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Review Article

Mainstreaming Flood Mitigation in Building Code: A Bibliometric Analysis

Nurin Mansoor[1,2]*, Aznah Nor Anuar[1], Akbariah Mohd Mahdzir[3] and Nurul Huda Md. Adnan[1,4]

[1]Disaster Preparedness and Prevention Center, Malaysia Japan Institute of Technology, Universiti Teknologi Malaysia, 54100 Kuala Lumpur, Malaysia
[2]Department of Architecture, Faculty of Design and Architecture, Universiti Putra Malaysia, 43400 Seri Kembangan, Selangor, Malaysia
[3]College of Life Sciences, George Davies Center, University of Leicester, LE17HA, United Kingdom
[4]National Water Research Institute of Malaysia, 43300 Seri Kembangan, Selangor, Malaysia

ABSTRACT

Integrating flood mitigation strategies into building codes on a global scale is a noteworthy initiative aimed at reducing the risk associated with flood-prone areas. The field of flood mitigation is constantly evolving and indirectly influences future building codes. However, there is a significant gap in research regarding optimizing building codes to mitigate flood-related risks. Therefore, this study aims to investigate the publication trends in mainstreaming flood mitigation into building codes by identifying the current state and critical key areas that potentially impact future building codes using bibliometric analysis. This research adopted a systematic review using the Web of Science database from 2002 to 2022, using the keywords «building code» and «flood». Bibliometric indicators were employed to summarize the key findings, including subject areas, publication trends, leading global contributors, influential institutions, citation patterns, authorship dynamics, and keyword analysis. The realm of research has experienced noteworthy expansion, emphasizing the necessity for further investigation. The findings also indicate that critical areas require attention in performance-based design, retrofitting of existing buildings, community resilience, the long-term effectiveness of flood mitigation measures, and the equity and social needs of the implications of flood-resilient building codes. In conclusion, such investigations are crucial in reducing community risk and creating resilient and sustainable communities in flood-prone areas.

Keywords: Bibliometric analysis, building code, flood, resilient building

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E-mail addresses:
nurinmansoor@gmail.com (Nurin Mansoor)
aznah@utm.my (Aznah Nor Anuar)
am1443@leicester.ac.uk (Akbariah Mohd Mahdzir)
nurulhuda.ma@gmail.com (Nurul Huda Md. Adnan)
*Corresponding author

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INTRODUCTION

A growing body of evidence agrees that the building codes formed the minimum standard for building designs and construction to meet performance requirements and ensure the safety of occupants and buildings (Nwadike & Wilkinson, 2021). It is a widely held view that building code is determined as a competent measure to protect lives, properties, and the built environment generally against a disaster of any kind (Nissanka et al., 2019). These codes are based on scientific research and engineering principles and are intended to ensure that buildings are safe and durable and can withstand the forces of nature and other hazards (Case & Codes, 2020). The research to date recognized the importance of building codes in reducing flood risk, particularly considering the increasing frequency and severity of flooding events worldwide.

Previous research by Escarameia et al. (2012) emphasized that building codes can significantly reduce the risk of flood damage to buildings, requiring flood-resistant construction materials and techniques supported by studies from the American Society of Civil Engineers (2015). Other studies have focused on the role of building codes in promoting community resilience to floods and on the importance of integrating flood risk reduction measures into building codes and other regulations (Aerts & Wouter Botzen, 2011). Over the years, a significant amount of research has been conducted on the effectiveness of building codes in reducing flood risk (Ingargiola et al., 2013).

Much of the criticism has attracted a Global Resiliency Dialogue conducted in 2021, managed by a voluntary collaboration of building code developers and experts, where they discovered that building codes need to be more effective to deal with environmental changes (International Code Council, 2021a). Developing and implementing flood-resilient building codes and standards is important to flood risk reduction and disaster preparedness (International Code Council, 2021b). Governments, professional organizations, and other stakeholders are working together to develop and implement more robust and effective flood-resilient building codes and standards and to promote their adoption and enforcement (Aerts & Wouter Botzen, 2011; Gnan et al., 2022a; Ingargiola & Quinn, 2013; López-Marrero & Tschakert, 2011; Piatek & Wojnowska-Heciak, 2020). Another recent study by Gnan et al. (2022) described that investing in flood mitigation with better evidence provides government decision-makers when considering building code changes.

It has been demonstrated that the field of flood mitigation is constantly evolving, and the research trends indirectly influence future building codes. Therefore, this study aims to investigate the publication trends in mainstreaming flood mitigation into building codes by identifying the current state and critical key areas that indirectly play an important role in future building codes using bibliometric analysis. To the best of our knowledge, this study is the first to use a bibliometric analysis of building

code focusing on flood mitigation. We address the following research questions to discover the bibliometric indicators:

RQ1: What is the status of research on mainstreaming flood mitigation in building codes?

