Technical Note

Scientometric Review of Articles Published in ASCE's *Journal of Construction Engineering and Management* from 2000 to 2018

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Abstract: This study aims to address research questions related to the evolution of academic research in the field of construction engineering and management (CEM): (1) what are the mainstream research topics since 2000? (2) what are the emerging topics or techniques in CEM within the recent decades? and (3) what are potential CEM research areas in the near future? A scientometric analysis was conducted to review articles published in *Journal of Construction Engineering and Management* since 2000, follow by a qualitative discussion. This study revealed that project performance indicator–related topics (e.g., cost, scheduling, safety, productivity, and risk management) have been the ongoing mainstream issues over the last decades. Labor and personnel issues gained even more research attention in the last 10 years. Information and communication technologies [e.g., building information modeling (BIM)] applied in CEM has been gaining the momentum since 2009. A variety of quantitative methods have gained popularity in the CEM discipline, such as algorithms, statistics, fuzzy sets, and neural networks. The follow-up qualitative analysis led to the contributions of this review-based study in terms that (1) it provided an overview of the research topics in CEM since 2000 through a text-mining approach; and (2) it offered insights into emerging and near-future research areas, including BIM and data analytics applied in various construction issues (e.g., safety), as well as integrations of research themes (e.g., risk assessment in newly emerging project delivery methods). **DOI: [10.1061/(ASCE)CO.1943-7862.0001682](https://doi.org/10.1061/(ASCE)CO.1943-7862.0001682).** © *2019 American Society of Civil Engineers.*

Author keywords: Literature review; Scientometric analysis; Construction engineering and management; Text mining.

Introduction

The field of construction engineering and management (CEM) involves managing a multitude of parties and workers in modern projects (Aboulezz 2003). CEM remains a relatively new discipline (Aboulezz 2003) and has become an established academic research area that produces a series of scholarly publications (Pietroforte and Stefani 2004). Academic journals such as the *Journal of Construction Engineering and Management* publish quality papers aiming to advance the science of construction engineering. An earlier review-based study conducted by Pietroforte and Stefani (2004) summarized the subjects with topics published in the *Journal* by recruiting articles published from 1983 to 2000. As suggested by Pietroforte and Stefani (2004), future research work could apply the citation analysis for publications. However, there is no study that follows up the suggestion provided by Pietroforte and Stefani (2004) to perform a review of the latest research topics published

in the *Journal*. This study aims to capture the latest research topics through reviewing the articles published in the *Journal* since 2000. These objectives are targeted in this review work: (1) provide the key information related to research keywords in the journal; (2) compare the mainstream research keywords between the recent decade and those published over 10 years ago; and (3) identify potential near-future research directions in the CEM field.

Scientometric Analysis Method

Scientometric analysis was introduced in assisting literature reviews to overcome subjectivity issues (Hammersley 2001) from some previous review-based studies (e.g., Ke et al. 2009) in the CEM field. A scientometric analysis consists of the text-mining and citation analysis. Detailed descriptions of scientometric analysis have been given by Song et al. (2016). Some existing software tools are available to conduct the scientometric analysis, e.g., VOSViewer (van Eck and Waltman 2010), CiteSpace (Chen 2016), and Gephi (Bastian et al. 2009). VOSViewer version 1.6.6 was adopted in this study to conduct the scientometric analysis. This was because VOSViewer is suitable for visualizing larger networks, and it also has special text-mining features (van Eck and Waltman 2014).

In this study, all articles published in the *Journal* since 2000 were downloaded and saved in a CVS-based data file, which was then loaded into VOSViewer for the scientometric analysis of keywords. More detailed steps of performing scientometric analysis have been described by Park and Nagy (2018) and Jin et al. (2019). In this research, scientometric analyses of keywords were performed to subsamples of literature on both a 10-year time span and yearly basis to view the trajectory of research topics over time. Following the scientometric analysis of keywords, a further

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J. Constr. Eng. Manage., 2019, 145(8): 06019001

qualitative analysis was conducted to evaluate the mainstream topics and to further propose near-future research directions in CEM.

