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Review

A Scientometric Analysis of Construction Bidding Research Activities

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Abstract: Bidding is the process in which a contractor submits a tender to the owner of a construction project to undertake its execution. This enables companies to properly employ required contractors. This paper investigates the trends of research conducted on construction bidding from 1975 to 2022 through a scientometric analysis from different viewpoints. A total of 299 relevant articles published in 191 journals were collected from the Web of Science database and analyzed by HistCite and CiteSpace software. The top journals, articles, institutes, and authors that contributed to bidding studies were ranked. The trends of published articles and contributions from different countries on the subject were examined. Moreover, the co-occurrence network, strongest burst detection, trends of the top keywords, and cluster analysis were determined. This review creates an in-depth insight into the content, enabling researchers to understand the existing body of knowledge and to trace a practical guideline for future studies.

Keywords: construction bidding; bidding strategy and models; scientometric analysis; CiteSpace; HistCite

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1. Introduction

The increase in global population and extension of societies over the last century, as well as the need for infrastructure development, has led to greater attention on the construction industry and subsequently higher funding and investment in construction projects [1,2]. As such, the larger the number of construction projects, the greater the problems and challenges created in this field [3,4]. The bidding issue has been one of the most challenging aspects for the construction industry over the last century [5]. For information, construction bidding is a process through which a contractor submits a proposal (known as tendering) to undertake the construction of a project. This process, which has several stages, is an incredibly important part of the project, as it allows the owners to find the best possible teams for the construction job at the most competitive price. Proper bid management assists contractors to avoid any time wastage and maximize each bid's efficiency. This is particularly important to contractors when other projects are occurring, and several tender processes are being held at the same time [6]. More than merely a technical matter, construction bidding also covers economic, legal, and managerial aspects of construction. Therefore, it plays an essential role in the successful implementation of construction projects [7,8]. Bidding can be independently investigated from the client's, contractor's, or consultant's viewpoints.

From the client's perspective, topics like analyzing, rating, and choosing the offers are usually addressed. As an example, Ballesteros-Pérez et al. [9] presented a graph and a mathematical equation for scoring construction offers. In further research [10], they developed a quick method for detecting abnormal and collusive bids, by extending a model that was introduced for capped auctions [11]. They also developed several scoring systems and a wide variety of economic scoring formula (ESF) and abnormally low bid criteria in construction tenders in a taxonomic review process [12]. Moreover, Chotibhongs and Arditi [13] found a step-by-step method for identifying collusions in bidding, using the data provided by a public agency. Porter and Zona [14] addressed the ways to detect rigging in procurement auctions, concentrated on highway construction contracts. Ballesteros-Pérez et al. [15] estimated the number of new and repeated bidders in construction auctions, using a multinomial model beneficial for selective and open tendering.

From the contractor's perspective, many pieces of research are related to bidding strategy models, categorized as Bid/No-Bid and Mark-Up decisions. For example, Friedman [16] presented the first bidding strategy model to address mark-up decision-making, a new method at the time and one which interested other scholars. In response to this innovative approach, several scholars presented further creative models for mark-up decision-making [17–19]. Some researchers also addressed Bid/No-Bid decision modeling. For example, Wanous et al. [20] and Dias and Weerasinghe [21] presented their new models using the artificial neural network (ANN) technique, which is a subset of artificial intelligence (AI). The studies by Ahmad [22] and Bagies and Fortune [23] are similar cases. A more prominent piece of research relevant to this topic was accomplished by Lin and Chen [24], which introduced the Bid/No-Bid decision as a crucial contractor action and proposed a fuzzy linguistic approach for a better decision-making process. From the other perspective, Skitmore and Picken [25] studied the accuracy of pre-tender cost estimation by analyzing the data collected from the USA construction industry.

Some academics characterized the electronic bidding (EB) procedure as an innovative method for construction bidding, although most acknowledged that the EB approach is yet to be efficiently implemented. For example, Nesan Lenin [26] proposed an online framework for solving this problem. A more functional model was also developed for EB by Arslan et al. [27] In a more advanced study, Aibinu and Al-Lawati [28] presented a technique capable of modeling the construction organization tendencies in the EB process. In addition, Idoro [29] compared the planning and performance of direct labor (DL) construction projects with those of design-bid-build (DBB) projects in Nigeria. The results showed that, despite the public viewpoint, the levels of design and construction planning achieved in DBB and DL projects differ, which should be improved. Banki et al. [30] conducted a quantitative analysis of the relationship between the number of bidders and the project bid price. They found that increasing the number of bidders will result in a reduced bid price. Hassanein and Hakam [31] offered the application of a systematic decision-making methodology for contractors based on the multi-attribute utility theory. This assists contractors to decide whether to bid on a certain project.

From the consultant's perspective, Gheorghe [32] described a specialized AI framework for consulting engineering management using ANN. This framework guides the complex and unstructured business of bid decision-making on large-scale projects and other consulting engineering tasks. Drew and Skitmore [33] examined the relationship between the size of a bidder and that of the contract, in terms of competitiveness from a consultant's perspective. The results showed that to prepare a bid list, consultants should be informed of some technical data, such as "the size of bidders", "type of bidders' preferences", and "recent experience of bidders in constructing projects with a similar type and contract value". A recent viewpoint on bidding as a multifaceted issue among stakeholders has introduced the BIM method as an Information Technology (IT) tool for organizing the reciprocal interdependencies among different stakeholders to manage the bidding process in construction projects [34].

Nevertheless, despite the passage of considerable time since the first studies into the field of bids in the construction industry, the emergence of new methods and innovative technologies continues to broaden horizons for researchers and specialists in this field. According to the authors, conducting studies that comprehensively review the literature will no doubt significantly affect the formation of a suitable mental foundation for researchers and form the basis for future research in this field. This matter will take on greater significance due to the importance of tenders in the construction sector, anticipated to become one of the most popular research topics in the years to come. This research is unique since, unlike other research studies, it does not confine itself to a particular subfield of problems associated with tenders. Second, by combining scientometric and systematic methods, it attempts to conduct a comprehensive quantitative and qualitative analysis of the literature produced over half a century.