RQ2: What are the key topic areas discussed in mainstreaming flood mitigation into building codes research?

RQ3: What areas involving flood resilient building code need additional study?

LITERATURE REVIEW

In the evolution of disaster risk management, numerous frameworks have been introduced to reduce the risk of hazards such as the International Decade for Natural Disaster Reduction, Yokohama Strategy and Plan of Action for A Safer World, the United Nations International Strategy for Disaster Risk Reduction, Johannesburg Plan of Implementation, Hyogo Framework for Action (2005–2015), followed by a recent international framework which is The Sendai Framework (2005–2030) (United Nations for Disaster Risk Reduction, 2015).

The Sendai Framework, ratified in Sendai, Japan, in March 2015, focuses on disaster risk reduction by establishing four priority areas to empower the city's resilience (Thepot et al., 2016). As part of its implementation, flood mitigation is addressed as one of the priority areas. The goal is to reduce the risks associated with flooding and enhance the city's ability to recover from such disasters. One of the priorities highlighted in the framework is the need to enhance disaster preparedness for an effective response using building codes as part of the tools for developing resilient buildings and cities (Wei et al., 2021). The philosophy supporting the integration of flood mitigation into building codes is rooted in disaster risk reduction principles as part of disaster management (Wei et al., 2021). Notably, these principles link the key objective of risk reduction and resilience to reducing the risk of flood-related damage and enhancing the resilience of communities and their built environment (Ingargiola & Quinn, 2013). By incorporating flood-mitigating measures into building codes, cities, and regions, Maqsood et al. (2016) found that the adverse impacts of flooding on people, property, and the economy can be minimized.

Flood mitigation has become increasingly important with the increase in climate change and the likelihood of more frequent and severe floods. Therefore, a review of existing research in mainstreaming flood mitigation in building codes was carried out with a focus on the bibliometric method to identify and analyze the literature related to flood mitigation in building codes. Bibliometric analysis is a quantitative research method used to evaluate the productivity and impact of scientific research in a particular field (Baier-Fuentes et al., 2019; Kamarrudin et al., 2022; Kent Baker et al., 2020).

Bibliometric analysis, which involves analyzing patterns and trends in academic literature, can help identify emerging

strategies, technologies, and knowledge gaps in the field (Puspitarini et al., 2023). By examining the frequency of keywords and citations in scholarly articles, bibliometric analysis can give insight into the most influential research and help guide future research and policy decisions. For instance, it can identify areas where new building codes may be necessary to protect communities from floods better or highlight promising approaches to flood prevention that warrant further investigation.

Among the valuable resources available to advance our understanding of this technique significantly is the paper published by Lim and Kumar (2024). The authors discussed the applicability of sensemaking in bibliometric analysis using three processes: scanning, sensing, and substantiating to derive a meaningful interpretation. In short, bibliometric analysis is a valuable tool for navigating the constantly evolving landscape of flood mitigation.

METHODS

This paper generally used bibliometric analysis to summarize the key findings, including subject areas, publication trends, leading global contributors, influential institutions, citation patterns, authorship dynamics, and keyword analysis. The paper employed a combination of performance analysis and science mapping to answer the research questions.

The performance analysis is used to answer RQ 1, and science mapping is used to answer RQs 2 and 3. The performance analysis provides insight into the research trends, publication patterns, and the most influential authors in the field (Nik Hassan et al., 2022; Puspitarini et al., 2023), where the status of research related to mainstreaming flood mitigation in building codes can be identified through this analysis. The science mapping is used to visualize the trends and key topic areas discussed in mainstreaming flood mitigation into building codes research. In addition, this study also adopted the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) method, which provides systematic guidelines in academic literature (Saja et al., 2021; Tariq et al., 2021; Zairul, 2021) and consists of four steps; identification, screening, eligibility, and inclusion.

First, the identification step is conducted using the selected database. Database such as Scopus, Emerald, and Science Direct commonly collect numerous databases, are commonly collected by researchers. However, the Web of Science (WOS) database has been chosen as the referral source as it has been recognized and widely used in the academic field because the key elements in the Web of Science database, such as the contents that cover diverse disciplines and high citation publications offer a reliable material in managing the review (Zhu & Liu, 2020). In addition, the Web of Science is the only database with citation tracking that offers reliable and comprehensive citation data, including information on the number of times a publication has been cited and its *h*-index. This information is valuable for evaluating the impact of publications and authors in answering research question number one.

The initial search string "building code" AND "flood" was entered into the Web of Science search engine. The second step is screening, where the subject filters are applied. The time frame in this study is limited between 2002 and 2022 to analyze the research patterns within twenty years; the source type is restricted to journals, and the document type excludes irrelevant papers. In addition, this twenty-year period provides a sufficient time frame to gather a comprehensive dataset of publications, allowing for a more robust and representative analysis of research trends and patterns. This quantitative data was collected worldwide on February 20th, 2023, to ensure comprehensive coverage of building codes research and the broader context in understanding the flood mitigation field.

