port Elizabeth provided geographic data on landscape evolution and explored the correlation between landforms and geographic processes, which are essential for effective risk assessment and adaptation planning in coastal construction. These results are useful for the integration of geomorphological analysis, geomorphological modelling and geographic processes in the field of GIS [54].

In 2002, Rejoice Mabudafhasi provided useful experience and guidance on the application of GIS in sustainable development and regional planning through the introduction of knowledge management and information-sharing mechanisms, which had a positive impact on enhancing capacity and promoting sustainable development in the field of GIS [55].

In 2006, Al-Barwani Hamdi H. and Anton Purnama looked at the impact of saltwater discharge from coastal desalination plants on eroding beaches and proposed an approach that combined GIS and mathematical modelling [56].

In 2008, the study conducted by Budetta et al. utilised a wide range of geographical, geological and environmental parameters. These parameters were combined with historical data on landslide events to develop a comprehensive model for assessing landslide hazards through interaction and weight assignment. The assessment results and relevant data were integrated into a GIS to establish a spatial database incorporating geological and geomorphological features, historical landslide data and landslide hazard index values. This study presents a significant tool and methodology for the assessment of landslide risks and the management of geological hazards [57].

In 2010, Rochette et al. conducted research that developed a habitat suitability model based on bathymetry and sediment structure using GIS technology. This model offers a novel approach for integrating data, conducting analysis, and providing decision support in the field of GIS [58].

In 2011, Alves et al. developed a decision support system using GIS for coastal erosion in the northwest coastal region of Portugal. The study improved the coastal zone risk map developed in 1998 by applying GIS and vulnerability modelling [59].

In 2015, Cigliano et al. promoted the use and development of GIS by examining the role of public science projects in policy development, education, community capacity building, site management, species management and research, and the results of this research have had a wide impact [60].

In 2015, Sabino et al. provided an integrated approach to assessing and predicting risks to coastal structures by combining consequence and risk maps with sensor data and risk determination methods [61].

Qu et al.'s research in 2019 utilised a large number of tide gauge station records and satellite altimetry data to conduct an integrated analysis of sea level rise. This approach to data integration and analysis is an important innovation for the field of GIS and can provide more comprehensive and accurate geographic data [62].

In 2020, a UN-funded study assessing the contributions of project proposals from 60 coastal adaptation projects (covering 39 countries and two regional projects) supported by multilateral adaptation funding found a general emphasis on climate-specific adaptive capacity, which differs from the widely discussed need for a synergistic response to climate change and development priorities. This provides an empirical study to advance the use of GIS in coastal adaptation [50].

From the above hotspot literature, we can see a continuing interest and shift in research in the field of GIS. From a focus on landscape evolution, geographic processes and landscape analysis to vulnerability modelling, risk assessment and decision support systems, and more recently to public science projects, risk prediction and sea level rise.

3.3. Research Trend

CiteSpace was used to generate the top 25 keyword highlighters. Figure 8 reflects that the field has progressed over time in different directions, with the last 5 years of research trends in coastal building including "natural disaster", "coastal community", "urban planning", "residential building" and "building material".

As revealed in CiteSpace's visualisation, future hotspots remain in the direction of coastal circulation, economic development, marine and storm surge. The key terms that have emerged in the last two years comprise machine learning, potential solutions, environment dynamics, remote sensing techniques, data assimilation, sustainable infrastructure, leading causes, structural performance and federal emergency management agencies.

In 2017, Saito et al. developed a model combining hygrothermal analysis with wood degradation processes to calculate the decay rate of building components and assess the effect of hygrothermal behaviour on structural performance [63]. In 2020, Deng et al. studied the causes of the Moranti disaster and analysed the situation, precipitation, wind, social conditions, built design, social prevention and education concerning the riskiness of hazard factors and the vulnerability of hazard carriers. The results unveiled many problems with building protection against typhoons in Xiamen. Corresponding and feasible protective measures and improvement schemes are proposed to minimise the damage to buildings in Xiamen under extreme typhoon conditions [64]. In 2022, Jorgenson et al. evaluated wind damage to tile roofs in Florida, providing insight into the diagnosis of wind-related deformation for the section of the Florida Building Code (Abbreviated as FBC) dealing with the repair of damaged tile roofs [65].