2. Significance of the Study

Scientometrics is the field of study which enables researchers to measure and analyze academic literature. It particularly includes quantifying the impact of research papers and academic journals and understanding scientific citations. In the past three decades, this field has become an extremely popular way of evaluating the research performance of researchers, universities, countries, and scientific journals. Accordingly, the current study aims at undertaking a scientometric assessment of the global research conducted on construction bidding from 1975 to 2022. This assessment provides an opportunity to gain valuable insights into the evolution of global bidding research and its relevant technical issues. This review provides an in-depth understanding of the existing research and specifies the developing trends in this area.

3. Materials and Methods

3.1. Data Collection

Although different databases are used by researchers, the Web of Science (WoS), Scopus, and Google Scholar are currently the most popular worldwide [35]. It should be noted that the Scopus database has attempted to dominate the research data market, but the WoS is still the research data center covering the most authoritative journals [36–38]. As such, the WoS core database was adopted for this study to conduct the scientometric analysis. A considerable number of outstanding publications in construction bidding were reviewed to identify related prestigious topics. “Bidding” and “tendering” in combination with “construction” were searched in the field of “topic”. The primary results delivered 356 records. Some researchers investigating the process of qualitative literature reviews have previously commented that a decision appears to be required on the benefits of the comprehensiveness of findings versus the accuracy of the studies identified [39]. Given the common usage of sub-sections of papers for systematic reviews, the findings suggest that comprehensiveness should be the key feature for this type of search. It means that using research tools (e.g., SPIDER, PICOS) are beneficial for review teams with extremely limited resources or time and those not aiming for a comprehensive search. Therefore, as comprehensiveness was a key factor for this research, the search tools were not applied preferentially [40]. This study followed the steps recommended in the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) checklist [41].

At the time of preparing this paper, the oldest documents in the WoS dated back to 1975, and the newest were from 2022. No limitation was adopted in terms of time to reach a complete analysis and comprehensive interpretation. As a result, this 47-year range was set for the analysis. Results were also limited to “English” in terms of language. Except for articles, proceeding papers, early access, and review articles, all other types of research, such as books and editorial materials, were excluded from the analysis, as journal articles commonly supply more holistic and higher-quality information than other documents. In addition, most literature reviews on construction management have only covered journal articles [42,43]. Irrelevant areas to exclude from the search process were carefully determined, such as medical science, chemistry, and thermodynamics. The number of records subsequently decreased to 327. At the second step in the filtration process, several topics in bidding areas that were unrelated to construction (such as the Olympics, antiques, and arts) were recognized and excluded by reviewing and analyzing the topic of papers (including title, abstract, and keywords) to identify the articles by industry, aim, and research methodology, as well as keywords that play a decisive role in selecting relevant articles for further purification of the results. This was done to ensure that the analysis was not misleading nor the results' precision compromised. After applying all the filters and result purification, 299 journal articles about construction bidding, published from 1975 up to September 2022, were collected. As depicted in Figure 1, publications in this research area have been an increasing trend, a tendency that is more intuitive since 2007, due to a boom in the construction industry and the challenges around it [44,45]. It is worth noting that the reduction in the number of publications in 2022 compared to the previous year is because the number of articles only represents 9 months.

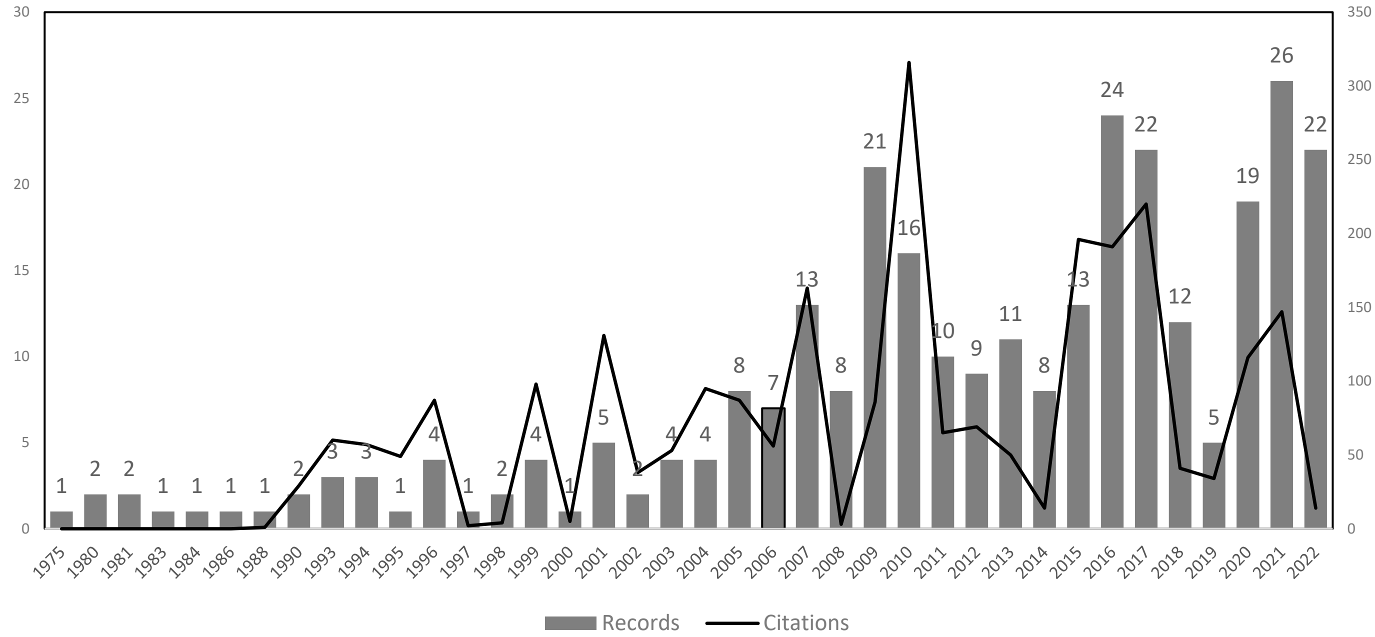

Figure 1. Trends in publication number and citations in construction bidding (1975–2020).