By referring to Figure 1, the search yielded 215 documents. After scanning the abstracts of all documents in the list, further exclusions were made relevant. One of the papers has been removed due to nonrelevant topics with the search string. After the documents were screened, 214 documents of building codes focusing on flood remained in the final database. The data was processed using various methods to acquire the information needed to answer the RQs. Certain findings were directly obtained from the Web of Science. Other findings were exported or manually recorded to an Excel file. The data was exported in Research Information Systems (RIS) and Comma-Separated Values (CSV) formats as part of the data sets. The VOS software (Visualization of Similarities Viewer) was utilized to represent the bibliometric networks because it is an open instrument for building and viewing networks (Wahid et al., 2020) (Figure 1).

RESULTS AND DISCUSSION

To answer research question number one (What is the status of research related to mainstreaming flood mitigation in building code?), we analyzed the publication trend in mainstreaming flood mitigation into building codes using total publications by year, country, journal, contributing author, and organization.

Table 1 represents the number of publications on building codes focusing on mainstreaming flood mitigation between 2002 and 2022. The sharp increase in publications after 2017 corresponds to the beginning of the Sendai Framework initiatives, which acknowledges the need to align building codes as part of national disaster risk management (Table 1).

With a total of 32 documents, the maximum productivity was recorded in 2022, while the lowest productivity was found in 2003, with a total of 1 document. Generally, a significant number of publications increased between 2017 and 2019, reflecting the rising interest in mainstreaming flood mitigation in building code research and its great potential for advancements, as shown in Figure 2. On the other hand, the Covid pandemic caused a drop in output between 2020 and 2021 before returning to the top spot in 2022 (Figure 2).

