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Review

A Scientometric Analysis of Studies on Risk Management in Construction Projects

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Abstract: Risk management is one of the topical areas in construction project management research. However, no attempt has been made in the past decades to explore the emerging themes in this area. This paper reviews the research trends in risk management in construction. The bibliometric data of 1635 publications between 1979 and 2022 were extracted from Scopus using a set of keywords. The study used VOSviewer and Gephi to conduct a scientometric analysis on the extracted publications. The review outcome indicates a significant increase in publications on risk management in construction, with about 205 publications recorded between 2021 and 2022 alone. Based on this analysis, it is projected that the next decade will see significant research on risk management, especially as the construction industry moves towards Industry 5.0 with many uncertainties. Further, the most productive countries of risk management studies in construction include China, the United States, the United Kingdom, Australia, and Hong Kong. Emerging key research areas are discussed using network diagrams and clusters. These areas include the processes in risk management, risk analytical models and techniques, sources of risk and uncertainties, effective knowledge-based systems for improved risk management, risk contingency in construction contracts, risk-integrated project planning and scheduling, and stakeholder management. The findings of this study inform researchers on the current progress of risk management studies in construction and highlight possible research directions that can be considered.

Keywords: risk management; scientometrics; construction research; review study; VOSviewer

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1. Introduction

According to the Project Management Institute [1], risk is an uncertain event or condition that, if it occurs, has a positive or negative effect on a project objective. In the construction industry, projects are primarily riddled with risks due to uncertainties that come from "variability" and "ambiguity" in relation to performance measures such as cost, duration, and quality [2]. Risk management in construction is the application of policies and procedures to identify, analyse, and assess risks, determine the degree of exposure to risk that construction projects can accommodate, and take appropriate steps to reduce the impact of risks on construction projects [3]. Risk management is critical in the decision-making process in construction projects. It involves the assessment of and reaction to uncertainties that can inevitably cause detrimental effects on the time, cost, and quality of projects [4,5].

Despite the considerable number of studies on risk management in construction during the last decades, many reported construction projects have failed to meet stakeholders' expectations due to poor risk management [5]. Many projects have failed either due to poor risk allocations or ineffective risk management practices. Considering this, it is therefore essential for a thorough and holistic review of risk management studies in construction to ascertain the emerging themes and significant knowledge gaps to improve industry practices. In fact, an overview of risk management studies is urgently needed in this era, considering that the construction industry is now moving towards Industry 5.0, which is associated with many uncertainties [6].

Against this background, this study aims to conduct a scientometric analysis and examination of the large strand of literature on risk management in construction with the following derived objectives to evaluate the annual publication trend of risk management studies in the construction research field:

1. Reveal the most productive countries, authors, and journals in the field.
2. Analyse the main research topics and their relationships.
3. Determine the key research areas in construction risk management.
4. Suggest the future research direction in the field.

Scientometric analysis was adopted because it has been proven to be the most suitable review method for examining and visualising a large volume of literature, such as that on risk management in construction. It is believed that the findings of this paper will adequately inform researchers, especially early career researchers, on the key areas to focus on to improve risk management practices in the construction industry. Further, researchers can identify potential authors for future collaborations on risk management studies in construction.

2. Methodology

A systematic approach was used to analyse a significant amount of research publications to generate the intellectual structure in risk management in construction. Science mapping is significant in visualising significant research patterns and trends within a large body of literature [7]. In science mapping methods, either a bibliometric analysis or scientometric analysis technique is used [8]. Bibliometrics is the study of the relationship of numbers and patterns in bibliometric data, i.e., the number of papers, the growth of the literature, and the patterns of library and database usage [9]. Bibliometric databases are representative samples of publication activity in a field of knowledge. With regards to scientometric analyses, it is the quantitative aspects of the production, dissemination, and use of scientific information to achieve a better understanding of the mechanisms of scientific research as a social activity [8]. A scientometric analysis technique was adopted in this study because it encompasses bibliometric tools and data and produces insightful patterns and trends [10]. Scientometric review studies have been growing in construction management research in the last couple of years because they allow researchers to examine a large strand of literature in a more objective and unbiased manner. In this study, a scientometric technique was used to analyse risk management in construction by visualisation and mapping the knowledge area in this research domain [11]. A scientometric analysis uses bibliometric data to generate a network model and identify research subjects [12]. There are various science mapping tools for analysing and visualising the scientific literature of a knowledge domain [7]. Some of the science mapping tools include VOSviewer, Gephi, and CiteSpace. This study used VOSviewer and Gephi as the appropriate tools for mapping out literature. VOSveiwer and Gephi are predominantly used to undertake scientometric analysis. They are designed to accommodate various features for visualising bibliometric data. The overall process used in conducting the review is presented in Figure 1.

2.1. Selection of Database

An appropriate database for subsequent literature identification in risk management in construction was selected in this study. Databases commonly used in scientometric analyses are Scopus, Web of Science, Google Scholar, and ResearchGate. However, in this study, the Scopus database was used because of its comprehensive coverage of scientific publications [13]. Scopus has a faster indexing process, which increases the possibility of the retrieval of more current publications [14]. It is one of the most important peer-reviewed literature sources, with the highest citations and abstract numbers [15].