3.2. Scientometric Analysis

Scientometric analysis is a procedure that utilizes statistical and mathematical methods for quantitatively analyzing the knowledge domain for a specific issue using a review of numerous articles [46]. It can be defined as a way of reviewing and summarizing studies conducted in a research area [47]. Scientometric analysis has been widely adopted in construction research to investigate the attributes, framework, essential and popular topics, and research trends [48–51]. It is noticeable that, although scientometric analysis is quantitative in process, the resultant data can be presented by qualitative attributes [52]. Scientometric analysis software is divided into two categories based on their outputs: (I) the output is raw and should be processed in another software to be interpretable; (II) the output is interpretable, with no need for further processing [53,54]. In the current study, two popular and applicable pieces of software, namely HistCite and CiteSpace, have been used for the quantitative and qualitative analysis. HistCite is open-access software produced by Garfield's team at the Information Science Institute (ISI). It focuses on generating chronological maps of bibliographic collections resulting from ISI–WoS searches on subject, author, institutional, or source journal [55]. CiteSpace is open-source scientific visualization software developed by Chaomi Chen [56,57] whose use has spread among scholars all over the world because of its robust function [58,59]. After importing the WoS' data into HistCite and CiteSpace, it was processed and analyzed in several terms. HistCite outputs were further processed in Excel, and the resultant tables, graphs, and figures were provided, as shown in the next section.

4. Results and Discussion

4.1. Top 20 Journals

The top 20 (out of 191) journals existing in this collection were ranked, as listed in Table 1. The results indicate that a significant amount (i.e., about 20%) of the collected papers belong to these top 20 journals. To make a qualitative comparison among relevant journals [60], the index of "Citation per Paper (CPP)" was employed based on Equation (1) [43].

$$\text{Citation Per Paper (CPP)} = \frac{Number\ of\ citations}{Number\ of\ papers} \quad (1)$$

Table 1. Top 20 journals on construction bidding studies (ranked by CPP).

Rank	Journal	IF (2021)	Quartile (2021)	No. Articles	No. Citation	CPP
1	*Management Science*	6.172	Q2	1	70	70
2	*Automation in Construction*	10.517	Q1	5	274	54.8
3	*Journal of Industrial Economics*	1.054	Q4	1	53	53
4	*Energy*	8.857	Q1	1	49	49
5	*Journal of Construction Engineering and Management*	5.292	Q1	4	180	45
6	*Transportation Research Part B-Methodological*	7.632	Q1	2	78	39
7	*Social Networks*	4.144	Q1	1	38	38
8	*International Journal of Project Management*	9.037	Q1	1	36	36
9	*Building and Environment*	7.093	Q1	2	67	33.5
10	*Journal of Financial Management of Property and Construction*	0.49	Q3	1	32	32
11	*Review of Industrial Organization*	0.35	Q3	1	29	29
12	*International Journal of Computational Intelligence Systems*	2.259	Q3	1	28	28
13	*Journal of the Operational Research Society*	3.051	Q2	2	48	24
14	*Canadian Journal of Civil Engineering*	1.771	Q3	2	47	23.5
15	*Operations Research Perspectives*	3.382	Q2	1	22	22
16	*Construction Management and Economics*	0.80	Q2	7	148	21.14
17	*Omega-International Journal of Management Science*	8.673	Q1	1	21	21
18	*Iranian Journal of Science and Technology Transaction B-Engineering*	0.719	Q2	1	20	20
19	*Journal of Computing in Civil Engineering*	5.802	Q2	1	20	20
20	*Construction Innovation-England*	2.667	Q2	2	38	19

Furthermore, as observed in Table 1, most of the top journals have only one highly cited article. In terms of CPP, *Management Science*, *Automation in Construction*, and *Journal of Industrial Economics* ranked first to third. The results of Table 1 show that, although the *Journal of Construction Engineering and Management* has been ranked third in terms of the citation of articles after the journals *Construction Management and Economics* and *Automation in Construction*, it was not included among the top three journals due to its low citation rate in comparison to other publications. Furthermore, although *Construction Management and Economics* is ranked first in terms of number of publications, it is placed sixteenth by CPP because of the low number of citations to its articles. A brief look at Table 1 indicates that there is no direct relationship between the number of articles published, or the number of citations, and the ranking of a journal. Journal ranking based on the CPP also has no specific relationship with the Impact Factor (IF), with some fluctuations observed in this index. Thus, CPP can be a more reasonable criterion for ranking journals.

4.2. Top 10 Articles

As described earlier, 299 papers published in 191 journals from 1975 to 2022 were collected in this study. The top 10 of these are listed in Table 2. They were ranked according to the number of citations as a critical indicator, demonstrating the quality of the research [61]. By reviewing their titles, it is found that these 10 papers are related to contractor selection [62–64], opportunistic bidding [65,66], bid price estimation [67–69], bid/no bid decision [70], and e-bidding [28]. For information, the most cited paper is for Aibinu and Al-Lawati [28] with 123 citations to date.

Table 2. Top 10 articles on construction bidding studies based on citation number.