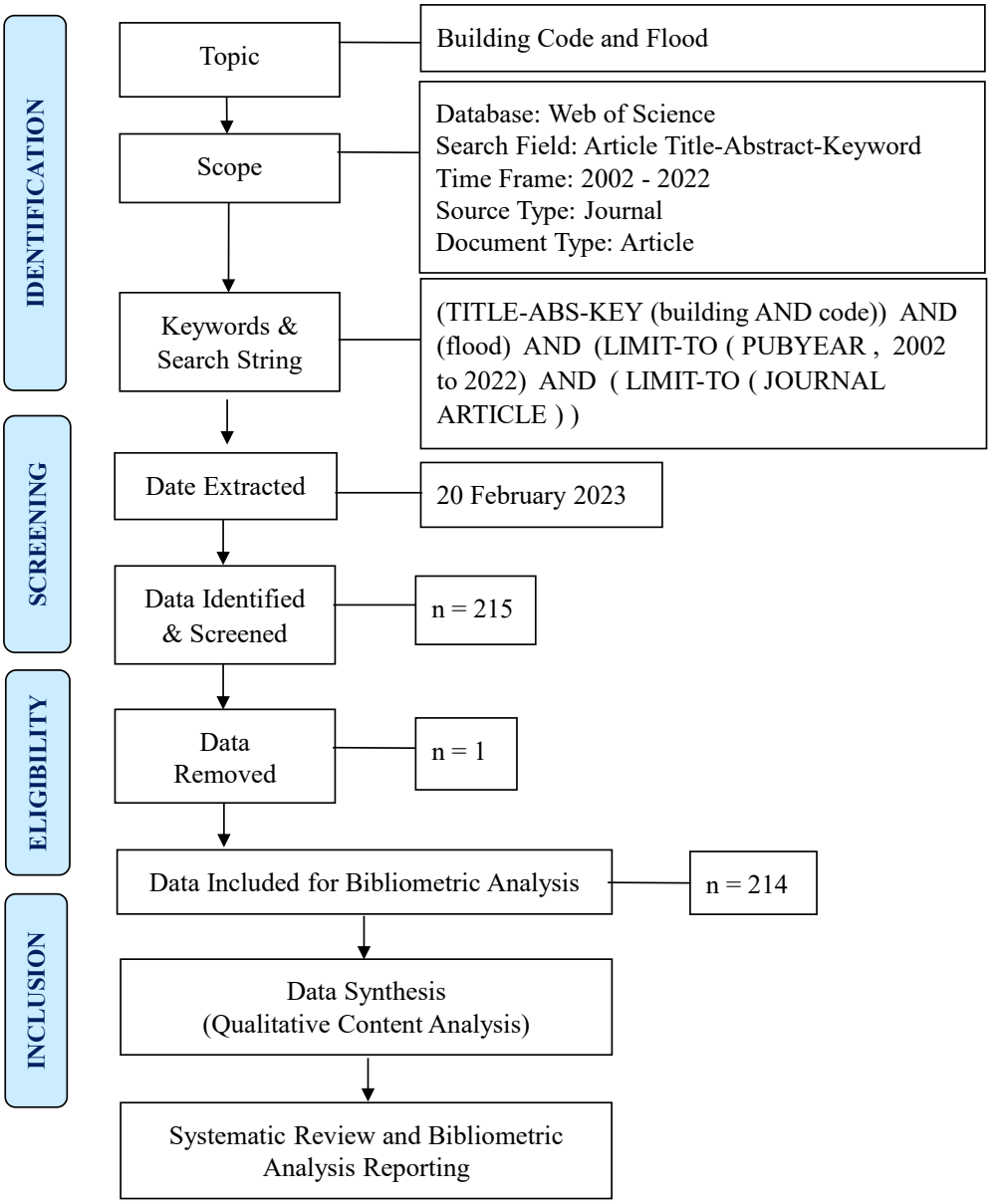

Figure 1. PRISMA Flow diagram of the systematic literature review combining bibliometric

Source: Authors' work

Table 1
Publication by year

Year	TP	%TP	TC	%TC
2022	32	15.0	811	17.56
2021	22	10.3	830	17.97
2020	26	12.2	682	14.77
2019	29	13.6	468	10.13
2018	17	7.9	349	7.56
2017	16	7.5	286	6.19
2016	8	3.7	264	5.72
2015	8	3.7	182	3.94
2014	8	3.7	178	3.85
2013	10	4.7	140	3.03
2012	9	4.2	125	2.71
2011	6	2.8	78	1.69
2010	4	1.9	86	1.86
2009	4	1.9	46	1.00
2008	2	0.9	39	0.84
2007	2	0.9	20	0.43
2006	3	1.4	16	0.35
2005	1	0.5	9	0.19
2004	2	0.9	8	0.17
2003	1	0.5	1	0.02
2002	4	1.9	0	0.00
Total	214	100.0	4618	100.0

Notes. TP=total number of publications; NCP=number of cited publications; TC=total citations; %=percentage of total publications
Source: Authors' work

Mainstreaming flood mitigation in building codes has attracted considerable attention from researchers, as indicated by the contributions from 55 countries. Table 2 lists the top 10 publishing countries, with the top three being the United States, England, and Germany. Meanwhile, the top publishing country in Southeast Asia is Vietnam, with ten publications and 130 citations, followed by Malaysia, with four publications and 52 citations (Table 2). Meanwhile, Figure 3 demonstrated the network visualization map of the bibliographic co-citation between the countries where the most dominant article linked between the United States of America, Netherlands, Germany, Canada, Austria, England, Wales, Scotland, Austria, Italy, France and Malaysia (Figure 3).

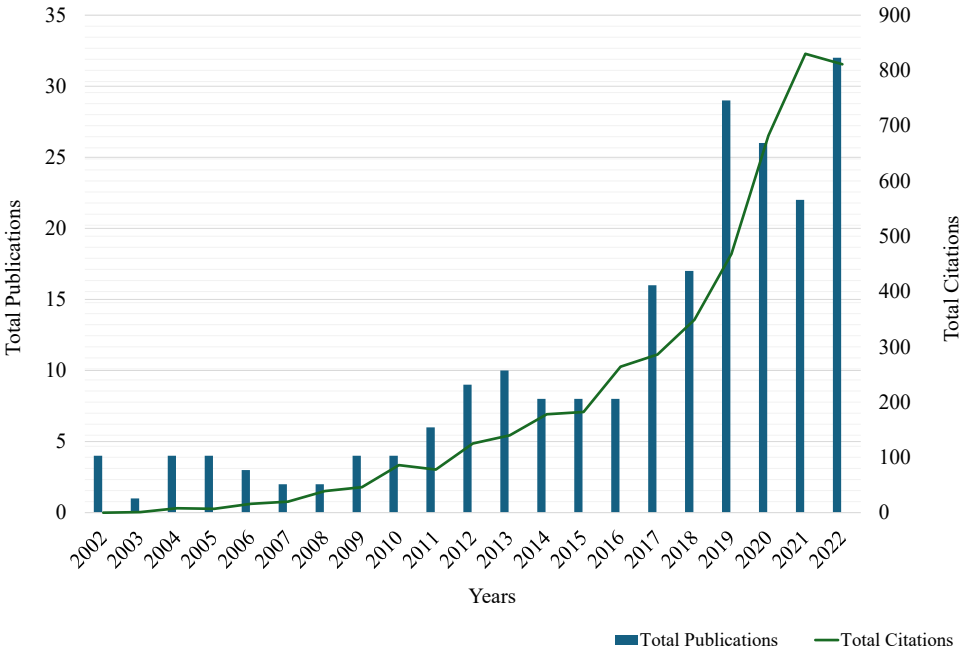

Figure 2. Total publications and citations by year

Source: Authors' work

Table 2
Publication by countries

Country	Total Documents	Total Citations
United States	83	1949
England	33	1166
Germany	19	400
Netherlands	18	491
Peoples China	14	348
Italy	18	206
Wales	7	362
Australia	8	333
Canada	11	74
France	5	67

Source: Authors' work

Based on our dataset, 882 authors from 425 organizations published articles related to the building code subject, focusing on flood mitigation. Table 3 lists the top five contributing authors. Five authors have the most publication documents and highest citations (Table 3).

