A BIBLIOMETRIC REVIEW OF ENGINEERING MANAGEMENT OVER TEN YEARS (2014-2023)

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Abstract
The subject of engineering management is concerned with the management of organizations, people and projects in a technological or engineering systems context and there are many studies across the field of engineering management in the extant literature. Engineering management also represents an approach to tackle the grand challenges of today, such as the need for sustainable development as well as digital transformation. Therefore, it is important for scholars to have a deep understanding of the scope of the subject as well as emerging patterns in the knowledge base and consequently this research study conducted a bibliometric review of engineering management. The review was underpinned by a systematic search of the literature on engineering management over a 10-year period (2014-2023). This allowed the documents to be categorized according to publication metrics accompanied by bibliometric analysis to determine a number of parameters, including co-occurrence of keywords, co-occurrence of text, and co-authorship in terms of countries. The bibliometric review provides insights into emerging trends across the subject of engineering management as well as collaboration patterns combined with an exploration of the intellectual structure of the subject. The study concludes with recommendations for the development of the engineering management subject.

Keywords
Engineering management, epistemology, systematic search, bibliometric review, co-occurrence map.

Introduction
The subject of engineering management is concerned with the management of organizations, people, and projects in the context of technological or engineering systems. Engineering management is practiced widely across technical environments and the discipline is implicitly linked to the organizational role of the engineering manager. Moreover, engineering management is carried out in different situations and across a range of industrial sectors, such as manufacturing, construction, production, transportation and business administration. Consequently, engineering management has been researched extensively, and there are many studies across the field of engineering management in the extant literature. There have been a number of articles that have sought to describe the main features of the discipline as well as the historical basis of the subject, for example, see the work of Lannes (2001), Roberts (2004), Kocaoglu (2009), Omurtag (2009), Chang (2016) and He (2023). Indeed, one of the challenges associated with the engineering management discipline is codifying the features of the subject, since it includes a broad range of topics and problem areas associated with both human and non-human elements (Spurlock et al., 2008). Engineering management can also be viewed in terms of the challenges for technical organizations and engineering managers, including the business environment trends and challenges (e.g. globalization); organizational trends and challenges (e.g. implementing a process-based organization); and engineering management/manager trends and challenges (e.g. understanding and managing uncertainty) (Kotnour & Farr, 2005).

In terms of a definition, the American Society for Engineering Management (ASEM) defines engineering management as "*an art and science of planning, organizing, allocating resources, and directing and controlling activities that have a technological component*" (Shah, 2015, p. 3). Interestingly, while engineering management is a subject area with a corresponding academic discipline; it is also composed of several sub-areas, which collectively can be viewed as the 'building blocks' of engineering management. These sub-areas include, for example, leadership and organizational management, project management, supply chain management, technology management, engineering economy, and systems engineering; many of which are described as domain areas in the Engineering Management Body of Knowledge (Shah, 2015). Reflecting on this situation further, engineering management would appear to be both a defined area of knowledge in its own right as well as representing a set of semi-independent knowledge areas. For instance, in the case of project management, there are studies that are focused on the management of engineering projects (Backlund et al., 2014; Hicks et al., 2020), which are clearly associated with the subject of engineering management. While there are other studies that are focused purely on the discipline of project

management in areas such as project leadership (Imam & Zaheer, 2021), risk management (Vujović et al., 2020) and economic analysis (Lin & Huang, 2020). Do these latter studies represent part of the knowledge base of project management or engineering management, or both? This question can be explored from an epistemological perspective (i.e. understanding the knowledge boundaries of engineering management) and it may be concluded that further studies are required to investigate this area. Nevertheless, there remains a need for both scholars and practitioners to have access to up-to-date knowledge on the subject of engineering management.

The utility of the engineering management subject can be readily observed through considering its use in different technological applications and industrial sectors. For example, Guoxin et al. (2020) considered the engineering management and technological dimensions of the commercial development of domestic continental shale oil and gas in Canada. Khatatbeh (2023) evaluated the impact of implementing quality standards for the project and engineering management of construction projects in Jordan. Whereas Chatterjee (2022) examined the value creation and engineering management perspectives of frontline employees during the COVID-19 pandemic through empirical studies in the Asia and EMEA (Europe, Middle East and Africa) regions. In addition to the the global adoption of engineering management in different industrial sectors, engineering management can also be harnessed to tackle important societal challenges that we currently face. This includes, for instance, the application of engineering management principles to the environmental management of ecological systems (Gorman, 2005), or engineering management to enable improved environmental outcomes through effective corporate social responsibility by companies (Isaksson & Kiessling, 2021). Additionally, engineering management can be viewed in regard to the current trend towards digitalization as part of the wider Industry 4.0 paradigm, for example, involving the integration of artificial intelligence into the development of complex products and systems (Yu et al., 2023) as well as machine learning applications in engineering management (Li et al., 2020; Chou et al., 2021).