Rank		Information	Year	Citations	Reference
1	Author(s) Title *Journal*	Aibinu, A.A.; Al-Lawati, A.M. Using PLS-SEM technique to model construction organizations' willingness to participate in e-bidding *Automation in Construction.*	2010	123	[28]
2	Author(s) Title *Journal*	Ho, S.P.; Liu, L.Y. Analytical model for analyzing construction claims and opportunistic bidding *Journal of Construction Engineering and Management.*	2004	85	[66]
3	Author(s) Title *Journal*	Song, J.; Regan, A. Approximation algorithms for the bid construction problem in combinatorial auctions for the procurement of freight transportation contracts *Transportation Research Part B-Methodological.*	2005	74	[62]
4	Author(s) Title *Journal*	Sullivan, J.; El Asmar, M.; Chalhoub, J.; Obeid, H. Two Decades of Performance Comparisons for Design-Build, Construction Manager at Risk, and Design-Bid-Build: Quantitative Analysis of the State of Knowledge on Project Cost, Schedule, and Quality *Journal of Construction Engineering and Management.*	2017	73	[68]
5	Author(s) Title *Journal*	Dyer, D.; Kagel, J.H. Bidding in common value auctions: How the commercial construction industry corrects for the winner's curse *Management Science.*	1996	70	[63]
6	Author(s) Title *Journal*	Dikmen, I.; Birgonul, M.T.; Gur, A.K. A case-based decision support tool for bid mark-up estimation of international construction projects *Automation in Construction.*	2007	67	[67]
7	Author(s) Title *Journal*	Chen, Z.S.; Zhang, X.; Rodriguez, R.M.; Pedrycz, W.; Martinez, L. Expertise-based bid evaluation for construction-contractor selection with generalized comparative linguistic ELECTRE III *Automation in Construction.*	2021	63	[64]
8	Author(s) Title Journal	Moselhi, O.; Hegazy, T.; Fazio, P. DBID—Analogy-Based Dss for Bidding in Construction *Journal of Construction Engineering and Management.*	1993	60	[69]
9	Author(s) Title *Journal*	Bageis, A.S.; Fortune, C. Factors affecting the bid/no bid decision in the Saudi Arabian construction contractors *Construction Management and Economics.*	2009	58	[70]
10	Author(s) Title *Journal*	Lo, W.; Lin, C.L.; Yan, M.R. Contractor's opportunistic bidding behavior and equilibrium price level in the construction market *Journal of Construction Engineering and Management.*	2007	54	[65]

4.3. Keywords Analysis

Keywords elucidate the main body of knowledge and summary of a specific research area. They are useful in understanding the research trend and the concerns of researchers in that field over time. To create a visual understanding of keywords, a keyword co-occurrence network including nodes and edges is illustrated in Figure 2. The nodes represent the frequency of the keywords, and each edge represents the co-occurrence relationship between the two keywords. The size of a node's area depends on the frequency of the keywords connected, and the thickness of any edge is proportional to the number of combinations of those two keywords in past studies [58,71]. As observed, 144 nodes and 250 edges were depicted in Figure 2, in which the density of the network is 0.0505. It should be noted that the words "Bidding", "Bid", "Tendering", and "Construction" were removed from the graph to ensure that more attention is paid to other words containing the basic concepts of construction bidding. Keywords help to achieve better results in the analysis process.

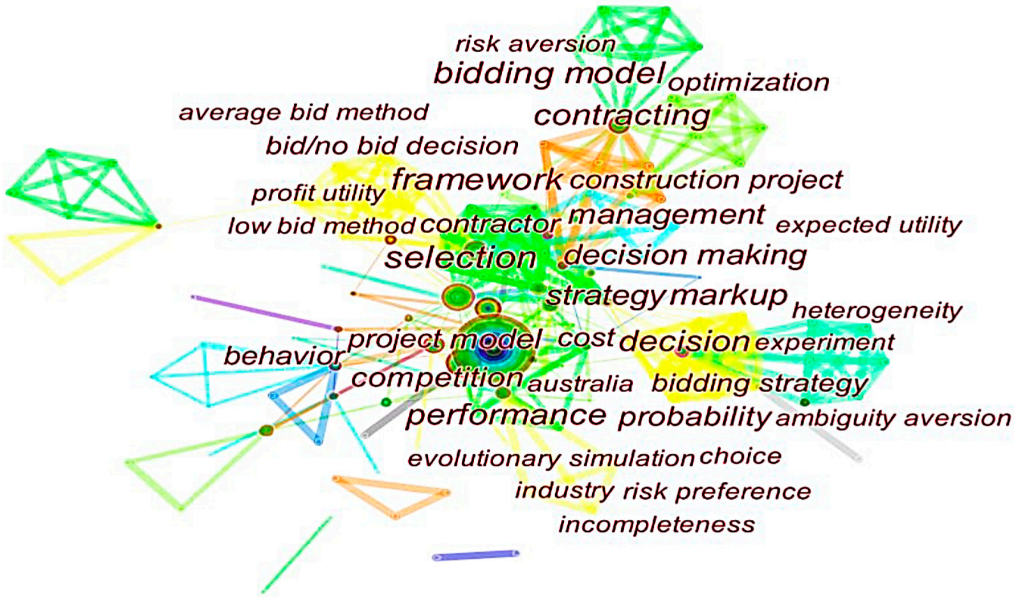

Figure 2. Keyword co-occurrence network for construction bidding.

It might be interesting that the words "Model" (with a frequency of 53), "System" (25), "Selection" (21), "Contractor" (18), "Competition" (17), "Framework" (17), "Contracting" (14), "Strategy" (14), "Market" (13), and "Decision" (11) were the top 10 keywords with the highest frequency. Since the presentation of the first model in construction bidding, analytical modeling has become an important part of this research field. Many scholars have introduced their models in the forms of Bid/No-Bid, competitive, and mark-up models from the contractor's perspective, and reasoning and scoring models from the client's perspective. This is just one of the major interests of scholars in this field.

The second keyword, namely "System", is a generic phrase related to project delivery, contracts, selection, checking process, bid price determination, etc. The trend of changing the top 10 keywords in 5 slots of 8-year periods is illustrated in Figure 3. As observed, keywords such as "Model", "Decision", "Contractor", and "Strategy" have experienced a more tangible rising trend in response to the expansion of various decision-making models from contractors' perspectives in recent years, while other keywords have indicated a slowly rising trend.