The 214 articles appeared in 145 journals. Table 4 lists the top 10 journals with the most articles and highest citations on flood mitigation in building code. The leading journal is the Natural Hazards and Earth System Science Journals, which published eight journals with 264 citations, at the sixth strongest link strength. This ranking is followed by the *Journal of Hydrology, Water*, and *Journal of Flood Risk Management*, each published in 7, 6, and 5 journals (Table 4).

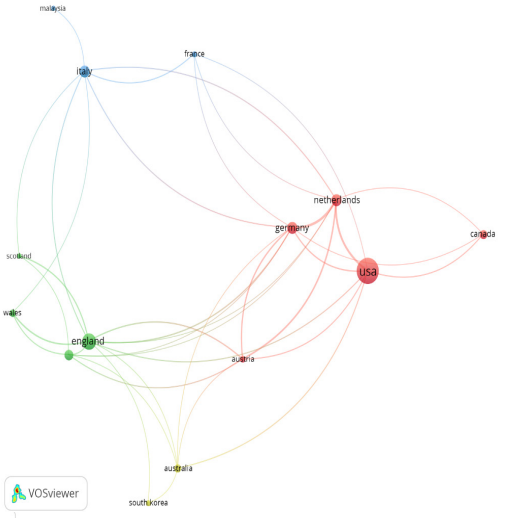

Figure 3. Network visualization map of the bibliographic co-citation

Note. Unit of analysis = Countries; Counting method: Fractional counting; Minimum number of documents of a source = 4

Source: Authors' work

Figure 4 demonstrates the network visualization map of the bibliographic coupling sources between the top journals, where the most recent article was published in the Journal of Flood Risk Management and the Journal of Hydrology (Figure 4).

Citation metrics are quantitative measures used to evaluate the impact and influence of a particular research publication, researcher, or institution within the scientific community (Donthu et al., 2020). Referring to the citation metrics in Table 5, the publication trend of the selected documents as of February 20th, 2023, indicates significant growth in this field (Table 5).

Twenty years of research development with 214 papers among countries, organizations, and authors has been

Table 3
Publication by authors

Author's Name	Organizations	Documents	Citations
Miguez, Marcelo Gomes	Federal University of Rio de Janeiro	7	50
Aerts, Jeroen Cjh	Vrije Universiteit Amsterdam	5	200
Botzen, W.J Wouter	Vrije Universiteit Amsterdam	5	133
De moel, Hans	Vrije Universiteit Amsterdam	4	218
Heidi Kreibich	GeoForschungsZentrum Potsdam, Germany	4	114

Source: Authors' work

Table 4
Publication by journals

Journal	Documents	Citations	Total Link Strength
Natural Hazards and Earth System Sciences	8	264	16.67
Journal of Hydrology	7	262	20.00
Water	6	72	26.00
Journal of Flood Risk Management	5	24	25.00
Environmental Science and Policy	4	49	6.00
Journal of Cleaner Production	4	44	9.00
Journal of Coastal Research	4	30	21.83

Table 4 *(Continue)*

Journal	Documents	Citations	Total Link Strength
Natural Hazards Review	4	12	3.00
Coastal Engineering	3	157	9.00
Earths Future	3	115	17.33

Source: Authors' work

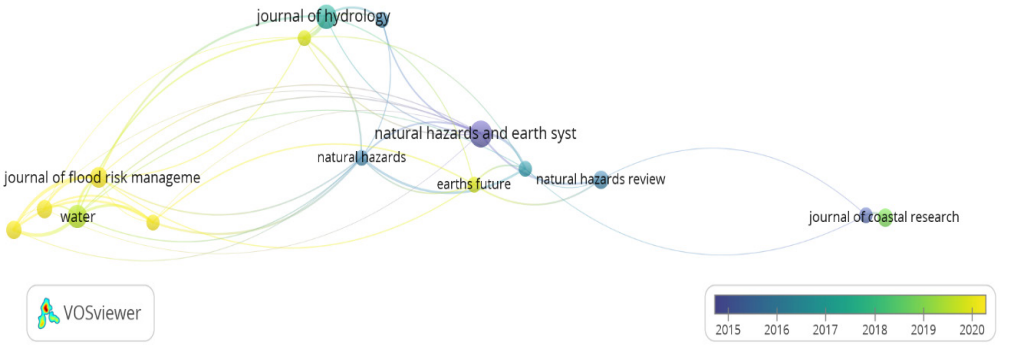

Figure 4. Network visualization map of the bibliographic coupling-sources

Note. Unit of analysis = Sources; Counting method: Fractional counting; Minimum number of documents of a source = 3

Source: Authors' work

recognized with a value of 34 for h-index and g-index of 60. This citation measure was created with Harzing's Publish and Perish software, which presented the raw citation metrics as an RIS-formatted file from the Web of Science database.