Results of Scientometric Analysis

Keyword Analysis

A total of 2,217 articles published in the *Journal* since 2000 were selected for the scientometric analysis. The overall sample was divided into two groups: 1,422 articles published between 2009 and 2018, and the remaining 795 articles published from 2000 to 2008. These two subsamples were conducted for separate keyword analysis in VOSViewer. Figs. 1 and 2 provide visualizations of most frequently studied keywords from each subsample of literature.

The keywords in both figures and the follow-up Table 1 were generated after initial screening and treatment in VOSViewer. Basically, general keywords such as construction management or construction were removed. Keywords with the same semantic meanings, such as Building Information Modeling and BIM, were combined as BIM. Some other keywords, for instance, delivery, design-build (DB), build-operate-transfer (BOT), and public–private partnership (PPP), were not combined based on the fact that project delivery methods cover a variety of different types, such as DB and construction management at risk, and DB, BOT, and PPP are different types of delivery methods.

In both figures, the font and corresponding circle size represent the occurrence of the given keyword studied in the sample. There are also connection lines between keywords demonstrating their interrelatedness. It can be seen in Fig. 1 that following keywords

represent the mainstream topics in the *Journal*: cost, scheduling, productivity, safety, and risk, which represent key measurements of construction project performance. These keywords are categorized into clusters and linked to each other through connection lines. For example, scheduling is often costudied with CPM (i.e., critical path method), and the goal of scheduling is to achieve optimization, which could be achieved by adopting an algorithm. Extending these key measurements of project performance such as cost and safety, further studies covered organizational issues, labor and personnel issues, contracting, procurement and project delivery method (e.g., DB). Information and communication technology (ICT) and computer-aided applications in construction gained some momentum during the first decade of 2000s. Fig. 2 shows the evolution of main research topics in the last decade.

Compared with Fig. 1, it can be inferred from Fig. 2 that the major project performance measurements (e.g., cost, scheduling, productivity, and safety) remained the focus within the CEM community. However, some emerging keywords could be identified, including materials and methods, planning, quantitative method, and BIM. Examples of materials and methods include material selection in the design stage to achieve sustainability (Lee 2018) and innovative construction methods (Zhang et al. 2017) to address site constraints and the surrounding environment. Although ICT and computer applications had become one of the ongoing research topics before 2000, as discussed by Pietroforte and Stefani (2004), the methods or technologies applied have been updated. For example, automation has been studied in both of the two periods. However, algorithms, which were frequently studied from 2000 to 2008, seem to be updated by other various quantitative methods, e.g., fuzzy multicriteria decision making (Xia et al. 2011). Besides, keywords such as organization, as well as labor and personnel, are
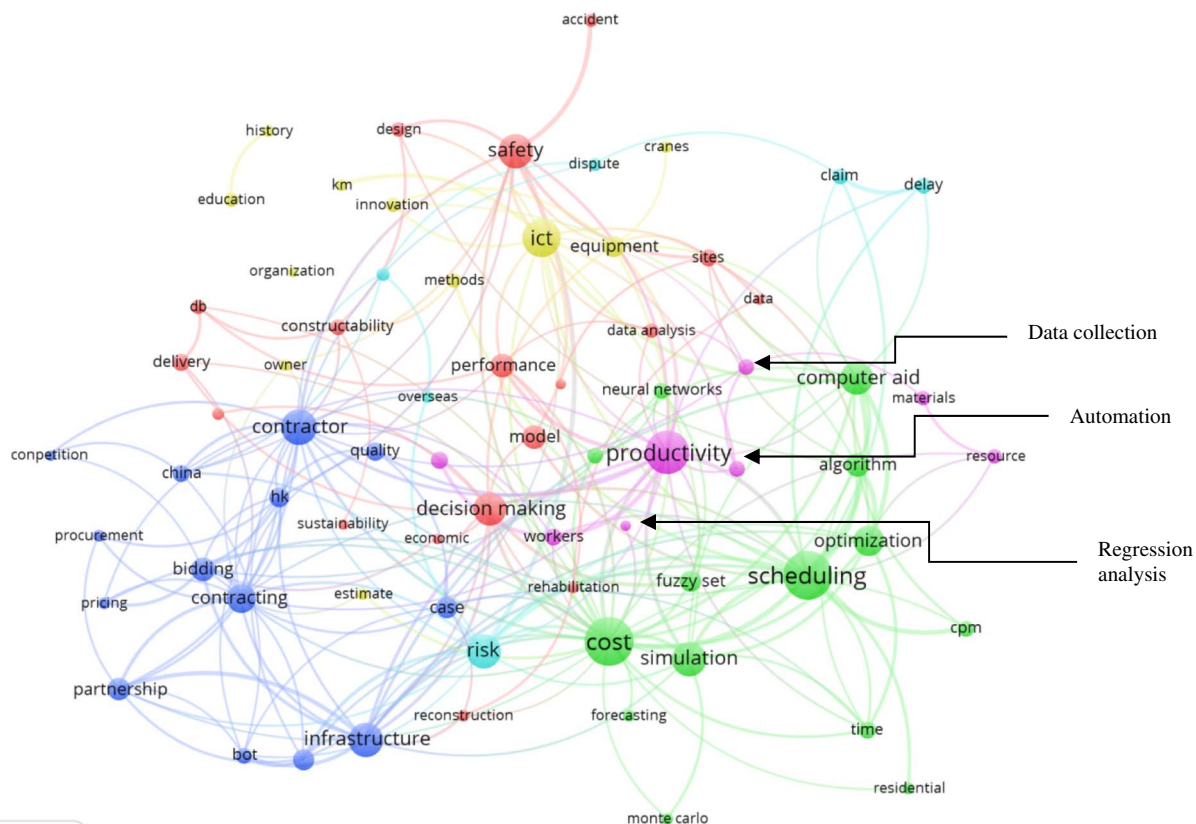