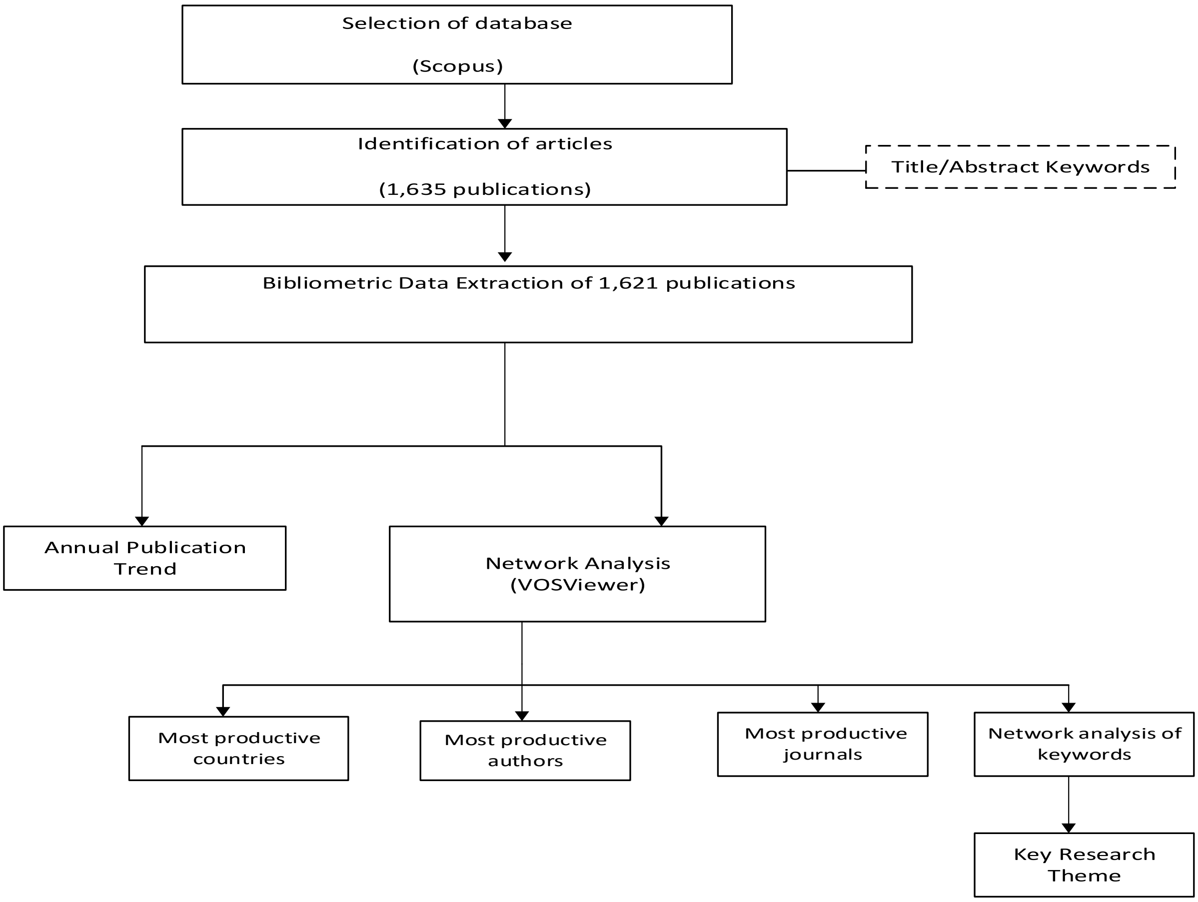

Figure 1. A flow chart of the research methodology.

2.2. Identification of Literature

In this review paper, a bibliometric search was performed using the title, abstract, and keyword codes for a comprehensive literature review of risk management in construction. Abstract and keywords are useful in scientometric analysis because they concisely represent the contents of publications [16]. The search terms were used to extract the bibliometric data from publications in Scopus. The title/abstract/keyword search bar was used to search for relevant publications using a set of terms. The research subjects were limited to journal articles, review papers, conference proceedings, the English language, and engineering. To avoid the omission of relevant papers, the date range was set to "all years until present". A comprehensive literature review was conducted in Scopus on 23 May 2022 to retrieve articles related to risk management in construction using the following keywords:

(TITLE-ABS-KEY ("risk management") OR TITLE-ABS-KEY ("risk identification") OR TITLE-ABS-KEY ("risk measurement") OR TITLE-ABS-KEY ("risk assessment") OR TITLE-ABS-KEY ("risk evaluation") OR TITLE-ABS-KEY ("risk control and monitoring") AND TITLE-ABS-KEY ("construction project")) AND (LIMIT-TO (SUBJAREA, "ENGI")) AND (LIMIT-TO (DOCTYPE, "ar") OR LIMIT-TO (DOCTYPE, "cp") OR LIMIT-TO (DOCTYPE, "re")) AND (LIMIT-TO (LANGUAGE, "English"))

The search results generated 1635 documents. The bibliometric data were downloaded in a "Comma-Separated Values (CSV)" file format from Scopus. The CSV file was imported to VOSviewer to map and analyse the risk management literature scientifically.

3. Results and Discussions

3.1. Annual Publication Trend of Risk Management in Construction Projects

Figure 2 shows the annual publication trend on risk management in construction. As presented in the figure, active research on this topic began in 1979 with one publication.

That year, Gnaedinger [17] researched attitude and communication in the management of underground construction projects. In 1983, only one study was conducted and published in the Underground Space Journal. In that year, Finch and Postula [18] conducted a risk evaluation study of alternative energy sources, which was published by Transactions of the American Association of Cost Engineers. No publications were recorded in the years 1980, 1981, 1982, or 1984. The reason can only be assumed that risk management in construction was entirely new during that era. In 1985 and 1986, two publications were recorded each year. The research of Perry and Hayes [19] increased the awareness of the risk of the multiple disciplines involved in construction projects. Their study addressed the financial risks associated with cost and time overruns. In that study, they addressed the main risk management stages, including identification, analysis, and response. Niwa [20] developed a knowledge-based human-computer cooperative system for ill-structured management domains. In the study, the author considered risk management in construction as an ill-structured management domain. The author developed a system that enabled project managers to make maximum use of an experimental knowledge base. Kangari [21] presented the potential application of knowledge-based expert systems in risk management. Three publications were recorded in 1987. Ashley and Perng [22] developed an intelligent risk identification system to help project management identify possible problems on construction projects. This system was designed to consist of an extensive database of the construction problem statements gathered from interviewing experienced construction personnel and other experts, an inference engine for intelligent search, and the graphical output of risk relationships. Kangari and Boyer [23] developed an integrated microcomputer-based knowledge system for risk management in construction. The system applied the fuzzy set theory to evaluate the overall risk of a project. It integrated a relational database that provided the system with financial and cost data necessary for bankruptcy and risk analysis.