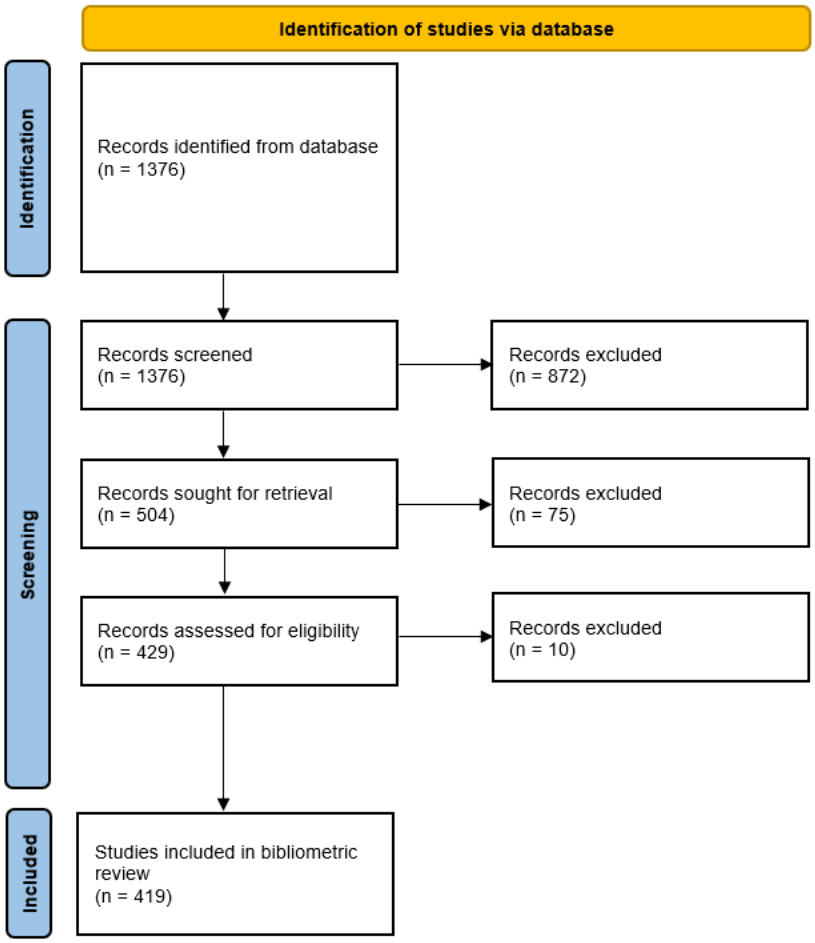
In this context, there is a need for scholars to have a deep understanding of the scope of the engineering management subject as well as the emerging patterns in the knowledge base. Consequently this research study conducted a bibliometric review of engineering management, which was underpinned by a systematic search of the literature on engineering management over a 10 year period (2014-2023). The bibliometric review methodology provides insights on the emerging trends across the subject of engineering management as well as collaboration patterns combined with exploration of the intellectual structure of the subject.

Methodology

The research study focuses on identifying the scope of the engineering management subject, including its main characteristics and emerging trends. Therefore, a bibliometric review was undertaken, which was supported by systematic searching of the extant literature. The bibliometric review methodology involves the application of quantitative techniques (i.e. citation analysis) to bibliometric data (i.e. publication data) (Donthu et al., 2021). The bibliometric review employed in this study included use of VOSviewer software to allow construction and visualization of bibliometric networks, which are derived according to citation and bibliographic coupling as well as co-citation and co-authorship relationships for a dataset of publications. Version 1.6.18 (date of release: January, 24th 2022) of the VOSviewer software was utilized in the study with Java, Version 1.8.0_411 (Oracle Corporation). As a software tool employed by researchers, VOSviewer can be used for scientific mapping of a discipline as recommended by McAllister et al. (2022). The bibliometric analysis and visualization software is used to quantitatively examine the trends and future direction of a specific research area, for example, in the case of the study by Tamala et al. (2022) on sustainable oil and gas production research. Bibliometric analysis utilizing VOSviewer has been undertaken to identify the research trends associated with machine learning adoption in engineering (Su et al., 2021); establish the status of research on nanocomposite hydrogels, which are a stable form of composite materials (Zhao et al., 2022); and investigate the development of professional skills in engineering education (Philbin, 2023).