Fig. 1. Visualization of keywords studied for articles published between 2000 and 2008.
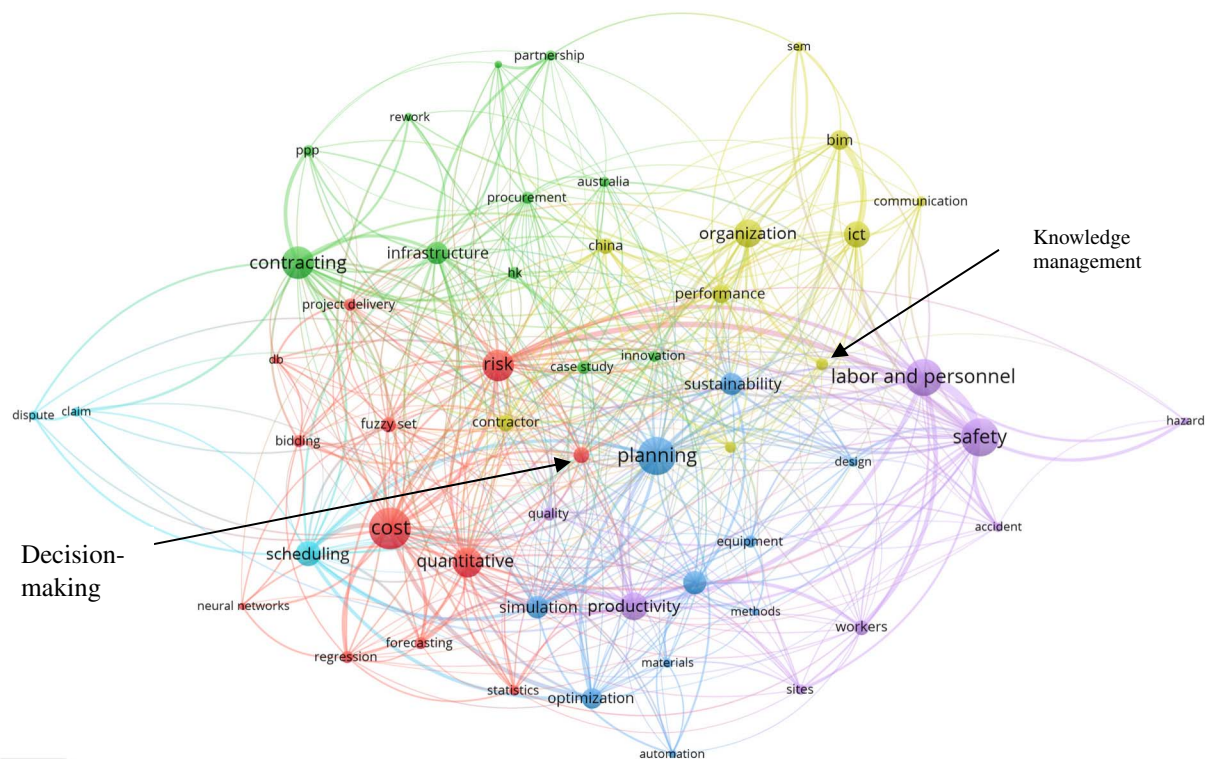
Fig. 2. Visualization of keywords studied for articles published between 2009 and 2018. ICT stands for information and communication technology, DB stands for design-build project delivery approach, SEM means structural equation modeling, and PPP means public–private partnership.