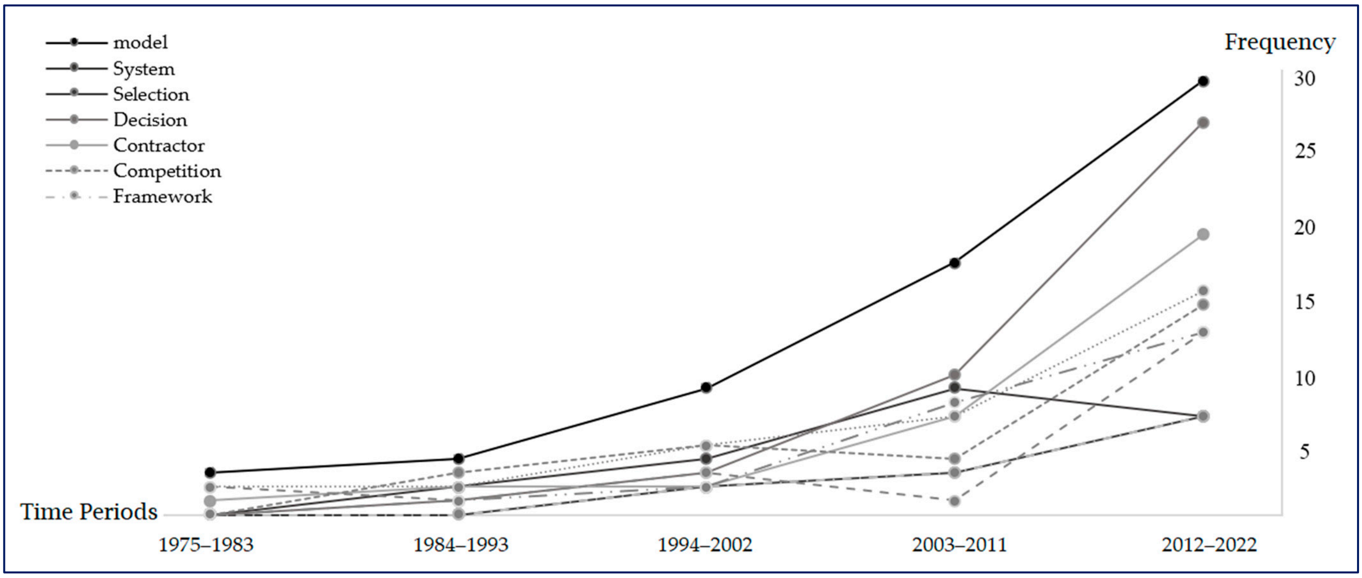

Figure 3. Trends of top 10 keywords' frequency related to construction bidding (1975–2022).

4.4. Cluster Analysis

Construction bidding is one of the popular research areas in the construction industry. Aligned to this area's development in various technical, legal, and financial aspects, research is divided into numerous extensive categories. Identifying and reviewing these categories enables scholars to improve their perception of this field. As a result, this approach will better guide future research efforts. Even though surveying the frequency of keywords is useful in recognizing the hot topics, it is inadequate to only consider the keywords' co-occurrence network for discovering these categories. Cluster analysis, performed by CiteSpace, is a beneficial approach to improve the study. It employs three algorithms to analyze the data, including (1) Latent Semantic Indexing (LSI), (2) Log-Likelihood Ratio (LLR), and (3) Mutual Information (MI), as described by Chen [58]. Each of these algorithms has its procedure, with the results obtained from each algorithm differing or being identical to each other. In this study, nine clusters were obtained based on the LLR algorithm, which is illustrated in Figure 4. The LLR algorithm is a statistical test used to examine the fit of two models: the null model and the alternative model. The approach is based on the likelihood ratio, which is used to demonstrate how frequently, or how likely, the data are covered by one model as opposed to the other [72].

For more clarification, detailed information on cluster analysis is described in Table 3. The table includes the quantities for "Size", displaying the number of published papers for each cluster, and for "Silhouette", representing an index that shows the homogeneity of the clusters, varying from 0 to 1. The closer the index is to 1, the higher the consistency between the members of a specific cluster [73]. The table also includes "Top Keywords", which indicates the representative keywords of each cluster. As observed in Table 3, the level of the silhouette is high (i.e., more than 0.8) for all adopted clusters. This implies that the consistency is high among the members of each cluster.

Figure 4. Cluster analysis of construction bidding.

Table 3. List of clusters in construction bidding research.

Cluster	Size	Silhouette	Top Keywords
#0 Public work	29	0.89	Construction contracting, Bidding phase, Environmental [74]
#1 Construction bid price evaluation	28	0.898	Clients' perspective, Bid evaluation process, Construction industry [75,76]
#2 Construction organization's willingness	26	0.878	The critical factor, using PLS-SEM technique, Bid/no bid decision [77]
#3 Highway construction industry	26	0.819	Bid evaluation, Indian government, Construction projects
#4 Transportation construction	21	0.883	Contractor bid, Highway construction industry, Transportation procurement auction
#5 Demand bidding construction	18	0.886	Hybrid IGDT-probability methodology, large consumer, Heterogeneous fleet
#6 Clients' perspective	14	0.942	Bid evaluation, Construction industry, Bid evaluation process
#7 Bid construction problem	13	0.982	Heuristic solution approaches, Preventing construction dispute
#8 Risk perception	13	0.918	The Australian construction industry, Bidding phase

4.5. Strongest Burst Detection

Recognizing the citation burst of keywords during different periods of research is one of the most appropriate approaches to understanding the researcher's concerns in a knowledge domain. The burst detection process has met this requirement. Burst detection is an analytical tool in scientometrics developed by CiteSpace, based on the algorithm introduced by Kleinberg [78]. Whenever a research topic experiences a citation burst as a keyword in a brief period, it is interpreted that the topic has attracted the attention of researchers and practitioners. In contrast, if there is no burst in a period, it is understood that the topic has not been attractive or a priority in that period [58]. This study performed a burst detection for the top 20 keywords in the construction bidding research area between 1975 and 2022. As illustrated in Figure 5, the columns "Begin" and "End" show the start and termination of each burst period, respectively. The index "Strength" represents the burst power degree for each keyword. It is noteworthy that each keyword was identified by burst detection, which was not necessarily the keyword with the highest frequency [52].