The PRISMA (Preferred Reporting Items for Systematic Reviews and Meta Analyses) (Moher, 2009) approach was followed to identify the dataset of publications. This method provides a standardized process for conducting systematic literature reviews, which is reproducible and readily documented (Page et al., 2021). Exhibit 1 is a summary of the systematic search of the literature according to PRISMA. The search was carried out on May 8th, 2024 using the Scopus Abstract and Citation Database. The search term of "Engineering Management" was applied to the field of 'Article Title, Abstract, Keywords' and this yielded a preliminary dataset of 1,376 documents. Initially the search was refined to only include publications over a ten year period from 2014 to 2023 and this resulted in 504 publications. Further screening limited the dataset to only journal articles and peer reviewed conference papers, thereby removing book reviews, editorials and other documents that are not peer reviewed. This resulted in 429 publications. Additional screening removed articles not in English, thereby excluding articles in Chinese, Ukrainian and Spanish. This resulted in 419 publications, which were included in the bibliometric analysis.

Exhibit 1. PRISMA approach utilized in the research study.



Results and discussion

The systematic search process identified 419 publications and relevant descriptive data is assembled for this set of publications. Exhibit 2 provides the distribution of the publications over the ten year period (2014-2023). The chart on the left is the histogram and the chart on the right includes linear regression analysis of the data (R^2 = 0.6546). Although the coefficient of determination (R^2) value reflects a significant level of spread in the data, nevertheless, the trend line does indicate that the level of publications is increasing over the ten year period, i.e. increasing from N=35 (in 2014) to N=50 (in 2023); where the arithmetic mean over the 10 years is 42 publications per annum (SD 10.1).

In regard to the subject matter covered by the publications, Exhibit 3 provides details of the subject areas of the publications. The data includes the following subject areas: Engineering (N=255); Business, Management and Accounting (N=155); Computer Science (N=118); Decision Sciences (N=90); Social Sciences (N=40); Mathematics (N=38); Environmental Science (N=28); Earth and Planetary Sciences (N=22); Materials Science (N=21); Energy (N=20); Physics and Astronomy (N=17); Medicine (N=8); Chemical Engineering (N=7); Agricultural and Biological Sciences (N=5); Neuroscience (N=3); Psychology (N=1); Multidisciplinary (N=1); Economics, Econometrics and Finance (N=1); Biochemistry, Genetics and Molecular Biology (N=1); Arts and Humanities (N=1). This identifies that the subject of engineering management not surprisingly spans both the engineering and business, management and accounting subject areas — which is actually a key feature of the subject that it is able to span across the STEM (science, technology, engineering, and mathematics) knowledge base and the management knowledge base. Another interesting aspect of the set of subject areas is that some of the areas are associated with STEM, e.g. computer science; mathematics; environmental science; and chemical engineering, while others are associated with management or social science, e.g. decision sciences; social sciences; and economics, econometrics and finance. This provides further evidence of the unique positioning of the engineering management subject spanning across STEM and management (or social science) knowledge areas.

Exhibit 2. Number of publications per year (left, histogram; right, linear regression).