being studied more in the recent decade. A more quantitative summary of mainstream keywords from these two different time spans is provided in Table 1.

Keywords in both time spans are listed in Table 1 following the ranking of occurrence. Table 1 displays the two main measurement items for each keyword, namely occurrence from the literature sample and the average normalized citation. The latter measurement, introduced by van Eck and Waltman (2017), represents the normalized number of citations of a keyword by correcting the misinterpretation that older documents gain more time to receive citations. In this case, a higher average normalized citation means that the given keyword has a higher impact in the academic community by gaining more citations per year. It can be observed from Table 1 that the occurrence of keywords may not be correlated to their impact. For example, cost-related issues remain the most frequently studied topic in both time spans, but the keyword that received the highest attention in each subsample is hazard and partnership, respectively. An obvious difference between the two literature samples is the emerging topic of BIM, which received the second highest average normalized citations in the recent decade. It can be observed that the main research topics summarized by Pietroforte and Stefani (2004) for articles published before 2000 were highly consistent with the studies published in the *Journal* after 2000. These include IT applications, site and equipment, time scheduling, human resources management, project delivery systems, contractual issues, and technology development. However, somewhat opposite to Pietroforte and Stefani's (2004) findings, studies on project delivery methods (e.g., DB) showed a decreasing trend. In contrast, studies related to IT applications in CEM have been increasing since 2000.

The evolution of mainstream research keywords since 2000 can be further disaggregated into yearly basis for further comparison (Fig. 3).

Fig. 3 can be viewed in two directions. Horizontally, Figs. 3(a and b) list top three keywords with the highest occurrence and average normalized citation, respectively. Vertically, the evolution of yearly top-ranked keywords can be seen from 2000 to 2018. Fig. 3 shows that these main performance indicators in construction management, including cost, scheduling, contracting, personnel, and safety, remain the most widely studied topics cross all the years. Mathematical methods/modeling and strategic planning were more popular research methods in early 2000s. In more recent years, labor/personnel issues have become more commonly studied topics.

Qualitative Analysis of Research Keywords

The visualization in Figs. 1 and 2, as well as the quantitative measurements of keywords' influences in Table 1, indicate that the main themes classified by Pietroforte and Stefani (2004), (e.g., scheduling, cost, safety, and contracting) remained the same as the most widely focused-upon topics in the CEM field. A further qualitative analysis was hence conducted to compare the mainstream keywords between the two time periods. Based on the top-ranked mainstream topics in Table 1 (e.g., risk), Table 2 displays a qualitative comparison of typical studies published within the two different time spans.