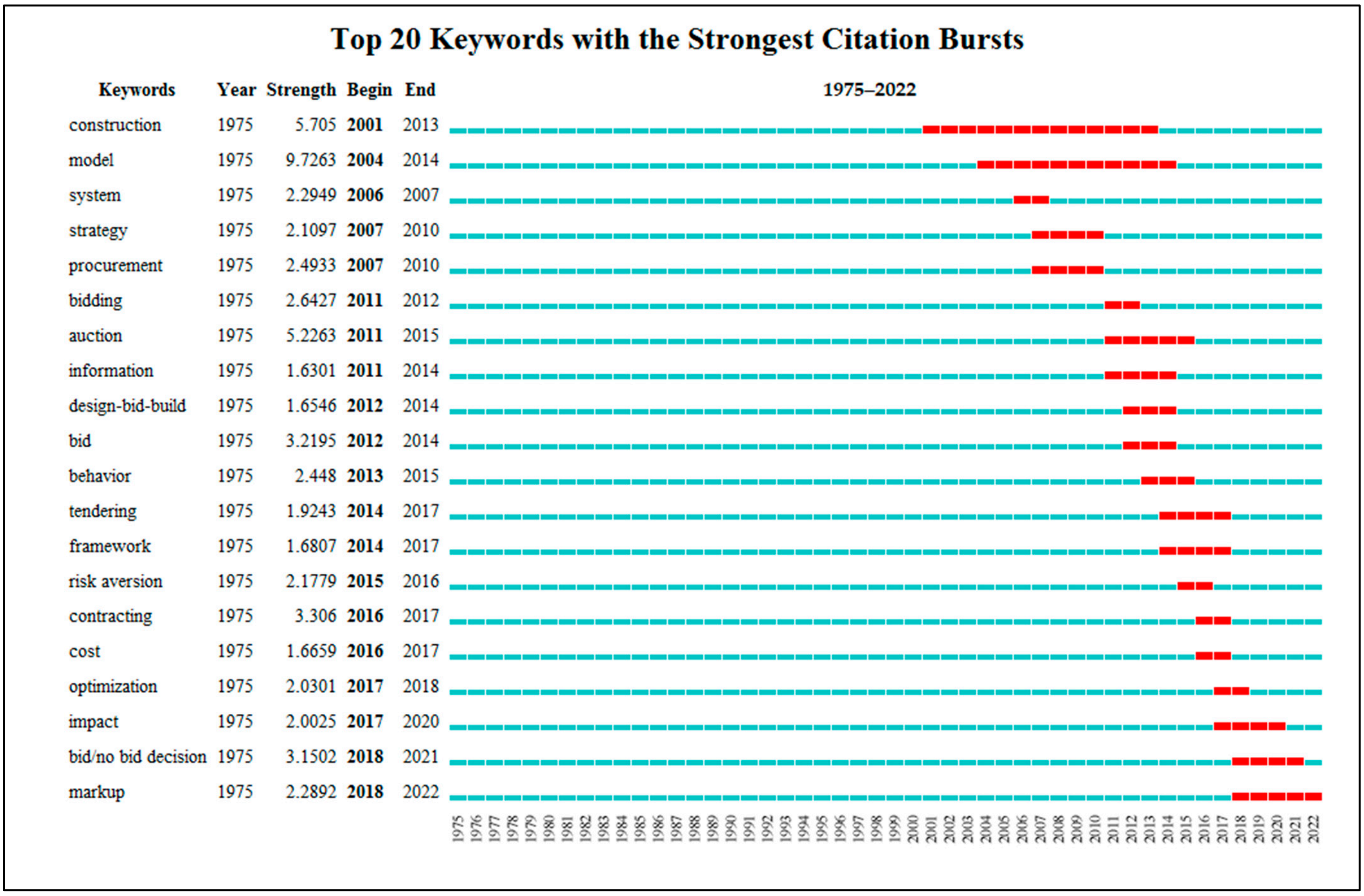

Figure 5. Top 20 keywords in construction bidding with the strongest citation burst.

The results show that the citation bursts started in 2001. Of course, this does not mean that the research work before 2001 was less than expected. As seen, a burst of the keyword "Construction" began in 2001 and continued until 2013, it being a general term that covers a wide range of different topics. The word "Model" was also the center of attention from 2004 to 2014. On the contrary, keywords like "Risk aversion" have received a limited amount of research attention and have experienced a short burst period. As expected, and observed, items like "Optimization", "Impact", "Bid/No Bid", and "Mark-up" have been extremely popular issues in recent years, due to their importance in decision-making models and financial influence.

4.6. Distribution of Published Documents Co-Citation Authors

To analyze the contribution of the best scholars, 640 authors were identified in 299 published articles. The top 10 authors are listed in Table 4, in rank order. The "H-Index" is an indicator introduced for a scholar's performance evaluation, which is calculated using the number of pieces of research and citations of each scholar [79]. As seen, Bee Lan Oo from the University of New South Wales, with 10 papers and 3.34% of the total papers, ranked first in the table. Martin Skitmore from the Queensland University of Technology held a similar position in the number of articles but ranked second due to his lower citation. Next are Khaled Hesham Hyari from Hashemite University and Kunhui Ye from Chongqing University, with 6 papers and 2.01% of the total papers, ranked third and fourth, respectively. It is remarkable that the research studies of Ballesteros-Perez P from the Universitat Politècnica de València have had the most citations, even though he has published fewer articles than the first four authors mentioned in the table. This indicates that more attention has been paid to his articles than those of others.

Table 4. Top 10 authors with the highest number of articles.

Rank	Author	H-Index	No. of Articles	Percent	Citation	CPP
1	Bee Lan Oo	-	10	3.34	167	16.70
2	Martin Skitmore	82	10	3.34	116	11.60
3	Khaled Hesham Hyari	16	6	2.01	128	21.33
4	Kunhui Ye	20	6	2.01	121	20.17
5	Ballesteros-Perez P	26	5	1.67	191	38.20
6	Islam H. El-adaway	28	5	1.67	87	17.40
7	Liu Jianbing	3	5	1.67	85	17.00
8	Muaz O. Ahmed	5	4	1.34	45	11.25
9	Tian JX	-	4	1.34	93	23.25
10	Zhen-Song Chen	21	3	1.00	83	27.67

4.7. Top 10 Institutes and Countries

Further investigation was conducted to recognize which institutions have had the most published journal papers in the construction bidding research field. Based on a preliminary review of the data, 309 research institutions were investigated, and accordingly, the top 10 academic institutions with the highest research contributions in construction bidding were specified, as listed in Table 5.