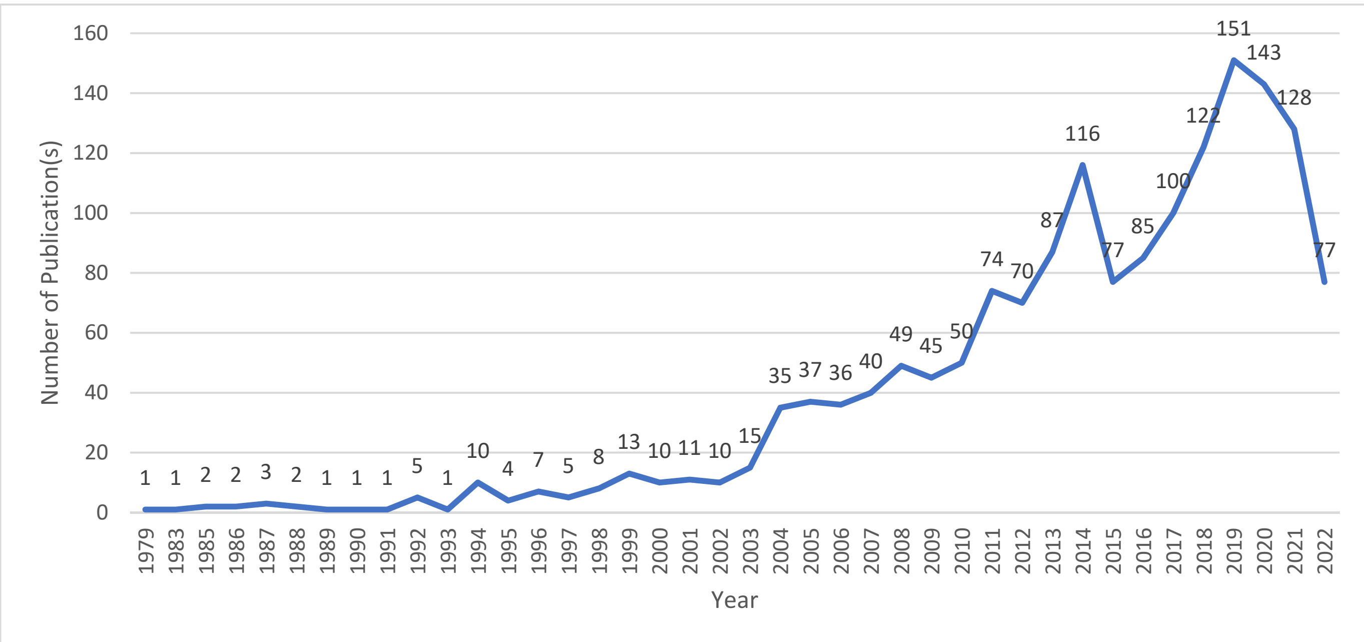

Figure 2. Annual publication trend.

The study by Kangari and Boyer [23] was published in two different journals: (1) Microcomputers in Civil Engineering and (2) Computer-Aided Civil and Infrastructure Engineering. Two publications were recorded in 1988, in which Ashley et al. [24] developed an intelligent construction risk identification that integrated a knowledge-based system with decision analysis formalism to assist construction project management in identifying, analysing, and managing construction project risks. Niwa [25] examined the risks faced by contractors on construction projects. In 1989, only one publication was recorded. Between 1979 and 1989, a total of 12 publications were published. In examining the publication trend in the 1980s, it can be deduced that they were focused more on the computerisation of construction risks to arm construction professionals with dense information on risk management. It was realised early in the 1980s how complex and dynamic construction projects were, with numerous and unprecedented risks. It seems that researchers in that era were more concerned about documenting contractors' and project managers' subjective and personal experiences in risk management.

Between 1990 and 1999, studies were focused on risk identification and risk analysis. Within this period, only 55 publications were published. The project types that this research focused on included underground construction (i.e., railways, tunnels), manufacturing, harbour construction, geotechnical works, offshore construction, bridge construction projects, dams, and highway projects. The average number of papers per year from 1990 to 1999 was five. In 1990 and 1991, one publication was recorded each year. Al-Bahar and Crandall [26] developed a construction risk management tool to help contractors identify project risks and systematically analyse and manage them. Mustafa and Al-Bahar [5] used the analytic hierarchy process to analyse and assess project risks during the bidding stage of a construction project. Within this period, 1999 was the highest publishing year, with 13 publications.

Between 2000 and 2020, 1363 publications were recorded within this period. This is a significant increase compared to the period between 1990 and 1999. It can be deduced that construction risk management has gained considerable attention, and this can be attributed to the complexity of construction projects as the years go by. Between 2021 and 2022, 205 publications have been recorded. Based on this analysis, it can be predicted that the next decade will see significant research studies on risk management, especially as the construction industry is moving towards Industry 5.0.

3.2. Most Productive Countries

The volume of research publications on a specific research area may be proportioned to the extent of policy and industry practices of the specific research area [27]. VOSviewer was used to create a network diagram of the most productive countries. The type of analysis selected in VOSviewer was "co-authorship", the unit of analysis was "countries", and the counting method was "full counting". For countries to be included in the network of most productive countries, the minimum number of documents of a country was set to 10, and the minimum number of citations of a country was set to 10. Out of the 101 countries, only 34 countries met the thresholds. Figure 3 depicts the network diagram of the countries that have contributed to risk management in the construction research area. VOSviewer subsequently grouped these countries into nine (9) clusters. Countries in the same cluster show that researchers from these countries have strong collaborations and citations. Indonesia, Poland, South Korea, Taiwan, the United States, and Vietnam are grouped as Cluster 1. France, Iraq, Pakistan, Russia, Sweden, and Turkey are grouped as Cluster 2. Egypt, Ghana, Qatar, Saudi Arabia, and South Africa are in Cluster 3. Germany, India, Malaysia, United Arab Emirates, and the United Kingdom are in Cluster 4. Australia, Greece, and Iran are in Cluster 5. The Netherlands, Portugal, and Spain are in Cluster 6. Canada, Hong Kong, and New Zealand are in Cluster 7. China and Singapore are in Cluster 8. Only Norway is in Cluster 9. In the network diagram produced by VOSViewer, the connections between the countries are not visible. Hence, the network diagram from VOSviewer was submitted to Gephi to produce a visual representation of all the connections between the countries, as shown in Figure 4. Figure 4 is an expanded version of Figure 3. Gephi calculated the "degree of centrality", which indicates the number of connections or links a country has with other countries. The higher the degree of centrality of a country, the more connections or collaborations it has with other countries in studies on risk management in construction. As shown in Table 1, the top five countries with a high degree of centrality are the United

Kingdom, Australia, the United States, China, and Hong Kong, with scores of 24, 22, 20, 17, and 12, respectively.

Figure 3. VOSViewer mapping of active countries in risk management in construction.