It can be found from Tables 1 and 2 that the commonly studied topics remain unchanged in the recent decade. However, the approach or methods have been evolving. For example, cost, schedule, and productivity, as three interrelated themes and major performance measurements of construction projects, remain the top-studied topics in the recent 10 years. However, new research methods have emerged. Specifically, prediction or control methods using probabilistic, stochastic system, or Monte Carlo simulation (Barraza and Bueno 2007) can be frequently observed in literature

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Table 1. Quantitative analysis of keywords studied in the two literature samples from the *Journal of Construction Engineering and Management*

Years	Keyword studied in the article sample	Occurrences	Average normalized citations
2000–2009	Cost	82	1.06
	Scheduling	82	1.01
	Productivity	67	0.89
	ICT	55	0.91
	Contractor	51	0.99
	Infrastructure	48	1.05
	Safety	48	1.18
	Risk	47	1.29
	Simulation	47	0.93
	Computer aid	44	0.95
	Decision making	43	1.04
	Optimization	40	1.06
	Contracting	37	1.19
	Algorithm	27	1.41
	Model	27	0.85
	Performance	27	1.10
	Bidding	26	0.90
	Partnership	24	2.09
	Finance	23	1.26
	Case study	22	0.88
	Equipment	22	0.73
	Fuzzy set	22	1.13
	HK	20	1.69
	Quality	19	0.66
	China	17	1.37
	Delivery	17	1.41
	Labor and personnel	16	0.78
	Sites	16	1.42
	Time	16	1.12
	Workers	16	0.78
	BOT	15	1.44
	Claim	15	0.63
	Constructability	15	0.62
	CPM	15	0.76
	Delay	15	1.23
	Automation	14	0.78
	Data collection	14	1.25
	Neural networks	14	0.85
	Prediction	14	0.96
	Innovation	13	0.98
	Materials	13	1.24
	Resource	13	0.87
	Data analysis	12	0.70
	DB	12	1.34
	Design	12	1.02
	Education	12	0.51
	Methods	12	0.96
	Accident	11	1.60
	Dispute	11	0.97
	International	11	1.40
	Estimate	10	0.82
	Evaluation	10	1.00
	Knowledge management	10	1.11
	Overseas	10	1.30
2009–2018	Cost	144	0.80
	Planning	123	1.10
	Safety	123	1.58
	Labor and personnel	122	1.23
	Contracting	96	1.06
	Risk	92	1.27
	Quantitative	82	0.94
	Organization	76	1.07
	Productivity	75	1.00
	ICT	68	1.51
	Scheduling	65	0.79

Table 1. (*Continued.*)

Years	Keyword studied in the article sample	Occurrences	Average normalized citations
	Materials and methods	56	0.79
	Infrastructure	53	1.13
	Sustainability	53	1.34
	Simulation	51	0.88
	Optimization	47	0.91
	BIM	44	2.14
	Performance	39	1.12
	Contractor	34	1.08
	Decision making	30	0.96
	China	29	1.41
	Fuzzy set	27	0.95
	Workers	27	1.17
	Quality	23	0.67
	Case study	22	0.91
	Forecasting	21	0.67
	Procurement	21	0.94
	Regression analysis	21	0.69
	Equipment	20	0.80
	Knowledge management	20	0.90
	Project delivery	20	0.90
	Bidding	19	0.83
	HK	19	0.97
	Companies	17	1.05
	Innovation	17	0.87
	PPP	17	1.14
	Australia	15	1.43
	Communication	15	1.38
	Partnership	15	1.62
	Sites	15	1.57
	Statistics	15	0.85
	Accident	14	1.13
	SEM	14	1.63
	Claim	13	0.50
	Design	13	1.78
	Dispute	13	0.46
	Materials	13	0.63
	DB	12	0.89
	Automation	11	0.79
	Rework	11	1.68
	Hazard	10	2.38
	Methods	10	0.80
	Neural networks	10	0.57
	Private sector	10	1.76

Note: Keywords with semantically consistent meanings have been combined, for example, BIM and building information modeling.