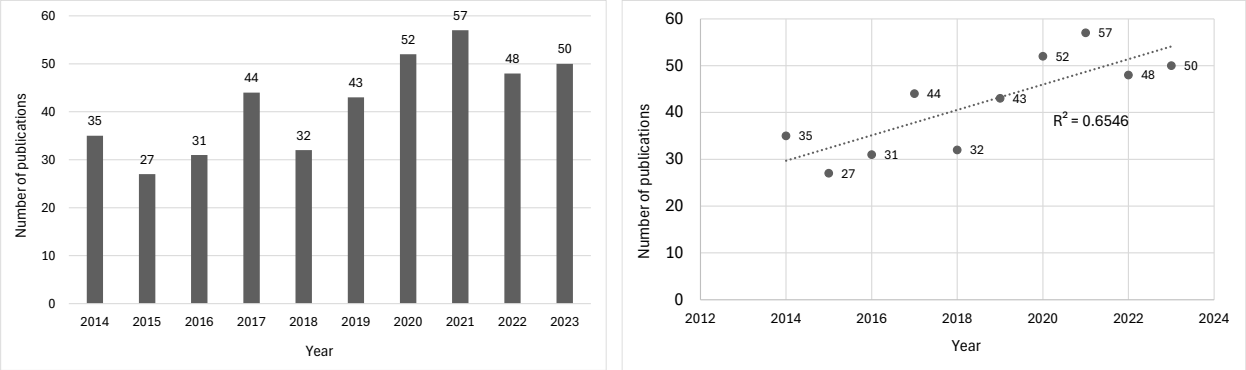
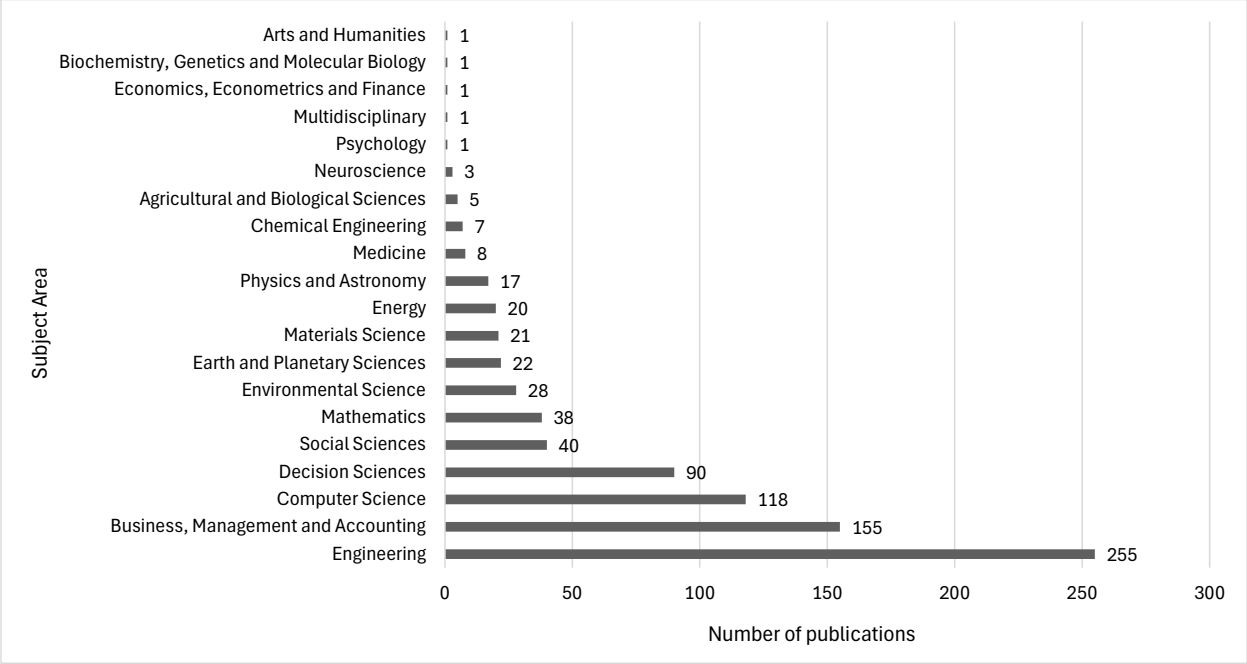


Exhibit 3. Subject areas of the publications.



The results of the bibliometric analysis are provided according to three strands and the first is based on analysis of the co-occurrence of keywords from the publications. Exhibit 4 provides the co-occurrence map and Exhibit 5 provides details of the clusters and keywords in the co-occurrence map. This analysis was based on a total set of 2,641 keywords with 94 keywords that meet the threshold of having 5 as the minimum number of occurrences. The 94 keywords are part of 6 clusters, which have 1,381 links and a total link strength of 3,376. In terms of the main features of this analysis, it can be observed that the largest cluster (# 1; N=26; red) is mainly associated with the knowledge areas of engineering management (e.g. decision making; innovation; and product design keywords) together with technological keywords (e.g. artificial intelligence; and information technology). Whereas the second largest cluster (# 2; N=21; green) is very much associated with the application of engineering management to the construction sector and the built environment (e.g. building information model; construction projects; and highway engineering keywords). Conversely the third largest cluster (# 3; N=16; blue) is more associated with engineering management education (e.g. engineering education; learning systems; and undergraduate engineering keywords). In the case of the remaining clusters # 4 and # 6 it is more difficult to identify an overall pattern of the keywords, although cluster # 5 (N=11; purple) appears to be associated with the information management area (e.g. big data; information systems; software engineering keywords).

Exhibit 4. Co-occurrence map of keywords from the publications.