To answer RQ2: What key topics are discussed in mainstreaming flood mitigation into building codes research? The selected articles were examined using co-occurrence analysis in VOS software based on the text data. A content analysis method, co-occurrence analysis, assesses how closely related terms are used in literature (Kamarrudin et al., 2022). Figure 5 shows a network visualization of all terms with at least ten occurrences. Of 7177 terms in total, 80 terms meet the threshold. However, for each of the 80 terms, a relevance score was calculated using the VOS software, where the most 48 relevant terms were selected, as shown in Figure 5. Those selected terms

Table 5
Citation metrics

Metrics	Data
Publication years	2002-2022
Citation years	20
Papers	214
Citations	4664
Citations/year	222.10
Citations/paper	21.79
Papers/author	4.20
h-index	34
g-index	60

Source: Authors' work

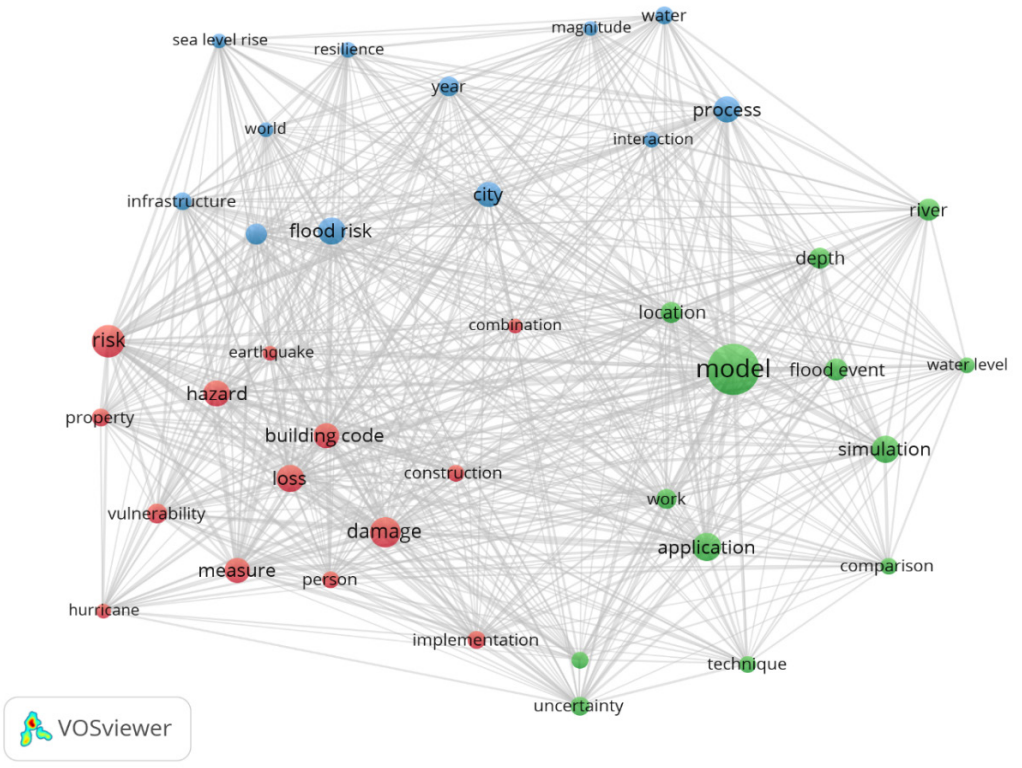

Figure 5. VOSviewer visualization of a term co-occurrence based on cluster

Note. Unit of analysis = Text Data; Counting method: Binary counting; Minimum number of occurrences of a term = 10

Source: Authors' work

were divided into three clusters, and the nodes' size depicts the terms' frequency.

The node's color denotes the cluster to which it belongs (Eck & Waltman, 2023) (Figure 5).

The three clusters indicate the top key topic areas in this research area. The first cluster in red is associated with building code, hazard, risk, vulnerability, property, measure, loss, implementation, construction, damage, earthquake, and hurricane. It led to the theme of "disaster preparedness and mitigation in construction and property management". The second cluster, denoted by green color, includes keywords such as model, river, simulation, technique, uncertainty, water level, depth, flood event, comparison, and application. It led to the second theme, «river and flood modeling and simulation». The third cluster, highlighted in blue, is associated with the city, climate change, flood risk, infrastructure, interaction, magnitude, resilience, sea level rise, and the world. This third cluster emphasizes the theme of "urban resilience to climate change and flood risk".