published before 2009. But since 2009, a variety of quantitative methods such as data mining, machine learning, and model improvement (Adeleye et al. 2013) have become more widely applied. Similarly, data analytics approaches such as the Bayesian decision tool (Gerassis et al. 2017) are gaining wider application in construction safety research. Research in safety management has also shown the application of artificial intelligence and smart monitoring (Cho et al. 2018). The topics studied from 2000 to 2008 may still be continuously studied in the more recent years, such as safety climate (Chen and Jin 2013). The typical studies listed in the time span from 2009 to 2018 have disclosed some emerging research trends, such as applying data analytics (Bonham et al. 2017), web-based system involving BIM (Zhang et al. 2017), and newly developed modeling approach (e.g., Said and Lucko 2016) in solving certain construction issues (e.g., site logistics). Finally, it is worth mentioning that these commonly studied topics are being integrated with emerging construction practices or concepts. These
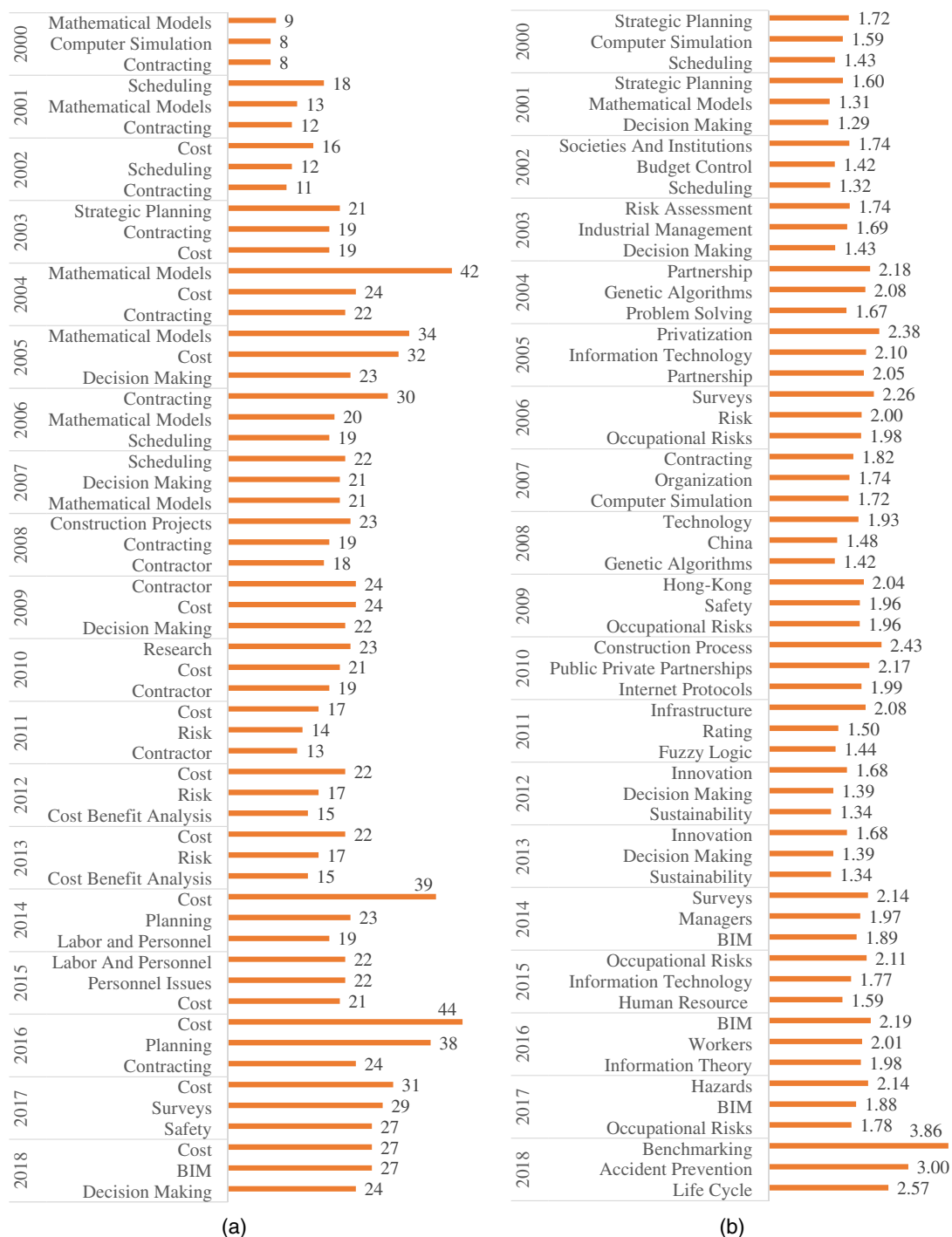
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(a) Top three keywords each year measured by occurrences