Table 5. Top 10 institutions with the highest number of articles in bidding.

Rank	Institution	No. of Articles	Percent	Citation	CPP
1	Chongqing University	14	4.68	57	4.07
2	Tianjin University	10	3.34	72	7.20
3	Queensland University of Technology	8	2.68	104	13.00
4	Hashemite University	7	2.34	37	5.29
5	Deakin University	5	1.67	44	8.80
6	Jiangxi University of Science and Technology	5	1.67	1	0.20
7	N China Elect Power University	5	1.67	9	1.80
8	Sichuan University	5	1.67	29	5.80
9	University of Alberta	5	1.67	146	29.2
10	University of Sydney	5	17	49	9.8

Regarding participation in the production of research content in construction bidding, these 10 universities possess a 21.4% share of all collected papers. As shown in Table 5, Chongqing University, Tianjin University, and the Queensland University of Technology, with 14, 10, and 8 published papers, are ranked first to third, respectively. Further study of the records indicates that Kunhui Ye has contributed to about 50% of the papers published by Chongqing University. This implies his in-depth contribution to construction bidding studies. Also, as shown in Figure 6, the contribution of different countries in construction bidding was analyzed. Their participation was measured based on the number of articles that each country published between 1975 and 2022. Their contribution ranges from just 1 article to more than 100 articles. It is observed that China, the United States, Australia, Canada, and Iran have had the largest contribution, each publishing more than 10 articles in construction bidding.

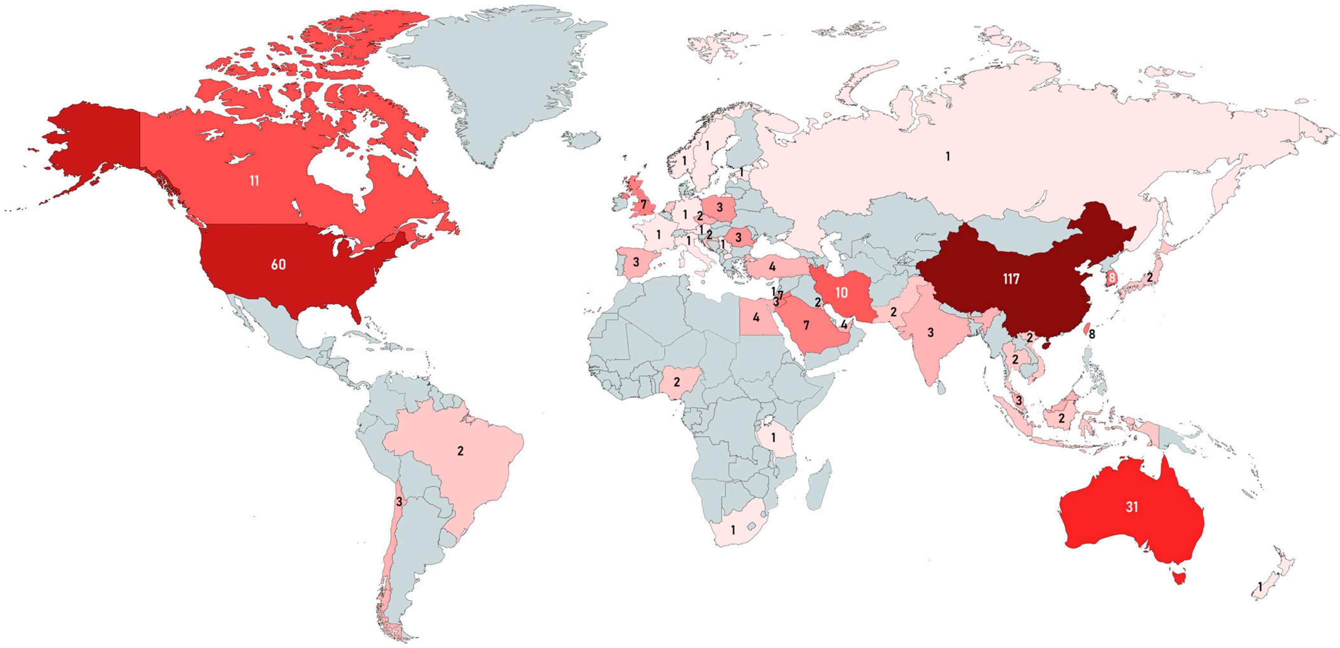

Figure 6. Contribution of countries based on the number of related publications on construction bidding research (1975–2022).

5. Discussions

Depending on the roles engaged in the tender process, studies in the field of tenders in the construction industry may be from the employer's or contractor's perspective as tenderers. From the standpoint of the employer, appraisal of contractors and proposals as well as fraud and collusion in bids have been of interest. Most of the articles have focused on the rating process, evaluation, and selection of contractors, as well as the bids submitted by them throughout the bidding process. Researchers have developed approaches for increasing accuracy, decreasing processing time, and optimizing the process [80,81] to resolve the problems and challenges posed by this crucial procedure for employers. In recent years, a substantial proportion of research on proposal evaluation from the employer's perspective has focused on finding and removing uneven bidding. Financial incentives make this topic particularly appealing to contractors. Even though a substantial number of prior studies consider unbalanced bidding to be a valid bidding strategy [82,83], public bidding regulations prohibit this technique and identify unbalanced bids as a significant problem in the bidding process. Construction projects are excluded from the competitive bidding procedure. Identifying and preventing their occurrence is a crucial and challenging responsibility for the employer; thus, it has been researched in relation to identifying and removing them from the tendering process [84].