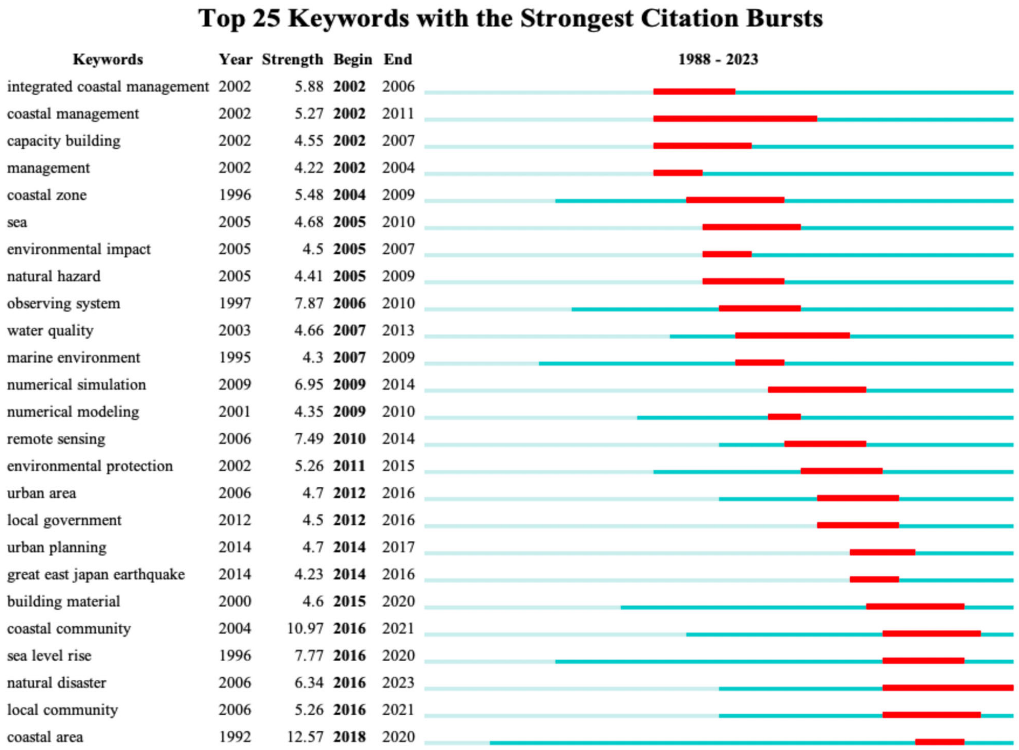

Figure 8. Top 25 highlighted keywords based on CiteSpace calculations.

To summarise, the recent construction of coastal buildings is still closely linked to urban climate hazards and sea level rise. Research in this field should focus on not only individual buildings but also the layout of building groups and local environmental characteristics, as well as the effects of coastal erosion and typhoons. In this way, dynamic data, neural networks and geographic information play crucial roles as methods and strategies. Additionally, there is significant interest in studying the corrosion of building materials and the performance of external structures in coastal buildings. Moreover, the role of coastal building construction in promoting urban economic development cannot be overlooked.

In order to visualise future research trends related to coastal building, we visualised keyword co-occurrences over the last five years from 2017 to 2013, yielding a total of 29 keyword cluster labels, which were cleaned up and pruned from smaller clusters, resulting in a final visualisation of 10 keyword cluster labels, as shown in Figure 9. The order is from zero to nine, with the smaller the number, the more keywords are included in the clusters, and each cluster is made up of multiple closely related words. S represents the average profile value of the clusters, where S > 0.5 is generally considered to be a reasonable cluster and S > 0.7 means that the clusters are convincing. Q represents the cluster module value, and Q > 0.3 is generally considered to be a significant cluster structure. This cluster has S = 0.9269 and Q = 0.8193, which is considered significant and reasonable. The top 10 keyword clustering labels were adaptation strategies, shoreline response, GIS, insar, machine learning, slam, unmanned aerial vehicle (UAV), tsunami and coastal erosion.

We have organised the keyword clusters according to the size of the clusters, from largest to smallest. The keywords within the cluster labels are some important terms or concepts related to the topic of the cluster, which can reflect the research hotspots and trends in the field. The contents of Table 4 were obtained.