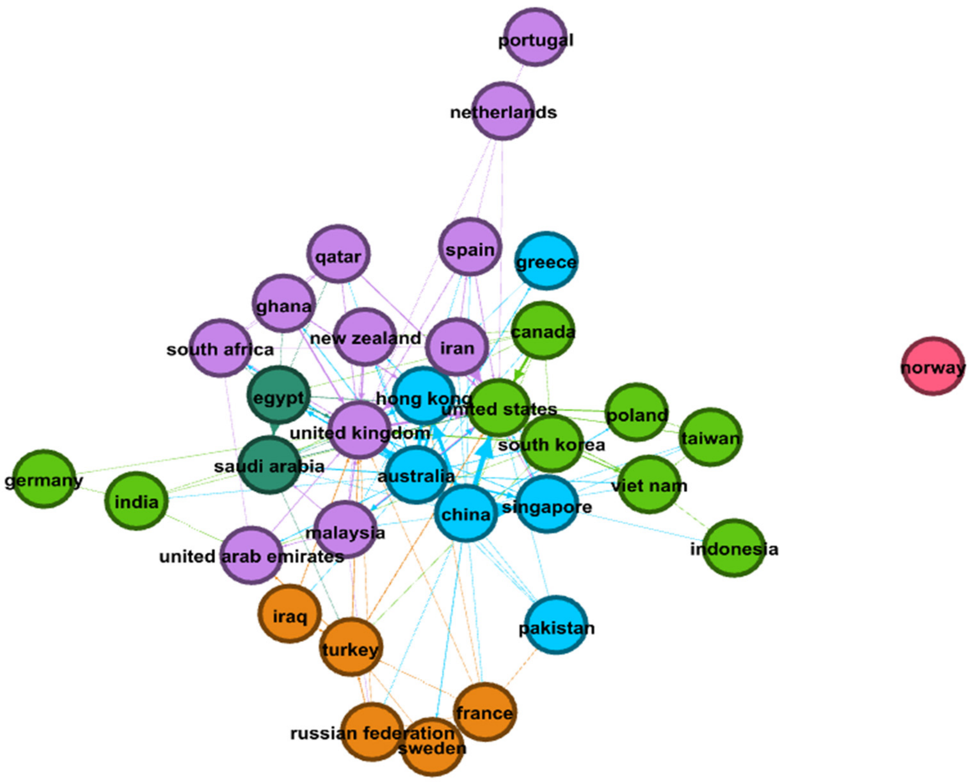

Figure 4. Gephi Mapping of active countries in risk management in construction.

3.3. Most Productive Authors

Table 2 shows the prominent researchers of risk management in construction and their collaboration links. The numerical analysis of the authors' collaborations is also shown in Table 2. VOSviewer was used to create a network of co-authorship. The type of analysis was "co-authorship", the unit of analysis was "authors", and the counting method was "full counting". For authors to be included in the network diagram of productive authors, the minimum number of documents per author was set to five, and the minimum number of citations per author was set to five. Of the 3098 authors, only 55 authors met the threshold. VOSviewer subsequently grouped the authors into 26 clusters. These clusters represent authors that collaborate amongst themselves. For instance, Adafin J., and Wilkinson S. are in Cluster 5. The network diagram from VOSviewer was submitted to Gephi to produce a visual representation of all the connections that exist between the authors, as shown in

Figure 5. As shown in Table 2, the five topmost active authors based on the number of their publications are Dikmen I., Wang Y., Birgonul M.T., Han S.H., and Fayek A.R. with 19, 17, 16, and 13 publications, respectively.

Table 1. Most productive countries in risk management in construction.

Country	Cluster	Degree of Centrality	Documents	Citations	Total Link Strength
United Kingdom	4	24	149	3759	76
Australia	5	22	117	3168	95
United States	1	20	281	5212	83
China	8	17	301	2798	79
Hong Kong	7	12	44	1731	38
Iran	5	10	72	1052	30
Malaysia	4	9	60	610	18
Saudi Arabia	3	9	18	276	19
Turkey	2	9	49	1351	14
Canada	7	8	61	879	14
Egypt	3	8	28	344	20
South Korea	1	8	65	1451	24
France	2	7	17	214	7
South Africa	3	7	31	150	10
United Arab Emirates	4	7	15	256	11
Ghana	3	6	10	143	13
Qatar	3	6	10	75	10
Russian Federation	2	6	29	182	8
Singapore	8	6	32	1184	23
Spain	6	6	11	293	9
Viet Nam	1	6	13	353	10
India	4	5	57	402	5
New Zealand	7	5	16	151	10
Pakistan	2	5	12	171	5
Taiwan	1	5	31	883	6
Netherlands	6	4	15	132	4
Sweden	2	4	15	228	6
Iraq	2	3	11	25	5
Poland	1	3	39	437	6
Germany	4	2	12	79	2
Greece	5	2	11	164	3
Indonesia	1	2	36	177	2
Portugal	6	1	10	249	1
Norway	9	0	15	246	0

Table 2. Most productive authors in risk management in construction.

Author	Cluster	No. of Publications	Degree of Centrality	Citations	Total Link Strength
Dikmen I.	2	19	3	723	18
Wang Y.	1	17	4	71	4
Birgonul M.T.	2	17	3	688	18
Han S.H.	7	16	2	603	13
Fayek A.R.	16	13	0	370	0
Zou P.X.W.	1	11	2	411	2
Zhang J.	1	10	6	48	7
Liu M.	1	10	4	69	6
Wang J.	1	10	4	67	4
Li H.	1	10	3	75	3
Deng X.	4	9	3	204	13
Kim D.Y.	7	9	2	382	13
Kim H.	7	9	2	383	12
Tah J.H.M.	2	9	2	801	4
Zhao X.	4	8	4	272	15
Breysse D.	6	8	2	87	12
Taillandier F.	6	8	2	89	11
Zhang H.	1	8	2	54	2
Chileshe N.	14	8	0	194	0
El-Adaway I.H.	15	8	0	71	0
Li X.	3	7	2	110	2
Liao P.-C.	3	7	2	25	4
Heravi G.	18	7	0	51	0
Adafin J.	5	6	2	49	12
Mehdizadeh R.	6	6	2	92	9
Rotimi J.O.B.	5	6	2	49	12
Wilkinson S.	5	6	2	49	12
Zhang L.	1	6	2	6	2
Liu R.	1	6	1	16	1
Molenaar K.R.	11	6	1	201	2
Nasirzadeh F.	10	6	1	148	3
Ardeshir A.	13	6	0	233	0
Gunduz M.	17	6	0	244	0
Latief Y.	19	6	0	27	0
Wang H.	25	6	0	82	0
Chang T.	4	5	3	98	12
Hwang B.-G.	4	5	3	138	11
Feng Y.	1	5	2	69	2
Liu J.	1	5	2	38	2