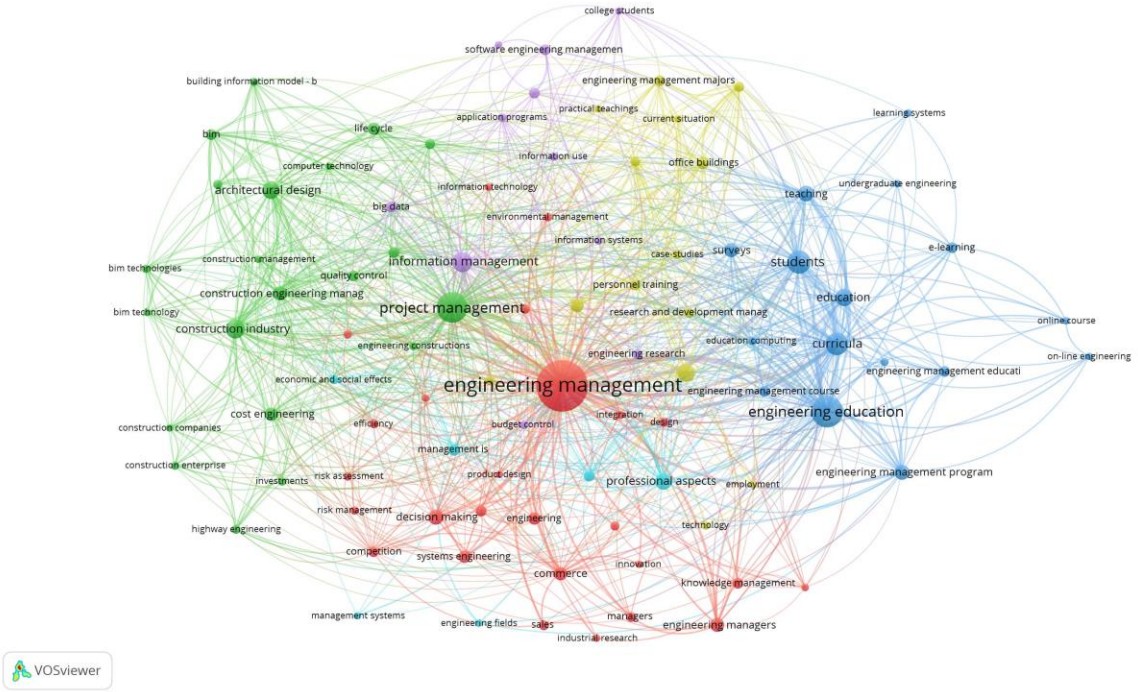


Exhibit 5. Details of clusters and keywords in the co-occurrence map.

Cluster	No. of items	Colour in map	Keywords of the publications
# 1	26	Red	Artificial intelligence, assessment, commerce, competition, decision making, design, efficiency, engineering, engineering management, engineering managers, environmental management, industrial research, information technology, innovation, integration, knowledge management, management, managers, optimization, product design, quality management, risk assessment, sales, systems engineering, technology management.
# 2	21	Green	Architectural design, bim, bim technologies, bim technology, building information model - bim, computer technology, construction, construction companies, construction engineering, construction engineering managements, construction enterprise, construction industry, construction management, construction projects, cost engineering, engineering constructions, highway engineering, investments, life cycle, project management, quality control.
# 3	16	Blue	Curricula, e-learning, education, education computing, engineering education, engineering management course, engineering management education, engineering management programs, learning systems, on-line engineering, online course, students, surveys, teaching, undergraduate engineering, undergraduate projects.
# 4	14	Yellow	Apartment houses, case-studies, current situation, curriculum systems, employment, engineering management majors, human resource management, office buildings, personnel training, planning, practical teachings, research and development management, sustainable development, technology.
# 5	11	Purple	Application programs, big data, budget control, college students, engineering research, information management, information systems, information use, software design, software engineering, software engineering management.
# 6	6	Light blue	Current, economic and social effects, engineering fields, management is, management systems, professional aspects.

The second strand of bibliometric analysis is based on an analysis of the co-occurrence of text data from the publications. Exhibit 6 provides the co-occurrence map and Exhibit 7 provides details of the clusters and text data in the co-occurrence map. This analysis was based on text data extracted from the title and abstract fields of the publications and included binary counting. Based on a total of 9,426 terms, 198 terms met the threshold of having at least 10 occurrences and 60% of the most relevant were considered further giving 119 terms that were selected for analysis. The 119 terms (or items) are part of 3 clusters, which have 4,525 links and a total link strength of 13,428. In regard to the main features of this analysis, it can be observed that the largest cluster (# 1; N=60; red) is mainly associated with the area of engineering management education (e.g. assessment; engineering education; engineering

management program; university; skill; and student text data) as well as words associated with the professional society for the engineering management discipline (e.g. american society; asem; and society text data). Whereas the second largest cluster (# 2; N=30; green) is associated with the application of engineering management to the construction sector and the built environment (e.g. bim technology; construction engineering; construction project; and construction industry text data) as well as a mixture of other engineering management areas associated with system and information aspects of engineering management (e.g. big data; engineering management system; and internet text data). Conversely the third largest cluster (# 3; N=29; blue) is associated with a range of applications of engineering management (e.g. artificial intelligence; decision making; information technology; management science; optimization; and risk management text data) as well as other miscellaneous aspects of engineering management (e.g. economy; effectiveness; international conference; investigation; machine; review; special focus; and topic text data).

Exhibit 6. Co-occurrence map of text data from the publications.

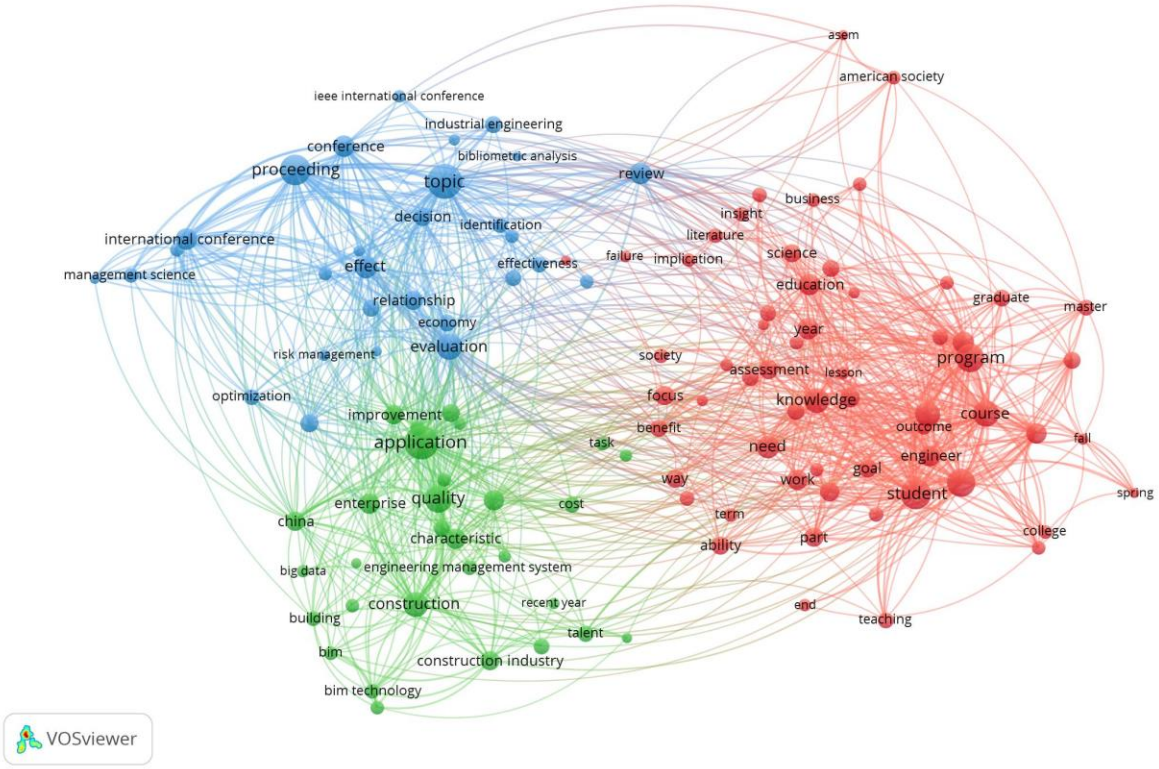


Exhibit 7. Details of clusters and text data in the co-occurrence map.

Cluster	No. of items	Colour in map	Text data of the publications
# 1	60	Red	Ability, addition, american society, asem, assessment, benefit, business, college, content, contribution, course, curriculum, discipline, education, end, engineer, engineering education, engineering management education, engineering management program, engineering manager, experience, failure, fall, focus, goal, graduate, implication, importance, insight, knowledge, lack, lesson, literature, manager, master, need, opportunity, outcome, part, practitioner, program, reliability, science, semester, skill, society, spring, stakeholder, student, success, teaching, team, term, today, uncertainty, understanding, university, way, work, year.
# 2	30	Green	Application, attention, big data, bim, bim technology, building, characteristic, china, complexity, construction, construction engineering, construction engineering management, construction industry, construction project, cost, efficiency, engineering management system, enterprise, experimental result, function, improvement, internet quality rapid improvement, internet, quality, rapid development, recent year, reference, safety, stage, talent, task.
# 3	29	Blue	Artificial intelligence, bibliometric analysis, conference, customer, decision, decision making, economy, effect, effectiveness, evaluation, experiment, icmsem, identification, ieee international

			conference, ieee technology, industrial engineering, influence, information technology, international conference, investigation, machine, management science, optimization, proceeding, relationship, review, risk management, special focus, topic.

The third strand of bibliometric analysis is based on analysis of country co-authorship. Exhibit 8 provides the country co-authorship map and Exhibit 9 provides details of the clusters and countries in the co-authorship map.

Exhibit 8. Country co-authorship map of the publications.

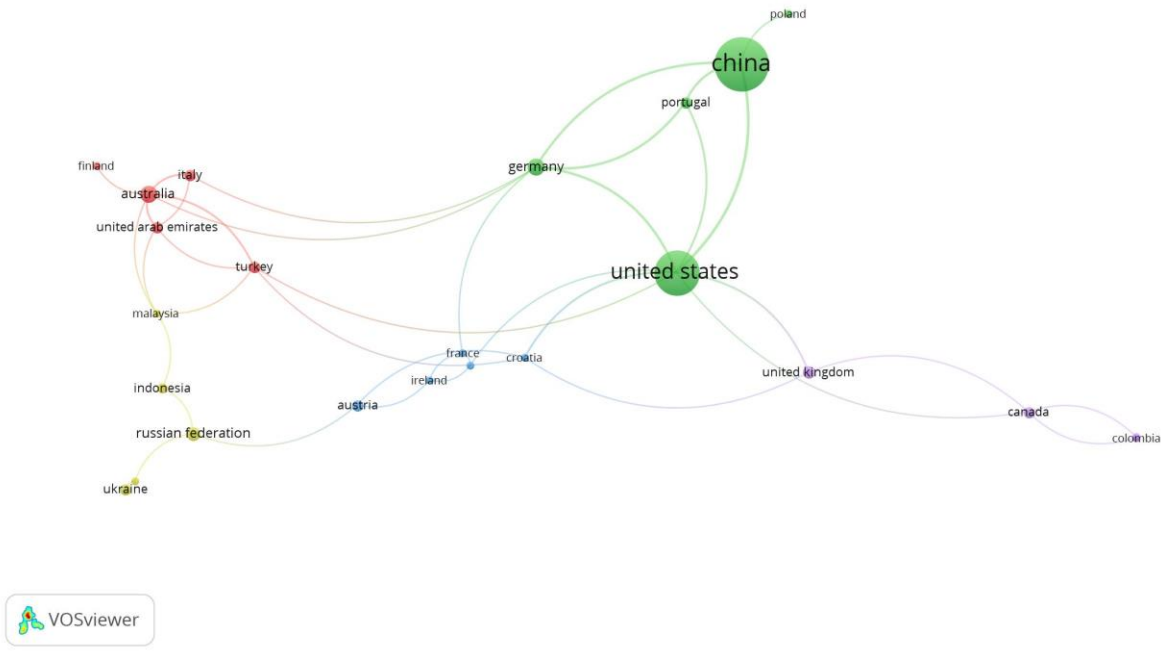


Exhibit 9. Details of the clusters and countries in the co-authorship map.

Cluster	No. of items	Colour in map	Co-author countries of the publications
# 1	5	Red	Australia, Finland, Italy, Turkey, United Arab Emirates.
# 2	5	Green	China, German, Poland, Portugal, United States.
# 3	5	Blue	Austria, Croatia, France, Ireland, Spain.
# 4	5	Yellow	Indonesia, Malaysia, Russian Federation, Serbia, Ukraine.
# 5	4	Purple	Canada, Colombia, Mexico, United Kingdom.
# 6	1	Not shown	Jordan
# 7	1	Not shown	Philippines
# 8	1	Not shown	South Africa
# 9	1	Not shown	Thailand

The third strand of analysis was based on the minimum number of documents per country of 3; from a total of 61 countries, 28 met this threshold requirement. The dataset included 28 countries (or items) in 9 clusters, which had 40 links and a total link strength of 59. The analysis identifies that there are five main clusters (# 1, N=5, red; # 2, N=5, green; # 3, N=5, blue; # 4, N=5, yellow; and # 5, N=4, purple) although the remaining four clusters consist each of a single country. This analysis provides a graphical view on the distribution of the author countries as well as the associated patterns of author collaborations across the publications. Additional analysis is also provided by the software, which is not shown in the country co-occurrence map and this relates to the density of publications per

country, i.e. in terms of the number of documents (N), citations (C), and total link strength (TLS). In this regard, the seven author countries with the greatest number of publications in the dataset are in descending order as follows: China (N=132; C=255; TLS=11); United States (N=94; C=163; TLS=16); Germany (N=13; C=34; TLS=12); Australia (N=13; C=129; TLS=9); South Africa (N=13; C=14; TLS=0); Russian Federation (N=9; C=59; TLS=3); and United Kingdom (N=8; C=62; TLS=4). This clearly highlights that a large proportion of the publications have authors from just two countries (i.e. China and the United States), although there is a broad range of authors across many other countries also contributing to publications focused on engineering management.