Due to the nature and fundamental characteristics of bids, it is inevitable that numerous violations will arise during the bid process. Therefore, this procedure has been strictly examined and supervised by the bidder, and the researchers have proposed numerous techniques to prevent or address them. In capped tendering, collusion happens when bidders do not adhere to a conventional pattern. It indicates that their proposed price is too high or cheap, as collusive proposals must typically be sufficiently high or low to influence the distribution of the offer [11]. The works offered in this subject, which frequently employ mathematical approaches and statistical analysis, propose ways for identifying odd bids submitted with the intent of collusion [11,85]. Although these studies believe collusion in the presentation of bids to be the most prevalent form of fraud, other studies [86,87] have explored alternative potential forms of fraud in the bidding process. For instance, altering the results of bids is another form of tender fraud [88]. According to other research, the range of bid prices increases as the probability of fraud in a bid increases [89].

On the other hand, most difficulties raised from the contractor's perspective can be recognized in the decisions that the contractor must make at the various stages of the bid. Situations such as the company's decision to participate or not participate in the tender, the calculation of the bid price, the decision to present the bid coefficient, and the competitive strategies that the contractor must adopt in the competitive bidding process are clear examples of this claim. Examining the historical progression of the studies offered in response to these decisions reveals that the path pursued in this research field began with the identification and rating of the decision-influencing factors. Interviewing informants, sending questionnaires, and utilizing AHP, TOPSIS, and statistical procedures with techniques such as the relative importance index have been among the most popular research methodologies [90,91] for this type of investigation. In subsequent rounds, the outcomes of these studies were also included in decision modeling. Modeling has been one of the most extensively employed study methodologies in this subject in response to the decisions contractors must make at various phases of tendering [92]. Examples of these models include the models offered on the company's decision to participate or not in the tender, the decision to provide the recommended coefficient, and the decisions to be taken regarding the competitive strategies of the tender. Friedman proposed the concept of modeling in bids for the first time in 1956 [16]. Using the mathematical techniques of the time, Friedman offered a competitive bidding model that generated a new concept in the minds of researchers. In recent years, neural networks, fuzzy expert systems, and methods based on artificial intelligence have been utilized in model construction [93,94]. Over time, the employment of diverse methods such as mathematical models and probabilities gave way to new approaches. This finding can be generalized to the entire research field. Further examination of the topic of the articles based on the time of publication confirms the trend that, in recent years, the research field of construction industry tenders has been affected by the progress of new technologies. Many researchers have analyzed and investigated the implementation of new technological methods on the sector. They have paid a variety of biddings in construction sector. Figure 7 presents the hot topics evaluated by the researchers, separated from the employer and contractor perspectives, which were produced by systematic analysis, based on the time of prosperity during the 47-year research period.

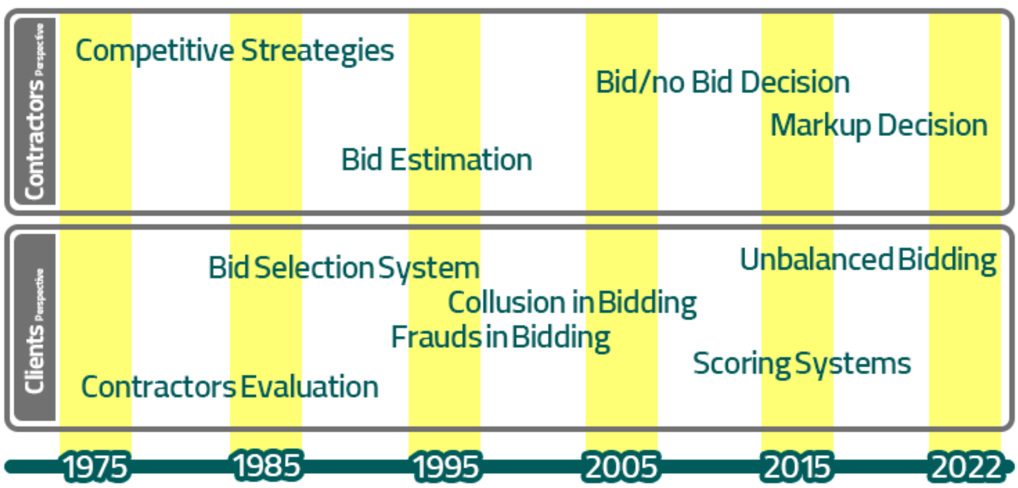

Figure 7. The chronological trend of the development of hot bidding topics during the past five decades (1975 to 2022).

6. Conclusions

This study contains a visualized and systematic overview of construction bidding research over the 47 years from 1975 to 2022. This paper covers not only the technical, but also the financial, legal, and managerial aspects of bidding. The required data were collected from the WoS database. Overall, 299 relevant articles were identified from 191 journals. Scientometric analysis was adopted to analyze the collected data in terms of yearly research trends, top 20 journals, top 10 articles, keyword analysis, cluster analysis, strongest burst detection, co-citation authors, top 10 institutes, and countries' contribution to construction bidding research. The documents imply a notable increasing trend in the number of publications since 2007. The *Management science*, *Automation in construction*, and *Industrial economics* journals were specified as the top three journals in the field. Bee Lan Oo, Martin Skitmore, and Khaled Hesham Hyari werealso recognized as the most active and influential scholars in construction bidding. Furthermore, the highest frequency keywords were identified using the keyword co-occurrence network. To further analyze the keywords, changes in the number of top keywords over time were identified. Cluster analysis was also conducted to supply a holistic review of the construction bidding research using CiteSpace software. The study demonstrated that "Analyzing", "Scoring", and "Choosing the Offers" from the client's perspective, "Bid/No-Bid Decision Modeling" and "Strategies" from the contractor's perspective, and "IT tools" from the consultant's perspective have been the main body of knowledge during these years. Based on the keywords' burst over the years, it was found that topics like the accuracy and validity of bidding documents, cost estimation, and the pre-bidding process represent some of the research gaps in this field requiring further research in the future. Moreover, it is expected that the future of this field in various stages of bidding will be affected by modern technologies like BIM, machine learning, and other tools of construction 4.0. This means that the direction of future studies in the field of construction bidding is recognized by scholars. In conclusion, by reviewing the research trend figures and creating an in-depth insight into the content of bidding, it is expected that the existing body of knowledge should be understood and a practical guideline for future research attempts carefully traced.

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