In answering RQ3: What areas involving mainstreaming flood mitigation in building

code need additional study, the literature gaps highlighted these needs. Some of these areas include:

1. Performance-based design: A demand for further research on performance-based design approaches (Lourenço et al., 2020; Nwadike et al., 2020; Nwadike & Wilkinson, 2022; Rezende et al., 2019; Wilkinson et al., 2019) that consider the specific flood risk characteristics of a given site and provide a more flexible and adaptable approach to flood-resilient design and construction.

2. Retrofitting of existing buildings: There is a need for a study on cost-effective methods (Maqsood et al., 2016; Orooji et al., 2022) for retrofitting existing buildings (Miano et al., 2019) in flood-prone areas to improve their flood resistance and resilience (Paprotny et al., 2021).

3. Community resilience: The necessity for research on the role of community resilience (Andráško et al., 2020; Douglas et al., 2010; Hudson et al., 2022) in promoting effective flood mitigation strategies and on the factors that contribute to the success or failure of community-based flood resilience initiatives (Wang et al., 2019; Wedel et al., 2008).

4. Long-term effectiveness: The analysis of the long-term effectiveness of flood mitigation measures (Kreibich et al., 2015; Paprotny et al., 2020), including building codes and standards and the factors that affect their effectiveness over time (Henderson, 2008; Ripple, 2020).

5. Equity and social needs: There is a demand for research on the equity and social justice implications of flood-resilient building codes and standards (King et al., 2016; Kondo, 2016; Pradhan et al., 2017) and on how these policies can be designed and implemented to promote social justice and address the needs of marginalized communities (Aerts, 2018; Aerts & Wouter Botzen, 2011).

Having analyzed the current trends in some detail, we can now return to significant implications for philosophy and practice in mainstreaming flood mitigation into building code. The co-occurrence analysis of these research areas recognized that buildings play a critical role in community resilience, and this theory can be expanded to include other forms of disaster mitigation. As flood-resistant buildings become more common, built environment professionals must adapt their practices to meet these new standards, which require additional training and expertise in flood-resistant design and construction techniques. Overall, a greater study in this area is critical for improving

the creation and implementation of effective flood-resilient construction regulations and standards, as it represents a significant shift in both theory and practice associated with flood risk reduction principles.

CONCLUSION

Referring to the objective of this study, the current state and critical key areas that may shape the future practice of flood mitigation have been identified. The main theme established by the co-occurrence analysis highlights the current and future flood mitigation practices. These practices include building codes in disaster preparedness and mitigation in construction and property management, river and flood modeling and simulation, urban resilience to climate change, and flood risk.

Consequently, the research publication patterns in mainstreaming flood mitigation into building codes show that while authors from different countries have contributed to the field, their relationships remain homogeneous within countries. The analysis of keywords and co-occurrences reveals that the study has continued to center on property performance, catastrophe risk, and the influence of preparedness on community resilience. To further investigate the primary subject matter of this study, a comprehensive co-citation analysis was conducted, and the results of this analysis revealed that the themes could be classified into three distinct clusters, each with its unique characteristics and attributes. These findings provide valuable insights into the topic and can be used to inform future research and decision-making.

Notwithstanding the unique features of the bibliometric analysis, this study has certain limitations. First and foremost, this study uses the Web of Science database as its major source of documents. Although the Web of Science is one of the most extensive databases for scholarly publications, it is always remarkable to observe what occurs when coupled with other databases. Next, due to the broad scope of the Flood and Building Code concept, we only looked at the relevant literature with limited search queries. Third, no further techniques have been used to triangulate the keyword co-occurrence network mapping. The results were generated directly from the specified terms, such as «building code» and «flood», based on the article title, abstract, and keyword mostly because studies that concentrate on a certain subject use the papers' title, abstract, and keywords only.

This study provides valuable contributions to the field by identifying key areas that require further investigation and development. Despite the absence of groundbreaking findings, the research offers new insights that can inform future studies. The identification of these areas can help researchers focus their efforts and resources on the most pressing issues, thereby advancing the field of flood mitigation from the perspective of a bibliometric analysis lens. Overall, this study underscores the importance of ongoing research and development in the field and highlights the need for continued exploration and

innovation to protect communities from the consequences of flooding.

The Implications of Bibliometric Analysis

Bibliometric analysis depicted the research landscape for mainstreaming flood-resilient building codes. Nonetheless, recent research highlights the essential role of sensemaking in extracting valuable insights from such analyses. This study explores several fruitful avenues for applying sensemaking within this context:

1. Identifying knowledge gaps and research priorities: By analyzing relationships between publications, we identified areas lagging behind practical needs, informing our discovery of a gap in research on performance-based design, retrofitting of existing buildings, community resilience, long-term effectiveness strategies together with the equity and social needs for developing countries where the publications are mostly led by the United States of America, followed by England and Germany.