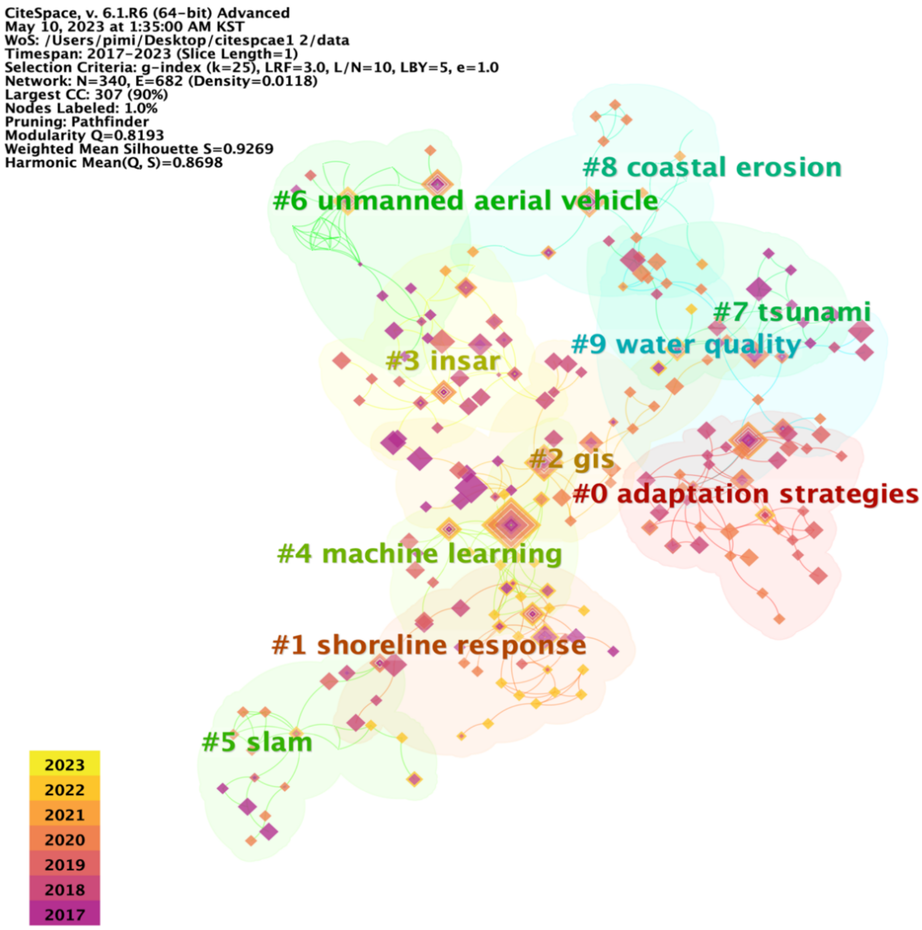

Figure 9. Top 10 keyword clusters for the last five years, from 2017 to 2013.

Table 4. Keyword clustering within the last five years (based on the LLR algorithm).

Cluster ID	Size	Silhouetee	Mean (Year)	Top Terms (LLR)
0	32	0.87	2018	adaptation strategies (9.68, 0.005); black sea (6.05, 0.05); opportunity (4.83, 0.05); small-scale fisheries (4.83, 0.05); coastal protection (4.83, 0.05)
1	29	0.98	2019	shoreline response (5.46, 0.05); designsafe (5.46, 0.05); multi-scale (5.46, 0.05); sustainable infrastructures (5.46, 0.05); shoreline change analysis (5.46, 0.05)
2	28	0.934	2018	GIS (11, 0.001); damage assessment (7.92, 0.005); flood (6.31, 0.05); reuse (5.79, 0.05); techno-economic analysis (5.79, 0.05)
3	27	0.811	2018	insar (10.37, 0.005); coastal flooding (10.37, 0.005); Ionian Islands in the region of Greece (5.17, 0.05); seismic risk (5.17, 0.05); adaptation measures (5.17, 0.05)
4	21	0.961	2019	machine learning (6.48, 0.05); flood mitigation (6.48, 0.05); sea level rise (4.57, 0.05); geospatial data (3.23, 0.1); iot (3.23, 0.1)
5	20	0.964	2019	slam (7.04, 0.01); neural networks (7.04, 0.01); classification (7.04, 0.01); underwater robotics (7.04, 0.01); neural network (7.04, 0.01)
6	19	0.887	2020	unmanned aerial vehicle (UAV) (5.07, 0.05); plant-sand interaction (5.07, 0.05); object-based image analysis (obia) (5.07, 0.05); renewable energy (5.07, 0.05); schedulability (5.07, 0.05)
7	18	0.886	2017	tsunami (11.03, 0.001); sea level rise (9.5, 0.005); flooding (7.34, 0.01); building (5.49, 0.05); community engagement (5.49, 0.05)
8	18	0.982	2020	coastal erosion (8.21, 0.005); remote sensing (6.58, 0.05); structural assessment (5.94, 0.05); embedded systems (5.94, 0.05); cliff (5.94, 0.05)
9	17	0.919	2019	water quality (9.08, 0.005); flood risk assessment (6.38, 0.05); robotics (6.38, 0.05); radium (6.38, 0.05); spatial planning (6.38, 0.05)