Table 2. *Cont.*

Author	Cluster	No. of Publications	Degree of Centrality	Citations	Total Link Strength
Sacks R.	2	5	2	374	2
Wang T.	3	5	2	36	3
Dey P.K.	8	5	1	249	2
Gurgun A.P.	9	5	1	11	4
Khanzadi M.	10	5	1	139	3
Koc K.	9	5	1	8	4
Ogunlana S.O.	8	5	1	374	2
Tran D.Q.	11	5	1	61	2
Wang C.	3	5	1	28	1
Adeleke A.Q.	12	5	0	15	0
Li C.	20	5	0	41	0
Love P.E.D.	21	5	0	201	0
Shen G.Q.	22	5	0	201	0
Smith S.D.	23	5	0	336	0
Song X.	24	5	0	17	0
Öztaş A.	26	5	0	181	0

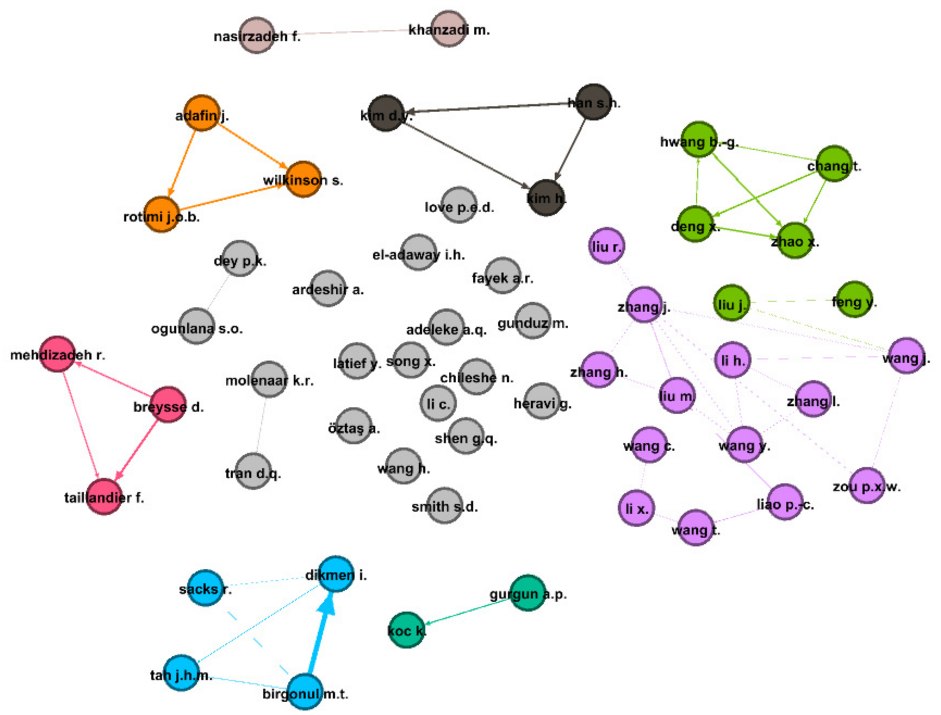

Figure 5. Most productive authors in risk management in construction.

3.4. Most Productive Journals

Journals are the hub for topical research areas where information can be garnered. Journals also inform researchers of the leading outlets and platforms to disseminate their research findings to achieve maximum impact in academia and industry [28]. Table 3 shows the productive journals and conference proceedings on risk management in construction. Figure 6 presents a visual representation of the most productive journals. The analysis used was “citation”, and the unit of analysis was “sources”. The ”minimum number of documents of source” and “minimum number of citations of a source” were set to 10. This resulted in 476 sources, out of which only 24 met the threshold. For each of the 24 sources, the total strength of the citations linked with other sources was calculated, as shown in Table 4.

Table 3. Outlets of risk management in construction research.

Source	Documents	Citations	Total Link Strength
Journal of Construction Engineering and Management	116	5498	229
Engineering, Construction and Architectural Management	55	1172	81
IOP Conference Series: Materials Science and Engineering	46	174	17
Construction Management and Economics	43	2476	118
Safety Science	42	1954	73
Journal of Management in Engineering	37	1139	72
Advanced Materials Research	34	35	5
Applied Mechanics and Materials	28	52	2
Automation In Construction	27	1156	107
International Journal of Construction Management	26	354	51
Proceedings, Annual Conference-Canadian Society for Civil Engineering	24	19	2
Journal of Civil Engineering and Management	23	761	71
Procedia Engineering	23	306	28
KSCE Journal of Civil Engineering	21	220	49
Proceedings of the International Conference on Industrial Engineering and Operations Management	19	28	12
Journal of Engineering, Design and Technology	17	206	36
Cost Engineering (Morgantown, West Virginia)	14	183	9
International Journal of Civil Engineering and Technology	14	70	8
AACE International Transactions	11	24	0
MATEC Web of Conferences	11	28	2
ASCE-ASME Journal of Risk and Uncertainty in Engineering Systems, Part A: Civil Engineering	10	30	15
Construction Innovation	10	99	16
Geotechnical Special Publication	10	28	0
Journal of Professional Issues in Engineering Education and Practice	10	277	15

Table 4. Numerical analysis of author keywords of risk management in construction.

Keyword	Clusters	Occurrences	Total Link Strength
Risk Management	2	378	417
Construction Industry	2	166	213
Construction Project Management	4	160	235
Construction Project	1	148	166
Risk Assessment	1	126	125
Risks	3	109	127
Risk Analysis	1	78	105
Fuzzy Set Theory	1	56	82
Risk Identification	1	36	41
Monte Carlo Simulation	3	35	53
Safety	2	32	51
Construction Safety	1	30	16
Uncertainty	3	29	47
Analytic Hierarchy Process	1	27	38
Scheduling	4	27	52
International Construction	2	25	31
Risk Factors	1	23	40
Decision Making	4	22	35
BIM	2	21	21
Risk Evaluation	1	19	18
Simulation	3	19	29
Contingency	3	17	29
Contracts	2	17	30
Cost	3	16	31
Procurement	5	16	19
Management	3	15	25
China	2	13	19
Factor Analysis	5	12	19
Bayesian Network	1	11	11
Contract Management	2	11	16
Project Performance	4	11	17
Risk Allocation	5	11	13
Collaboration	5	10	12
Construction Planning	4	10	21
Knowledge Management	1	10	14
Machine Learning	1	10	10

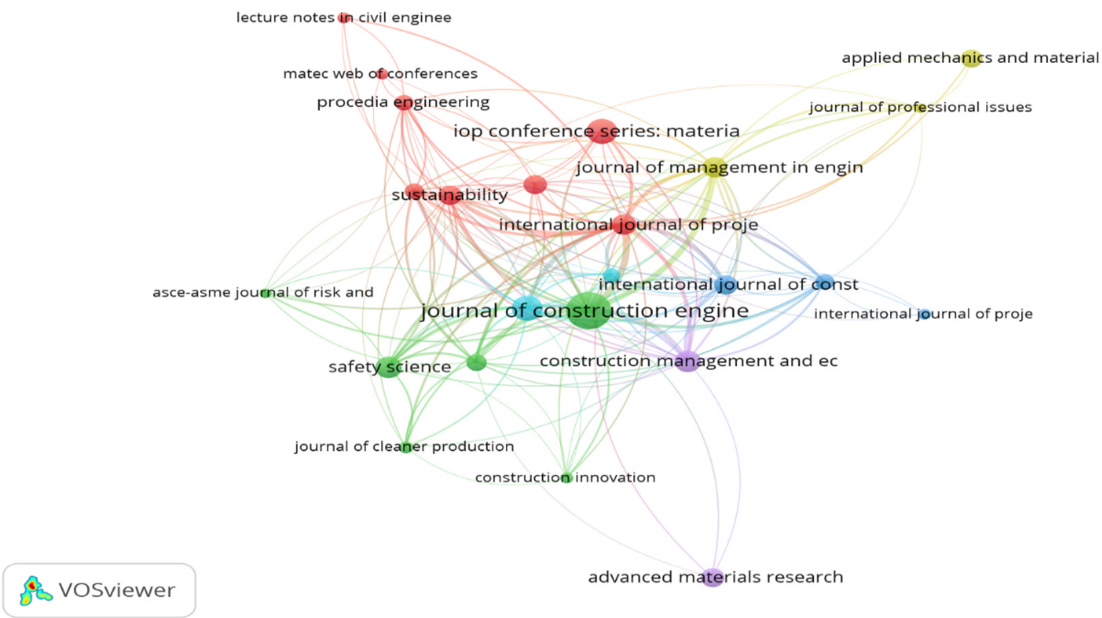

Figure 6. Outlets of risk management in construction research.

Journals with the most published research on risk management in construction were the Journal of Construction Engineering and Management, Engineering, Construction and Architectural Management, Construction Management and Economics, Safety Science, and the Journal of Management in Engineering. Similarly, conference proceedings that have contributed the most to the research field of risk management in construction include IP Conference Series: Materials Science and Engineering, Proceedings, Annual Conference—Canadian Society for Civil Engineering, Procedia Engineering and Proceedings of the International Conference on Industrial Engineering and Operations Management.

3.5. Main Research Topics and Their Relationships

Keywords are used in indexing research articles in databases to reflect the main themes of the articles [29]. Analysing keywords in selected publications allows for discovering the main research directions in any field [30]. According to Su and Lee [31], "keywords represent the core research of a paper". A network of keywords provides a graphical view of the research area, indicating the sampled articles' research topics and how they are associated intellectually [32]. In simple terms, the co-occurrence of keywords is the number of times keywords occur together in a document [33]. "Co-occurrence keywords" and "author keywords" were used. The counting method used was "full counting". The analysis showed that 2885 author keywords were used in research papers on risk management in construction. The minimum number of occurrences of a keyword was set to 10 to refine the outcome, of which only 36 keywords met the threshold. The total strength of the co-occurrence links with other keywords was calculated and is shown in Table 4. VOSviewer subsequently grouped the keywords into five clusters. The clusters can be differentiated by different colour codes, including red, green, blue, yellow, and purple.

Figure 7 presents the emerging keywords of risk management in construction. The keywords with large nodes indicate that they are the most frequently used author keywords in risk management in construction. These keywords include risk management, construction industry, construction project management, construction project, risk assessment, risks, risk analysis, fuzzy set theory, risk identification, and Monte Carlo simulation.

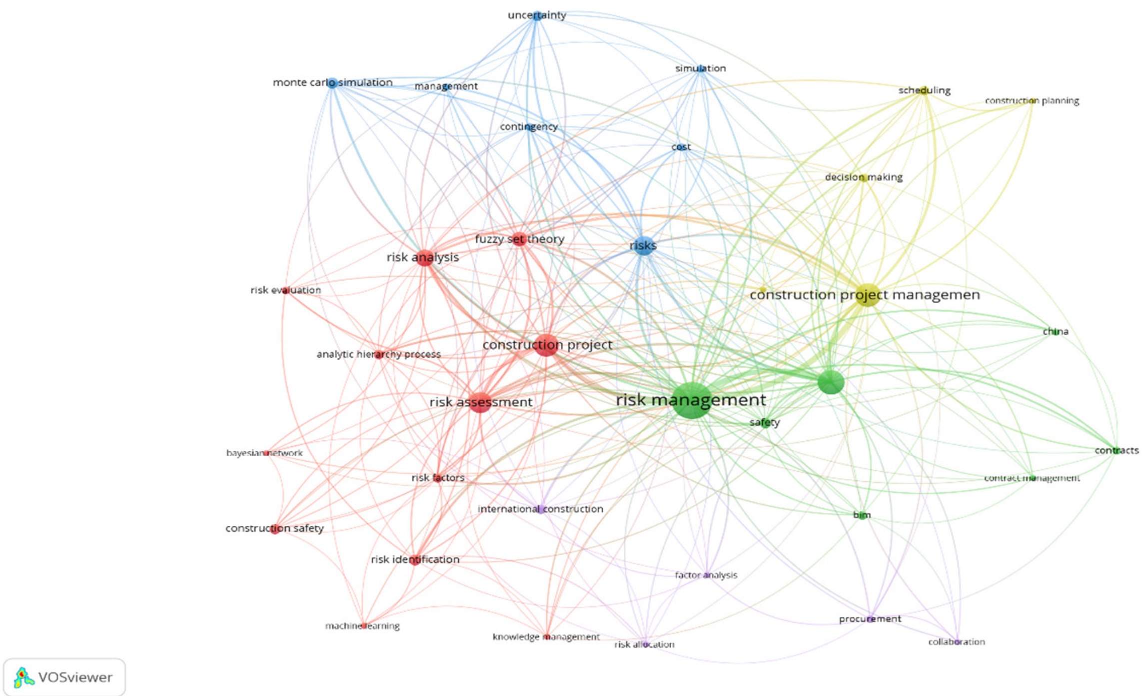

Figure 7. Network diagram of author keywords.

