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Bibliometric Analysis to Reveal Research Evolution and Educational Technology Trends in Civil Engineering Education

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Abstract. Civil engineering education is a discipline that endeavors to find the best way through various pedagogical methods to teach civil engineering to prospective civil engineers. Civil engineering education is in the spotlight along with developments in construction technology and its application in learning. Thus, civil engineering education offers a broad field of research in the context of education and construction sciences. Therefore, investigating the evolution of educational research and technology trends in civil engineering education is of interest. In this context, we performed a bibliometric analysis of 545 Scopus and Web of Science (WoS) global publications in the field of civil engineering education published during the period 1967 to 2022. A comprehensive bibliometric analysis was conducted using the R language-based software Biblioshiny. The research results show that, first, research trends in civil engineering education in the 55-year period were divided into 6 themes,

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namely: engineering education, civil engineering education or construction education, fields of civil engineering, technology in engineering education, global and social aspects, and other. Second, the United States is a leader in civil engineering education research, as most authors and journals are from this country. Third, the evolution of educational technology in civil engineering education can be described in five eras: 1) simple software era (1976–1990); 2) geographic information systems (GIS) and virtual reality (VR) era (1991–2000); 3) multimedia and e-learning era (2001–2010); 4) building information modeling (BIM) era (2011–2022); and 5) the forthcoming era (2023−future). Using computers as analysis and visualization tools became increasingly accurate and real, such as the integration of VR technology and incorporation of BIM technology. These findings might help researchers regarding the future direction of research and educational technology in civil engineering.

Keywords: bibliometric analysis; construction education; educational technology; engineering education; civil engineering education

1. Introduction

Shelter and public infrastructure, from roads and bridges to dams, airports, and seaports, is a vital human need. This necessitates civil engineering as an applied multidiscipline that underlies development. Over time, the construction of specific buildings through trial and error has also been taught technically and managerially, leading to the establishment of civil engineering education. This educational field aims to determine the best methods to teach civil engineering to prospective engineers (Ghaly et al., 2003; Walker et al., 2020). It also focuses more on the education or training containing unique practical learning, including teaching methods, ethics literacy, and other pedagogical aspects at the undergraduate or advanced level (ASCE, 2023). The course is thus used to teach civil and construction engineering to students as prospective engineers. The science of this course also encompasses pedagogic aspects, including the teaching methods and ethics related to civil engineering.

In the Industrial Revolution 4.0 era, the development of digital technology is effective in the work and organization in the construction project environment (Kuper, 2020; Taher, 2021). This influences the methods and content of civil engineering education at vocational schools and universities. The application technology in education has two general tendencies, namely: 1) the use of technology by including digital competencies in the curriculum and assessment; and 2) the use of technology as teaching content and a tool that facilitates learning (Scherer et al., 2019). