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A Scientometric Review of Articles published in ASCE 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 evolutionof academic research in the field of construction engineering and management (CEM): (1) what are the mainstream research topics since 2000? (2) whatare the emerging topics or techniques in CEM within the recent decades? (3) whatarepotentialCEM research areas in the near future? Ascientometric analysiswas conducted to review articles published in *Journal of Construction Engineering and Mnagement* (*JCEM*) since 2000,follow by a qualitative discussion.Thisstudy revealed that project performance indicator-related topics (e.g., cost, scheduling, safety, productivity, and risk management) had been the ongoing mainstream issues over the past decades.Labor and personnel issues had gained even more research attention in the last ten years. Information and communication technologies (e.g., Building Information Modeling or BIM) applied in CEM had been gaining the momentum since 2009. A variety of quantitative methods had gained popularity in the CEM discipline, such as algorithm, statistics, fuzzy set, 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; (2) it offered insights on the emerging and near-

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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 emering project delivery methods).

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). CEMremained a relatively newdiscipline(Aboulezz, 2003) and had become an established academic research areathat produced a series of scholarly publications (Pietroforte and Stefani, 2004).Academic journals such as *Journal of Construction Engineering and Mnagement* (*JCEM*) publish quality papers aiming to advance the science of construction engineering (ASCE Library, 2018). An earlier review-based study conducted by Pietroforte and Stefani (2004) summarized the subjects with topics published in*JCEM* by recruiting articles published from 1983 to 2000. As suggested by Pietroforte and Stefani (2004), the future research work could apply the citation analysis for publications. However, there is no study which follows up the suggestion provided by Pietroforte and Stefani (2004) to perform the review of the latest research topics published in *JCEM*. This study aims to capture the latest research topicsthrough reviewing the articles published in *JCEM*since 2000. These objectives are targeted in this review work: (1) to provide the key information related to research keywords in the journal; (2) to compare the mainstream research keywords between the recent decade and those published over ten years ago; and (3) to identify potential near-future research directions in the CEM field.

Scientometric analysis method

The scientometric analysis was introduced in assisting theliterature review to overcome the subjectivity issues (Hammersley, 2001) from some previous review-based studies (e.g., Ke et al., 2009) in the CEM field. The scientometric analysis consists of the text-mining and citation analysis.Detailed descriptions of the scientometric analysis can be found in 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* was adopted in this study to conductthe scientomeric analysis. This was because:VOSViewer wassuitable for visualizing larger networks; and it also had special text mining features (Van Eck and Waltman, 2014).In this study, all articles published in JCEM since 2000 was 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 can be found in Park and Nagy (2018) and Jin et al. (2019). In this research, scientometric analyses of keywords were performed to sub-samples of literature on both a ten-year time span and yearly basis to view the trajectory of research topics over time.Following the scientometric analysis of keywords, a further 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 *JCEM* 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*. Fig.1 and Fig.2 provide the visualizations of most frequently studied keywords from each subsample of literature.

<Insert Fig.1 here>

It should be notedthat these keywords in both figures and the follow-up Table 1were 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, 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 inter-relatedness. It can be seen in Fig.1 that followingkeywords represent the mainstream topics in *JCEM* publications: 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 co-studied with CPM (i.e., critical path method), and the goal of scheduling is to achieve optimization, which could be achieved by adopting 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., Design-Build or DB). ICT (i.e., information and communication technology)and computer-aided applications in construction had gained some momentum during the first decade of 2000s. Fig.2shows the evolutionof main research topics in the last decade.

<Insert Fig.2 here>

Compared to Fig.1, it can beinferred from Fig.2 that the major project performancemeasurements (e.g. cost, scheduling, productivity, and safety) remained the focus within theCEMcommunity. However, some emerging keywords could be identified, including materials and methods, planning, quantitative method, and BIM. Examples of materials & methods include material selection in the design stage to achieve sustainability (Lee, 2018) and innovative construction method (Zhang et al., 2017) to address site constraints and surrounding environment.Although ICT and computer applications hadbecomeone 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, algorithm, which was being frequently studied from 2000 to 2008, seems being updated by other various quantitative methods, e.g.,fuzzy multi-criteria decision-making (Xia et al., 2011). Besides, keywords such as organization as well aslabor and personnel show 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.

<Insert Table 1 here>

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 its impact.

For example, cost related issues remain the most frequently studied topic in both time spans, but keywords that had received the highest attention are *hazard* and *partnership* in the two subsamples respectively. An obvious difference between the two literature samples is the emerging topic of BIM, which receives 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 *JCEM* 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 (2004)'s findings, the studies on project delivery methods (e.g., DB) showed a decreasing trend.On the contrary, studies related to IT applications in CEM have been increasing since 2000.

The evolutionof mainstream research keywords since 2000 could be further disaggregatedinto yearly basis for further comparison (seeFig.3).

<Insert Fig.3 here>

Fig.3 can be viewed in two directions. Horizontally, the Fig.3-a) and Fig.3-b) list top three keywords that are with highest occurrence and average normalized citation respectively. Vertically, the evolutionof 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 issueshave become more commonly studied topics.

Qualitative analysis of research keywords

The visualization in Fig.1 and Fig.2, as well as the quantitative measurements of keywords' influencesin Table 1 indicated that the main themes classified by Pietroforte and Stefani

150 (2004), (e.g. scheduling, cost, safety, and contracting)remained the same as most widely
151 focused topics in the CEM field. A further qualitative analysis was hence conducted to
152 compare the mainstream keywords between the two time periods. Based on the top-ranked
153 mainstream topics in Table 1 (e.g., risk), Table 2 displays a qualitative comparison of typical
154 studies published within the two different time spans.

155 <Insert Table 2>

156 It can be found from Table 1 and Table 2 that the commonly studied topics remain
157 unchanged in the recent decade. However, the approach or method has been evolving. For
158 example, cost, schedule, and productivity, as three interrelated themes and major
159 performance measurements of construction projects, remain the top-studied topics in the
160 recent ten years. However, newresearchmethodsemerged. Specifically, prediction or control
161 methods using probabilistic, stochastic system, or Monte Carlo simulation (Barraza and
162 Bueno, 2007) can be frequently observedin literature published before 2009. But since 2009,
163 a variety of quantitative methods such as data mining, machine learning, and model
164 improvement (Adeleye et al., 2013) have become more widely applied. Similarly, the data
165 analytics approach such as Bayesian Decision Tool (Gerassis et al., 2017) is gaining more
166 application in construction safety research. Research in safety management has also shown
167 the application of artificial intelligence and smart monitoring (Cho et al., 2018). It should be
168 noticed that the topics studied from 2000 to 2008 may still be continuously studied in the
169 more recent years, such as safety climate (Chen and Jin, 2013). The typical studies listed in
170 the time span from 2009 to 2018 have disclosed some emerging research trends, such as
171 applying data analytics(Bonham et al., 2017), web-based system involving BIM (Zhang et al.,
172 2017), and newly developed modeling approach (e.g., Said and Lucko, 2016) in solving
173 certain construction issues (e.g., site logistics). Finally, it is worth mentioning that these
174 commonly studied topics are being integrated with emerging construction practices or

concepts. These 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*Journal of Construction Engineering and Management*(*JCEM*) 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-orientedscientometric method. A total of*2,217JCEM* articles published since 2000 was adopted as the whole literature sample. Through a comprehensive analysis of keywords by dividing the whole sample into two sub-samples according to publication year, the evolution of mainstream research topics was evaluated. Results showed that the 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 into foreseeing the near-future research trends.

The scientometric review revealed that: (1) the main research subjects and most frequently studied themes in CEM remained generally consistent, including cost, scheduling, risk management, safety,and productivity related issues; (2) project delivery remained one of the main research themes in CEM realm. The difference between publicationswithin the recent decade and those before 2009 lied in the type of delivery methods, specifically:delivery methods including Design-Build and BOT (i.e., Build-Operate-Transfer) appeared to be more frequently studied over ten years ago, but in the recent decade partnership (such as PPP) has been gaining its momentum in the academic field; (3) unlike studies before 2009 which had largely focused on mathematical modelingor computer-aided design,a variety of quantitative methods and ICT application (e.g., BIM) are gaining the increased attention in the CEM field in the recent decade; (4) traditional topics such as safety, labor and personnel issues, and contracting continue being studied and have even gained more attention in CEM.

Several research trends are hencehighlighted according to the quantitative and qualitative keyword analyses of the CEMtopics. These include: (1) applying a variety of data analyticsapproachesinto 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 system involving BIM) in various construction activities (e.g., site logistics) ; (3) integration of research topics between conventional themes andmore 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.

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365 Table 1. Quantitative analysis of keywords studied in the two literature samples from *JCEM*

Keywords studied in the article sample from 2000 to 2009			**Keywords studied in the article sample from 2009 to 2018**		
Keyword	**Occurrence**	**Average normalized citations**	**Keyword**	**Occurrence**	**Average normalized citations**
Cost	82	1.06	Cost	144	0.80
Scheduling	82	1.01	Planning	123	1.10
Productivity	67	0.89	Safety	123	1.58
ICT	55	0.91	Laborand Personnel	122	1.23
Contractor	51	0.99	Contracting	96	1.06
Infrastructure	48	1.05	Risk	92	1.27
Safety	48	1.18	Quantitative	82	0.94
Risk	47	1.29	Organization	76	1.07
Simulation	47	0.93	Productivity	75	1.00
Computer Aid	44	0.95	ICT	68	1.51
Decision Making	43	1.04	Scheduling	65	0.79
Optimization	40	1.06	Materials & Methods	56	0.79
Contracting	37	1.19	Infrastructure	53	1.13
Algorithm	27	1.41	Sustainability	53	1.34
Model	27	0.85	Simulation	51	0.88
Performance	27	1.10	Optimization	47	0.91
Bidding	26	0.90	BIM	44	2.14
Partnership	24	2.09	Performance	39	1.12
Finance	23	1.26	Contractor	34	1.08
Case Study	22	0.88	Decision Making	30	0.96
Equipment	22	0.73	China	29	1.41
Fuzzy Set	22	1.13	Fuzzy Set	27	0.95
HK	20	1.69	Workers	27	1.17
Quality	19	0.66	Quality	23	0.67
China	17	1.37	Case Study	22	0.91
Delivery	17	1.41	Forecasting	21	0.67
Labor and Personnel	16	0.78	Procurement	21	0.94
Sites	16	1.42	Regression analysis	21	0.69
Time	16	1.12	Equipment	20	0.80
Workers	16	0.78	Knowledge management	20	0.90
BOT	15	1.44	Project Delivery	20	0.90
Claim	15	0.63	Bidding	19	0.83
Constructability	15	0.62	HK	19	0.97
CPM	15	0.76	Companies	17	1.05
Delay	15	1.23	Innovation	17	0.87
Automation	14	0.78	PPP	17	1.14

Data Collection	14	1.25	Australia	15	1.43
Neural Networks	14	0.85	Communication	15	1.38
Prediction	14	0.96	Partnership	15	1.62
Innovation	13	0.98	Sites	15	1.57
Materials	13	1.24	Statistics	15	0.85
Resource	13	0.87	Accident	14	1.13
Data Analysis	12	0.70	SEM	14	1.63
DB	12	1.34	Claim	13	0.50
Design	12	1.02	Design	13	1.78
Education	12	0.51	Dispute	13	0.46
Methods	12	0.96	Materials	13	0.63
Accident	11	1.60	DB	12	0.89
Dispute	11	0.97	Automation	11	0.79
International	11	1.40	Rework	11	1.68
Estimate	10	0.82	Hazard	10	2.38
Evaluation	10	1.00	Methods	10	0.80
Knowledge management	10	1.11	Neural Networks	10	0.57
Overseas	10	1.30	Private Sector	10	1.76

Note: keywords with semantically consist meanings have been combined, for example, BIM and Building Information Modeling.

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

Topic	Typical studies selected from 2000 to 2008	Typical studies identified from 2009 to 2018
Cost	Mathematical modeling(Nassar, Gunnarsson and Hegab, 2005); Statistical process (Nassar, Nassar and Hegab, 2005)	A variety of modeling approach for cost prediction or control (Ammar, Zayed and Moselhi, 2013)
Project Delivery Systems and Contracts	Design-Build (Lee and Arditi, 2006), Build-Operate-Transfer (Chan, Chen, Messner and Chua, 2005)	PPP (Mahalingam, 2010)
Information and communication technology	General term of information technology (Kang, O'Brien, Thomas and Chapman, 2008); Computer-aided design (Kale and Arditi, 2005)	BIM assisting project management (Ham, Moon, Kim and Kim, 2018), BIM for sustainable design and construction (Bynum, Issa and Olbina, 2013)
Scheduling	Computer application and visualization (Chau, Anson and Zhang, 2004); Time & cost tradeoff(Moussourakis and Haksever, 2004); Mathematical programing and algorithm (Senouci and Eldin, 2004)	Computer programming for optimization under a restricted project scenario (Liu and Lu, 2018)
Risk	Risk factors and mitigation (Spielholz, Davis and Griffith, 2006)	Risk analysis using data analytics or programming (Zhao, Liu, Zhang and Zhou, 2018);
Productivity	Regression and statistical methods in analyzing productivity (Hanna, Chang, Lackney and Sullivan, 2007)	Computation of productivity involving visual techniques, data analytics, or framework establishment (Mani, Kisi, Rojas and Foster, 2017)
Safety	Safety climate (Fang, Chen and Wong, 2006); Safety hazard identification (Carter and Smith, 2006); Causes of safety incident/accident (Beheiry, Chong and Haas, 2006)	Social network analysis (Allison and Kaminsky, 2017); Data analytics of accidents (Gerassis, Martín, García, Saavedra and Taboada, 2017); smart safety monitoring (Cho, Kim, Park and Cho, 2018)
Labor and Personnel	Employees' work-life balance (Lingard, Brown, Bradley, Bailey and Townsend, 2007); Training and education (Russell, Hanna, Bank and Shapira, 2007)	Demographic factors contributing to employees' health and work stress (Kamardeen and Sunindijo, 2017)

386 Note: only one reference is cited for each typical study in Table 2. More references related to the same type of
387 study can be found from other relevant JCEM articles. For example, risk analysis using data analytics approach
388 can be found also in other studies such as (Mazher, Chan, Zahoor, Khan and Ameyaw, 2018).
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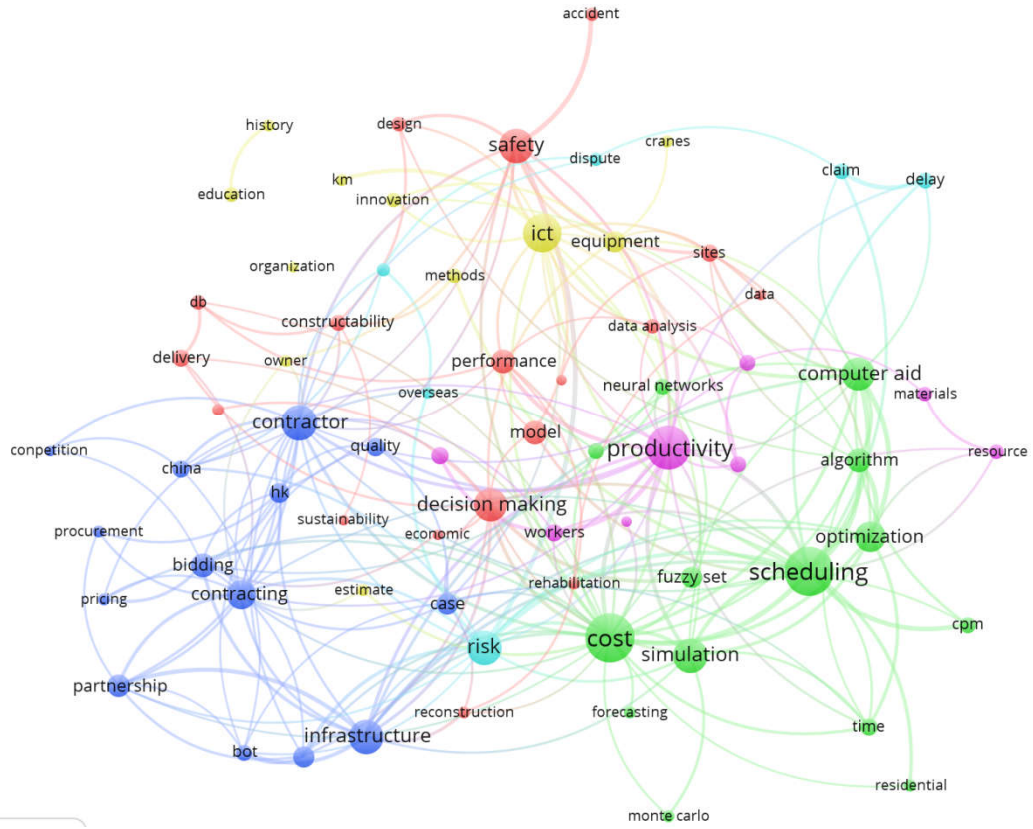