2. Understanding citation patterns and knowledge transfer: Co-authorship and citation patterns highlight collaboration networks and knowledge transfer, revealing leading institutions and researchers. It suggests opportunities for knowledge-sharing initiatives, as seen in the concentration of disaster preparedness and mitigation in construction and property management research in the US.

3. Tracking the evolution of best practices and emerging trends: The dynamic shifts in publication topics and keywords offer crucial insights into how our understanding and approaches to flood mitigation are evolving. Refer to Figure 6, the network visualization map of a term co-occurrence based on the year published demonstrated how the keywords evolved throughout the year. It paves the way for formulating potential research directions and tailoring research to effectively address current challenges, as reflected in the literature gaps previously discussed (Figure 6).

This research showcases the transformative potential of sensemaking in bibliometric analysis. Its impact extends beyond pinpointing research gaps and guiding future directions with robust data. It fosters a collaborative environment by identifying key players in the field, ultimately accelerating progress in mainstreaming flood-resilient building codes.

Recommendation of Future Bibliometric Analysis Studies

With increasingly frequent floods threatening communities worldwide, robust research and implementation efforts are crucial to

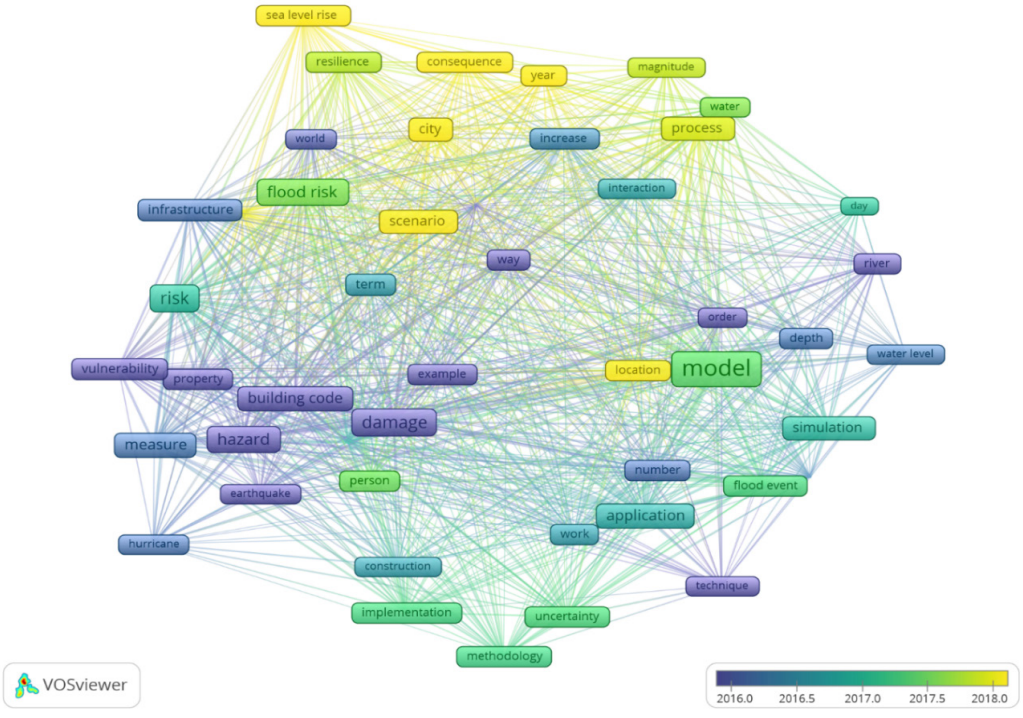

Figure 6. Network visualization map of a term co-occurrence based on year published

Note. Unit of analysis = Text data; Counting method: Binary counting.

Source: Authors' work

building resilience. One key strategy is mainstreaming flood mitigation measures into building codes, ensuring structures can withstand rising waters and protect residents. Bibliometric analysis has emerged as a powerful tool for gaining insights into the research landscape and informing future directions. Building on the previous studies, below are the recommendations for future bibliometric analysis studies focused on mainstreaming flood mitigation in building codes:

1. Deeper explorations focused on themes like flood types, building types, material choices, and disaster management integration to yield a richer and more nuanced understanding.
2. Discover the flow of knowledge through maps of interdisciplinary research partnerships. The next potential research may involve unveiling partnerships between engineers, architects, policymakers, and social scientists and highlighting international collaborations to exchange knowledge and best practices between developed and developing countries.

3. Track the evolution of best practices and emerging trends by analyzing time-based trends in publication topics and keywords. It may include examining how research responds to new regulations, policies, and disaster events.

By focusing on these particular areas and employing innovative methodologies, future bibliometric analysis studies can be vital in accelerating research progress, facilitating knowledge exchange, and bridging the gap between research and practice towards reducing community risk towards flood events.

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