Year	Keyword	Occurrences
2000	Mathematical Models	9
2000	Computer Simulation	8
2000	Contracting	8
2001	Scheduling	18
2001	Mathematical Models	13
2001	Contracting	12
2002	Cost	16
2002	Scheduling	12
2002	Contracting	11
2003	Strategic Planning	21
2003	Contracting	19
2003	Cost	19
2004	Mathematical Models	42
2004	Cost	24
2004	Contracting	22
2005	Mathematical Models	34
2005	Cost	32
2005	Decision Making	23
2006	Contracting	30
2006	Mathematical Models	20
2006	Scheduling	19
2007	Scheduling	22
2007	Decision Making	21
2007	Mathematical Models	21
2008	Construction Projects	23
2008	Contracting	19
2008	Contractor	18
2009	Contractor	24
2009	Cost	24
2009	Decision Making	22
2010	Research	23
2010	Cost	21
2010	Contractor	19
2011	Cost	17
2011	Risk	14
2011	Contractor	13
2012	Cost	22
2012	Risk	17
2012	Cost Benefit Analysis	15
2013	Cost	22
2013	Risk	17
2013	Cost Benefit Analysis	15
2014	Cost	39
2014	Planning	23
2014	Labor and Personnel	19
2015	Labor And Personnel	22
2015	Personnel Issues	22
2015	Cost	21
2016	Cost	44
2016	Planning	38
2016	Contracting	24
2017	Cost	31
2017	Surveys	29
2017	Safety	27
2018	Cost	27
2018	BIM	27
2018	Decision Making	24

(b) Top three keywords each year measured by average normalized citation

Year	Keyword	Average Normalized Citation
2000	Strategic Planning	1.72
2000	Computer Simulation	1.59
2000	Scheduling	1.43
2001	Strategic Planning	1.60
2001	Mathematical Models	1.31
2001	Decision Making	1.29
2002	Societies And Institutions	1.74
2002	Budget Control	1.42
2002	Scheduling	1.32
2003	Risk Assessment	1.74
2003	Industrial Management	1.69
2003	Decision Making	1.43
2004	Partnership	2.18
2004	Genetic Algorithms	2.08
2004	Problem Solving	1.67
2005	Privatization	2.38
2005	Information Technology	2.10
2005	Partnership	2.05
2006	Surveys	2.26
2006	Risk	2.00
2006	Occupational Risks	1.98
2007	Contracting	1.82
2007	Organization	1.74
2007	Computer Simulation	1.72
2008	Technology	1.93
2008	China	1.48
2008	Genetic Algorithms	1.42
2009	Hong-Kong	2.04
2009	Safety	1.96
2009	Occupational Risks	1.96
2010	Construction Process	2.43
2010	Public Private Partnerships	2.17
2010	Internet Protocols	1.99
2011	Infrastructure	2.08
2011	Rating	1.50
2011	Fuzzy Logic	1.44
2012	Innovation	1.68
2012	Decision Making	1.39
2012	Sustainability	1.34
2013	Innovation	1.68
2013	Decision Making	1.39
2013	Sustainability	1.34
2014	Surveys	2.14
2014	Managers	1.97
2014	BIM	1.89
2015	Occupational Risks	2.11
2015	Information Technology	1.77
2015	Human Resource	1.59
2016	BIM	2.19
2016	Workers	2.01
2016	Information Theory	1.98
2017	Hazards	2.14
2017	BIM	1.88
2017	Occupational Risks	1.78
2018	Benchmarking	3.86
2018	Accident Prevention	3.00
2018	Life Cycle	2.57

Fig. 3. Research keywords evolution over time disaggregated by publication year from 2000 to 2018: (a) top three keywords each year measured by occurrences; and (b) top three keywords each year measured by average normalized citation.

include risk allocation in PPP projects (Shrestha et al. 2018), knowledge management in BIM (Wu et al. 2018), and BIM for safety management (Kim et al. 2018).