Conclusions

This study has provided a bibliometric review of engineering management according to systematic searching of the literature over a ten year period (2014-2023), which has enabled a detailed analysis of the status of the knowledge base as well as identification of key features, trends and insights. Use of the PRISMA methodology identified a dataset of 419 publications focused on engineering management, which was followed by descriptive statistical analysis to identify the main features of the dataset as well as bibliometric analysis to determine co-occurrence of keywords, co-occurrence of text and co-authorship in terms of countries for the dataset of publications. The study found that over the 10-year period, there is an overall trend of an increasing number of publications that are focused on the subject of engineering management. Indeed, the subject of engineering management spans both the engineering and business management disciplines, while there is also a linkage to a subset of STEM areas (such as computer science; mathematics; environmental science; and chemical engineering) and a subset of management areas (such as decision sciences; social sciences; and economics). This further underscores the inherent multidisciplinary nature of the engineering management field through spanning the STEM and management (or social science) subject areas.

Analysis of keyword co-occurrence of the publications identified distinct clusters of keywords in six main areas. This includes a cluster focused on the knowledge areas of engineering management (such as decision making) combined with technological areas (such as artificial intelligence); a cluster focused on the application of engineering management to the construction sector and the built environment (such as building information model); and a cluster focused on the information management area (such as big data). Analysis of text co-occurrence of the publications identified distinct clusters of text in three main areas. This includes a cluster focused on engineering management education (such as engineering management program); a cluster focused on the application of engineering management to the construction sector and the built environment (such as construction project); and a cluster associated with a range of applications of engineering management (such as optimization) and other miscellaneous aspects of engineering management (such as economy). Analysis of the country co-authorship of the publications identified nine clusters of countries, although four consisted each of a single country. The analysis also identified a large proportion of the publication on engineering management have authors from just China and the United States along with a broader range of author countries (including Germany, Australia, South Africa, Russian Federation, United Kingdom, and others) also contributing to publications focused on engineering management.

The study provides the opportunity to synthesize a set of recommendations arising from the bibliometric review of the extant literature on engineering management, which are as follows:

- Further studies are suggested to enhance the epistemological basis of the engineering management discipline and how it is defined in terms of being a subject in its own right as well as also serving as a collection of other subject areas, such as project management, engineering economy, and systems engineering. Such studies are likely to be conceptual in nature and will need to incorporate historical perspectives on engineering management as well as more contemporary views.
- A large proportion of studies on the application of engineering management are focused on the construction sector and the built environment. While it is beneficial to observe the level of adoption of engineering management within this industrial sector, it would however be useful to see a greater number of studies that investigate the application and utility of engineering management in other industrial sectors, such as high-tech manufacturing, transportation and service industries. This would also strengthen further the practitioner relevance of engineering management through broadening the use cases for engineering management.
- Within the engineering management subject area there is a significant theme of research directed towards engineering management education as part of wider studies on engineering education. It is recommended that studies continue to improve the understanding of effective engineering management education, while also strengthening the connection to wider pedagogical studies across engineering and STEM subjects so as to ensure engineering management education benefits from holistic developments across the education domain.
- Engineering management has an established base in traditional areas, such as continuous improvement in manufacturing; management of engineering projects; and modelling and simulation of complex systems.

Such studies are recommended to continue but the application of engineering management to major societal challenges (such as realizing the goals of sustainable development and the introduction of renewable energy technologies in different applications) is an emerging area and further studies are encouraged so as to highlight the utility and relevance of engineering management in the future.

- The information management and adoption of digital technologies are further emerging areas of engineering management, and it is recommended that they continue to be investigated. In this context, further engineering management studies that evaluate the application of Industry 4.0 technologies (such as the internet of things; artificial intelligence & machine learning; big data & analytics; cyber security; digital twins; virtual & augmented reality; and additive manufacturing) are recommended and across different industrial sectors.

In regard to the study limitations, it is recognized that systematic searching focused on publications that explicitly state 'engineering management' in the title or abstract and there will be many other publications that would be part of the wider knowledge base on engineering management which would not necessarily have this feature. Nevertheless the study provides a robust and systematic evaluation of engineering management over a 10-year period, which has enabled various insights to be developed. Future research studies are proposed to address the abovementioned areas, which include conceptual and empirical studies that advance the field and discipline of engineering management.

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