Based on the analysis of important terms in the table over the last 5 years, the following trends can be drawn:

a. Climate change and natural disaster adaptation measures: key words include "adaptation strategies", "adaptation measures", "sea level rise" and "tsunami".
b. Hydrology and marine environmental protection: including "water quality", "coastal erosion", "flood risk assessment" and "radium".
c. Shoreline protection and management: including "coastal protection", "shoreline response" and "shoreline change analysis".
d. GIS and remote sensing technologies: including "gis", "remote sensing" and "object-based image analysis".
e. Artificial intelligence and machine learning: including "machine learning", "neural networks" and "underwater robotics".
f. Sustainable infrastructure design and techno-economic analysis: including "sustainable infrastructures", "techno-economic analysis", "renewable energy" and "Renewable energy".
g. Disaster risk assessment and damage assessment: including "damage assessment", "seismic risk" and "flood mitigation".

In general, these trends indicate that in recent years there has been an increasing emphasis on climate change, environmental protection, shoreline protection and disaster risk assessment in the field of coastal construction. Based on the emergence of new terms, it can be predicted that emerging technologies, such as artificial intelligence and machine learning, will gradually be adopted in the future to solve related problems.

4. Discussion

Based on an analysis of literature data and research institutions, it is evident that Chinese research institutions and members have demonstrated the highest level of activity in the field of coastal building, establishing China as a prominent contributor in terms of the number of published papers over the past decade. The Chinese Academy of Sciences, along with other prominent institutions, has been at the forefront of coastal building research for several years. In addition, new research institutions have emerged internationally and in specific countries such as India and Indonesia, indicating a growing interest in and involvement in coastal building research. However, there is a need to strengthen cooperation between research institutions in different countries. Collaborative projects and knowledge exchange programmes can promote an interdisciplinary approach and facilitate the sharing of best practises and innovative solutions.

The analysis based on author collaboration networks found that although some authors have established good collaboration networks, the overall level of collaboration between authors needs to be strengthened. Although authors collaborate intensively in their respective fields, the lack of collaboration between different disciplines may limit the ability to synthesise complex issues. The use international organisations and institutions as core authors, and the lack of involvement of individual authors from the academic community can lead to some academic research and innovation being overlooked in the development of the field.

Climate change impacts related to issues such as coastal erosion caused by sea level rise have become a focus of coastal building research, as revealed by keyword co-occurrence analysis and clustering techniques. This indicates that researchers are increasingly concerned with how to address the challenges of climate change in coastal buildings and improve their climate resilience.

The literature on sea level rise prediction and strategy hotspots demonstrates that there are research limitations in terms of methods used, such as aerial photography-assisted presentation (AVVA) techniques, geographic information systems (GIS) and numerical modelling. While GIS has been regularly employed in sea level rise research, it is important to acknowledge that there is room for improvement in the modelling and data processing techniques associated with GIS. Moreover, research frameworks in the fields of coastal management, sea level rise adaptation, and marine ecosystems often lack comprehensiveness, resulting in the potential for one-sided solutions. The regional characteristics of coastal buildings vary significantly, limiting the applicability and replicability of research findings. Therefore, conducting more comparative studies across different regions and countries is crucial to obtaining more widespread and generally applicable conclusions and recommendations. Furthermore, there is still limited capacity for forecasting, analysing trends, and understanding the long-term impacts of sea level rise on time scales spanning decades or longer. Developing effective long-term planning and adaptation strategies requires a deeper understanding of these trends and impacts.

As can be seen from the hot content of GIS, from a data perspective, problems of data consistency and standardisation still exist, and attention should be given to developing consistent data standards and integration methods to improve data accuracy and comparability. From a methodological perspective, the accuracy and efficiency of spatial analysis algorithms and models need to be improved to address the challenges of complex spatial relationships. From the perspective of data visualisation, enhancing the interactivity and user experience of GIS systems is also an important research direction. In terms of data security, with the widespread use of GIS data, more attention needs to be paid to the development of secure GIS data storage and transmission mechanisms to protect sensitive geographical information and ensure the privacy rights of users. In terms of social impact, there is a need to improve the application of GIS technology in areas such as social planning, resource management and environmental protection in order to promote social justice and sustainable development. These recommendations can help researchers focus on key issues in future research and promote development and innovation in the field of GIS.