Conclusion

This review-based study focused on research topics covered in the *Journal of Construction Engineering and Management* through a text-mining approach. It contributes to the academic community of CEM by continuing the prior literature review-based research through a text-mining-oriented scientometric method. A total of 2,217 *Journal* articles published since 2000 was adopted as the whole literature sample. Through a comprehensive analysis of keywords by dividing the whole sample into two subsamples according to publication year, the evolution of mainstream research topics was evaluated. Results showed that conventional construction management themes (e.g., cost) were being integrated into newly emerging research techniques (e.g., data analytics). Overall, this study provides the overview of research topics in the CEM field and leads to foreseeing near-future research trends.

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Table 2. Comparison of mainstream research keywords between the recent decade and 2000–2008 period

Topic	Typical studies selected from 2000 to 2008	Typical studies identified from 2009 to 2018
Cost	Mathematical modeling (Nassar et al. 2005a) and statistical process (Nassar et al. 2005b)	A variety of modeling approaches for cost prediction or control (Ammar et al. 2013)
Project delivery systems and contracts	Design-build (Lee and Arditi 2006) and build-operate-transfer (Chan et al. 2005)	PPP (Mahalingam 2010)
Information and communication technology	General term of information technology (Kang et al. 2008) and computer-aided design (Kale and Arditi 2005)	BIM assisting project management (Ham et al. 2018) and BIM for sustainable design and construction (Bynum et al. 2013)
Scheduling	Computer application and visualization (Chau et al. 2004); time and cost trade-off (Moussourakis and Haksever 2004); and mathematical programing and algorithms (Senouci and Eldin 2004)	Computer programming for optimization under a restricted project scenario (Liu and Lu 2018)
Risk	Risk factors and mitigation (Spielholz et al. 2006)	Risk analysis using data analytics or programming (Zhao et al. 2018)
Productivity	Regression and statistical methods in analyzing productivity (Hanna et al. 2007)	Computation of productivity involving visual techniques, data analytics, or framework establishment (Mani et al. 2017)
Safety	Safety climate (Fang et al. 2006); safety hazard identification (Carter and Smith 2006); and causes of safety incident/accident (Beheiry et al. 2006)	Social network analysis (Allison and Kaminsky 2017); data analytics of accidents (Gerassis et al. 2017); and smart safety monitoring (Cho et al. 2018)
Labor and personnel	Employees' work–life balance (Lingard et al. 2007) and training and education (Russell et al. 2007)	Demographic factors contributing to employees' health and work stress (Kamardeen and Sunindijo 2017)

Note: Only one reference is cited for each typical study in Table 2. More references related to the same type of study can be found from other relevant *Journal* articles. For example, risk analysis using data analytics approach can be found also in other studies such as Mazher et al. (2018).

The scientometric review revealed the following:

- The main research subjects and most frequently studied themes in CEM remained generally consistent, including cost, scheduling, risk management, safety, and productivity related issues.
- Project delivery remained one of the main research themes in CEM realm. The difference between publications within the recent decade and those before 2009 concerned type of delivery methods; specifically delivery methods including DB and BOT appeared to be more frequently studied over 10 years ago, but in the recent decade, the topic of partnership (such as PPP) has been gaining its momentum in the academic field.
- Unlike studies conducted before 2009, which largely focused on mathematical modeling or computer-aided design, a variety of quantitative methods and ICT applications (e.g., BIM) are gaining increased attention in the CEM field in the recent decade.
- Traditional topics such as safety, labor and personnel issues, together with contracting, continue being studied and have gained even more attention in CEM.

Several research trends are hence highlighted according to the quantitative and qualitative keyword analyses of the CEM topics. These include (1) applying a variety of data analytics approaches to these everlasting management issues (e.g., safety, sustainability, and risk assessment); (2) upgrading and integration of information and communication technologies (e.g., database-driven and web-based systems involving BIM) in various construction activities (e.g., site logistics); and (3) integration of research topics between conventional themes and more recently emerging topics, e.g., performance and organizational issues in PPP projects, as well as contracting and bidding system updates in BIM-oriented projects.

Data Availability Statement

Data generated or analyzed during the study are available from the corresponding author by request. Information about the *Journal*'s data-sharing policy can be found here: http://ascelibrary.org/doi/10.1061/(ASCE)CO.1943-7862.0001263.

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