3.6. Key Research Areas

This section analyses past studies on risk management in construction using the author keywords in Table 4. In scientometrics, keywords can be used to derive trending research areas that are represented as clusters in keyword network analyses. VOSviewer grouped the keywords under five clusters. Cluster 1 consisted of analytical hierarchy process, Bayesian, construction project, construction safety, fuzzy set theory, knowledge management, machine learning, risk analysis, risk assessment, risk evaluation, risk factors, and risk identification. Based on Cluster 1, it was realized that most of the studies that adopted techniques such as AHP, fuzzy, etc., focused on construction projects and construction safety; therefore, construction project and safety were likely to be some of their keywords, which is why they appear in this cluster. Cluster 2 had keywords such as BIM (i.e., building information modelling), China, construction, contract management, contracts, risk management, and safety. Cluster 3 had keywords such as contingency, cost, management, Monte Carlo simulation, risks simulation, and uncertainty. Cluster 4 included keywords such as construction planning, construction project management, decision making, project performance, and scheduling. Cluster 5 consisted of keywords such as collaboration, factor analysis, international construction, procurement, and risk allocation. In the following sections, these clusters are named to reflect their representative keywords.

3.6.1. Cluster 1

a. Process in Risk Management

Risk management is the application of policies and procedures to the tasks of identifying, analysing and assessing risks, and determining the degree of exposure to risk that construction projects can accommodate. A risk management process takes appropriate steps to reduce the risk impact on construction projects and avoid any mitigation amongst project participants [3]. The process involves risk identification, risk assessment, risk analysis, and risk evaluation. Risk assessment is a topical area in risk management in construction. Risk identification is conducted in the early stages of risk management. Risk identification involves developing a checklist and categorising the risks that might evolve during the project execution [34]. Historical experiences with risks in past projects can be leveraged to identify risks in current construction projects [35]. Risk allocation is the process of identifying project risks and determining how they may be equitably and realistically shared by all of the parties in a construction project [36]. Risk allocation can be categorised into qualitative and quantitative approaches. The qualitative approach leads to the development of a risk allocation matrix, which identifies what type of risk is allocated to whom [37]. The quantitative approach to risk allocation is an extension of the qualitative approach where how much of a risk is borne by each party is addressed [37]. Risk allocation strategies should be determined at the inception of the project by the client [38].

b. Risk Analytical Models and Techniques

The research methods predominantly used in risk management in construction include factor analysis, fuzzy set theory, Monte Carlo simulation, analytical hierarchy process, machine learning, and Bayesian network. The complexity of construction projects makes the use of traditional risk assessment methods non-effective in identifying the cross-relationships and mutual influence among risk factors [39]. The Bayesian network can determine the risk factors that are more prone to occur and describes the relationships among these factors [40]. Tian, Chen, and Zhang [39] used the Bayesian network to develop an assessment method to analyse the interrelationship and risk ranking of crossed risk in construction safety. Bayesian networks are a new project management approach to risk assessment and uncertainties in decision making [41]. Fuzzy set theory is a mathematical approach for modelling human intellectual and subjective thought processes, and was established in 1965 by Lofti A. Zadeh [42]. Linguistic terms are converted to numerical values by a set of rules and membership functions to allow for the decision-making process based on probability [42]. The fuzzy set theory was first used in 1987 to evaluate the overall risk of a project. Gurgun and Koc [43] used a hybrid fuzzy multi-criteria decision approach to determine the role of contract incompleteness factors in project disputes. Koc and Pelin Gurgun [44] used the fuzzy method to assess readability risks in contracts causing conflicts in construction projects. Monte Carlo simulation uses statistical distribution to represent each risk identified and run multiple iterations using an equal number of random values for durations that belong to the prescribed distribution [45]. Qazi et al. [46] used Monte Carlo simulation to prioritise risks in sustainable construction projects. Monte Carlo simulation is a powerful tool that can handle many risks due to its simplicity [42]. Monte Carlo simulation was first used in 1990 by Al-Bahar and Crandall [26] to help contractors identify project risks. The analytical hierarchy process was developed by Dr Thomas Saaty in 1980 as a tool to help with solving technical and managerial problems [47]. The analytical hierarchy process is a decision-aided method that decomposes a complex multi-factor problem into a hierarchy in which each level is composed of specific elements [48].

c. Sources of Risk and Uncertainty

Research on understanding various sources of risk and uncertainty has been a major area in construction risk management. The findings (with representative keywords such as uncertainty, risk factors, and factor analysis) suggest that the investigations to understand, model, and manage risk and uncertainty sources are trending in the literature. Among others, major uncertainty sources that attract the researchers' interest are the complexity of a built environment (especially in large-scale projects), the continuing inaccuracy of project estimation approaches (e.g., for budget, duration), harsh or vague environmental conditions (especially in large-scale projects), and increasing sustainability requirements. Unless such sources are properly understood and managed, construction projects will continue to experience substantial cost overruns, duration delays, poor customer and stakeholder satisfaction, and failure to meet their economic, social, and environmental requirements [49–51].

3.6.2. Cluster 2

a. Effective Knowledge-Based Systems for Improved Risk Management

The representative keywords in this cluster are BIM, construction, contract management, contracts, risk management, and safety. Knowledge management creates a thriving work and learning environment that fosters the continuous creation, aggregation, use, and reuse of both organisational and personal knowledge in construction risk management [52]. Knowledge management of risks in construction projects assists in proactive and timely decision-making and contributes to project performance indicators such as time, cost, and quality [53]. Risk management in construction is a knowledge-intensive activity that relies on the professional knowledge or expertise of the stakeholders of a project [54]. Knowledge on risk management must be available and actively used in contract management [55]. Risk management can enable the best outcomes and further reduce risks in projects by leveraging the best available knowledge. A relationship between knowledge and risk is where knowledge feeds into risk information, which then informs what is known. Essentially, an increase in knowledge leads to decreased uncertainty and risk [56]. BIM is a knowledge repository with constant digital data acquisition and authentication, which enables project participants to capture and overcome inconsistencies with a responsive decision [57].

3.6.3. Cluster 3

a. Risk Contingency in Construction Contracts

Numerous studies with their representative keywords (contracts, contingency, cost, contract management, and procurement, as in Table 4) have addressed the estimation and management of cost contingency in construction contracts. Project managers use cost contingencies to respond to specific risks proactively or accept residual risks passively in projects [58]. Therefore, the findings reveal the growing interest in studies that estimate, negotiate, and manage cost contingency as part of the project budget in construction contracts. Promising research topics in this area cover the use of effective tools and approaches for cost contingency estimation during the project planning phase, negotiation of the contingency budget during project bidding, dynamic management of the cost contingency spending and its impact on the project cost and other outcomes [59,60]. Failing to identify risks in construction projects early results in poor final cost estimates [61], which may cause huge cost overruns [62].