From the analysis of research trends, the focus seems to be more on technical and engineering aspects, such as climate change adaptation measures and the structural performance of buildings. We also need to take into account the impact of social, economic and political factors on coastal building. How sustainable urban planning and development can be based on a combination of factors is an issue worth exploring.

While focusing on shoreline protection and disaster risk assessment, should community participation and social vulnerability also be taken into account? Research and practise in the field of coastal building should focus more on community participation and resilience to ensure that the building process does not exacerbate social inequalities and vulnerabilities.

Are there some potential risks and challenges in the development of technology and the application of emerging technologies, such as artificial intelligence and machine learning? For example, data privacy and ethical issues, as well as the risk of technological dependency. We need to carefully evaluate the application of these technologies and ensure that their use in the field of coastal building is in line with the principles of sustainable development and social benefit.

In addition to technical and engineering considerations, research and practise in the field of coastal building need to focus on multiple dimensions such as social, economic, environmental and ethical issues in order to achieve truly sustainable and inclusive coastal building development.

This study has several limitations that should be highlighted. Firstly, the data analysis was conducted using CiteSpace software, and the analysis primarily focused on English-language publications. Therefore, there is a possibility of linguistic bias, and it is likely that non-English literature or research in other languages might have been overlooked. Furthermore, this study exclusively analysed literature from the Web of Science database, potentially missing out on valuable research from other databases or alternative literature sources. Additionally, this study's chosen time frame for analysis was from 1988 to 2023. However, it is important to acknowledge that this time frame may not have encompassed all relevant research literature, as there are inherent limitations in the data analysis methods employed.

To mitigate these limitations and further refine this study, the following improvements could be considered:

Expanding language coverage: In future studies, literature searches and analyses could be attempted in multiple languages in order to more comprehensively cover research results in different languages.

Multi-database search: In addition to the Web of Science database, consideration could be given to including other academic databases (Scopus, PubMed) as well as non-traditional literature sources (technical reports) for search and analysis in order to obtain a more comprehensive perspective of the research.

Extended time horizon: Depending on the purpose of this study and the feasibility of the resource, the time horizon can be extended to include earlier literature to capture trends and changes in research over a longer period.

These improvements could further improve the comprehensiveness and reliability of this study.

5. Conclusions

The dataset analysed for this study comprises 2067 records, covering the period from 1988 to 2023. Among these, 1627 records are derived from conference proceedings, while the dataset also includes 439 articles and proceedings, along with two conference abstracts. Through a comprehensive examination and analysis of the present state, research focal points, and trends in the field of coastal architecture over the past three decades, the following main conclusions can be drawn:

Firstly, the gradual increase in the number of research papers in this field indicates a growing recognition of the significance of coastal building. Researchers and policymakers should continue to prioritise this area and allocate additional resources to support the research and development of coastal buildings.

Secondly, the dominance of the USA in the past three decades underscores the need for enhanced global collaboration and knowledge sharing in coastal building research. While developing countries in Asia have emerged as significant contributors in recent years, fostering greater collaboration between research institutions across different countries is essential.

Thirdly, there are limitations in the author collaboration network, necessitating increased interdisciplinary collaboration to address complex problems in a holistic manner.

Fourthly, the impact of climate change on coastal buildings, particularly coastal erosion due to sea level rise, has become a focal point of research. However, related studies face methodological and data limitations, highlighting the necessity for a comprehensive and accurate understanding of the actual state of coastal building. Integrated research frameworks that amalgamate findings on coastal management, sea level rise adaptation, and marine ecosystems are lacking, potentially resulting in narrow-sighted solutions. In the field of GIS, attention should be paid to issues such as data consistency and standardisation, accuracy and efficiency of spatial analysis algorithms and models, interactivity and user experience of GIS systems, and data security.

Fifthly, research trends primarily emphasise technical and engineering aspects, yet it is equally important to consider the influence of social, economic, and political factors on coastal building for achieving sustainable development. Factors such as community engagement and social vulnerability need to be examined to ensure that coastal building development does not exacerbate social inequalities and vulnerabilities. When implementing emerging technologies like artificial intelligence and machine learning, potential risks and challenges must be thoroughly assessed to ensure adherence to the principles of sustainable development and social benefit. Research and practise in the field of coastal building should integrate multiple dimensions, encompassing technical, engineering, social, economic, environmental and ethical considerations, to foster sustainable and inclusive development.

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