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397 **Fig.1.** Visualization of keywords studied for articles published between 2000 and 2008
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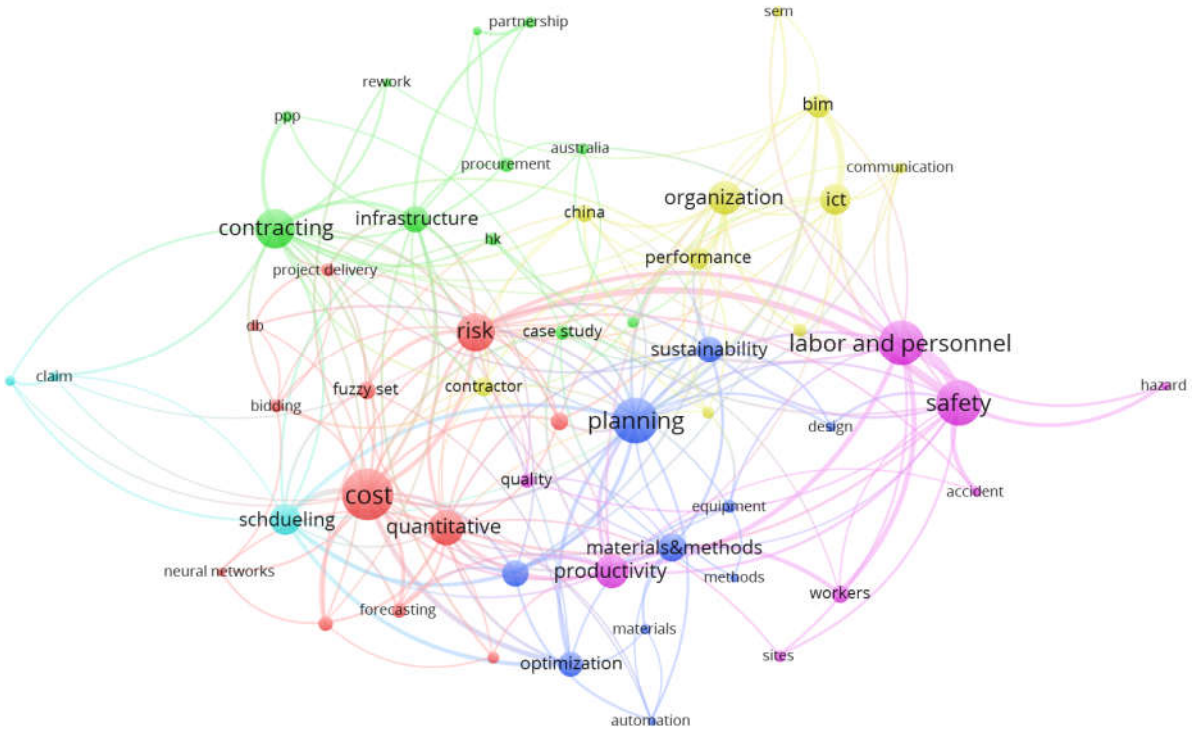
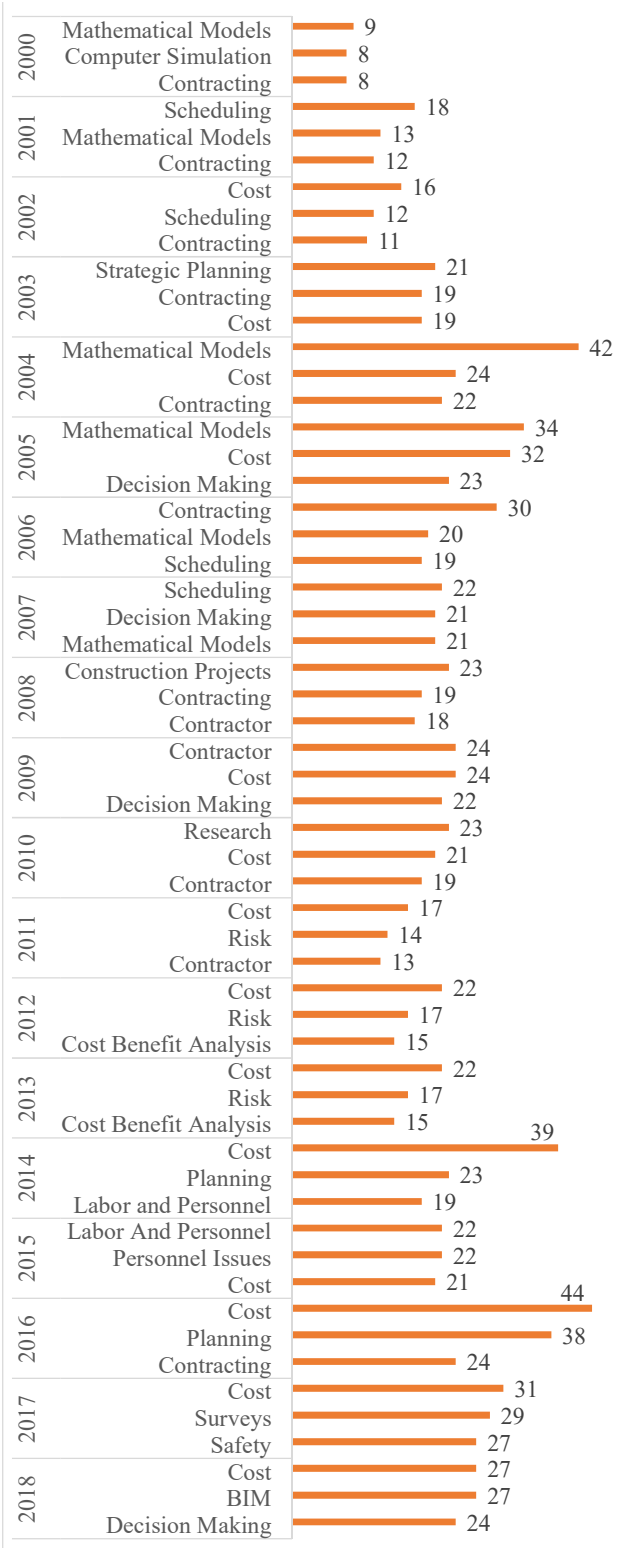


Note: ICT stands for information and communication technology, DB stands for Design-Build project delivery approach, SEM means structural equation modelling, and PPP means public-private-partnership.

Fig.2. Visualization of keywords studied for articles published between 2009 and 2018



a) Top three keywords each year measured by occurrences

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

Fig.3. Research keywords evolution over time disaggregated by publication year from 2000 to 2018