3.6.4. Cluster 4

a. Risk-Integrated Project Planning and Scheduling

The representative risks in the clusters are construction planning, construction project management, decision making, project performance, and scheduling. The methods used in construction project planning have evolved over the years from a traditional planning approach based on more deterministic networks to a more sophisticated approach based on probabilistic methods and supporting tools [63]. Industry 4.0 has brought another dimension to project planning and scheduling by considering the digitalisation and automation of construction operations with multiple software platforms, interconnecting stakeholders and collecting and analysing big data streams [64].

3.6.5. Cluster 5

a. Stakeholder Management

Effective communication serves as a tool in stakeholder management. Risk information must be communicated to project teams to ensure that the right information reaches the right people. Risk management requires coordination and management among stakeholders [64]. Mutual agreement and a wide range of participation of the stakeholders are required for effective risk management [65]. Risk allocation must be equitably and realistically shared by all stakeholders [66]. Allocating risks to one stakeholder will result in an unfavourable effect on both transferees and transferrers, which might subsequently impact the project [67]. Stakeholder management is a part of risk management in which risks associated with each stakeholder are identified and categorised with risk mitigation strategies [68].

4. Future Research Directions

Considering the complexity that current construction projects embody, risks in construction will continue to be dynamic. Every construction project is unique in terms of its design, construction, and even risks. Construction professionals have to keep adjusting their risk management skills to suit the dynamics of the project they are managing. Project managers and construction managers may have dense experience that can be accumulated as reasonably as possible to be used as a reference. With the growing adoption of technology in construction projects, risk management in construction should be computerised just as it began in 1979. A computerised approach, such as artificial intelligence can be adopted to effectively predict risks by considering the project's characteristics. A probable solution can also be suggested to guide project managers, especially amateurs in their line of duty. Artificial intelligence models can solve dynamic, uncertain, and complex tasks [69]. The construction industry is experiencing a rapid digital transformation due to technological advancement [70] and moving towards Industry 5.0. Artificial intelligence can monitor, recognise, evaluate, and predict potential construction risks [70]. Artificial intelligence-based risk analysis can provide assistive and predictive insights on risks to determine proactive actions instead of reactive actions for risk mitigation [70]. As the construction industry is becoming more digitised, more studies may have to be conducted on using artificial intelligence models in risk prediction and mitigation.

Secondly, researchers of risk management in construction should consider studies on risk mitigation strategies. Most of the studies on risks have been purely quantitatively based, which limits the ability to gain dense knowledge from construction professionals. As stated earlier, construction projects are dynamic and complex. However, there might be some similarities among risks in different projects. Hence, using qualitative studies to gain dense expertise and knowledge on risk mitigation strategies and computerisation may reduce the amount of time spent on brainstorming risk mitigation strategies.

Thirdly, future studies can consider the mental health risks that construction projects pose for construction professionals, especially project managers and construction managers. It is necessary to treat mental health issues appropriately. Such issues are a leading cause of work losses, in terms of absenteeism, presentism, and sick leaves [71]. Work tasks for project managers are more cognitively demanding than physically demanding. Project managers perform tasks that rely heavily on cognitive functioning, the mental processes involved in information processing such as decision-making, working memory, attention, and learning [72]. Research on disruption and interruptions has demonstrated that many working conditions impair the performance of cognitive capacities [73,74].

Fourthly, the majority of the authors are from developed countries as opposed to developing countries. It is recommended that more studies especially use a qualitative research approach to interrogate the risk management approaches in developing countries to achieve better project management performance.

5. Conclusions

Construction risks are multi-faceted both in developing and developed countries. The economic situation in a country may also dictate the risks that countries may face. Construction risks are inherent and challenging to deal with. This study conducted a scientometric analysis of the research trend on risk management in construction. Scopus was selected as the database for the analysis. A total of 1635 documents were retrieved and analysed. The analysis was conducted on the annual publication trend, co-occurrence networks (which included those of the most productive countries, most productive authors, most productive journals, and most frequently occurring keywords), and key research areas.

According to the annual publication trend, the period between 1979 and 1989 recorded 12 publications on risk management in construction. In this era, the studies were predominantly focused on the computerisation of construction risks to provide construction professionals with dense information on risk management. It was realised early in the 1980s how complex and dynamic construction projects are with their numerous and unprecedented risks. The period between 1990 and 1999 recorded only 55 publications. The period between 2000 and 2020 recorded 1363 publications. Between 2021 and 2022, 205 publications were recorded. Based on this analysis, it can be predicted that the next decade will see significant research studies on risk management, especially as the construction industry is moving towards Industry 5.0. In addition, the most productive countries were China, the United States, the United Kingdom, Australia, and Hong Kong. This signifies a considerable increase as compared to the 1990s and 1980s eras. Journals with the most published research on risk management in construction were the Journal of Construction Engineering and Management, Engineering, Construction and Architectural Management, Construction Management and Economics, Safety Science, and the Journal of Management in Engineering. Similarly, conference proceedings that have contributed the most to the research field of risk management in construction include the IP Conference Series: Materials Science and Engineering, Proceedings, Annual Conference-Canadian Society for Civil Engineering, Procedia Engineering and Proceedings of the International Conference on Industrial Engineering and Operations Management. Emerging key research areas were discussed using the network diagrams and clusters developed by VOSviewer and Gephi. The emerging keywords were discussed under the following themes: process in risk management, risk analytical models and techniques, sources of risk and uncertainties, effective knowledge-based systems for improved risk management, risk contingency in construction contracts, risk-integrated project planning and scheduling, and stakeholder management. The network diagram of author keywords produced by VOSviewer and Gephi were grouped and discussed under key risk management in construction research areas using the basic understanding of risk management.

The study contributes significantly to the existing body of knowledge on risk management in construction. It informs researchers on how well studies on risk management in construction have progressed and suggests some of the possible future studies that can be conducted. The findings provide researchers with knowledge on the genesis of risk management in construction and the research trend over the past four decades.

This review study has some limitations that may affect the generalizability of the research findings. First, the search for risk management studies was limited to only construction projects. Second, the publications considered in this study were those that are indexed in Scopus only. Other databases, such as Google scholar and Web of Science, were not included, and this was done to avoid duplications. Notwithstanding these limitations, this study was thoroughly conducted, and the findings contribute significantly to future risk management studies and practices in the construction industry.

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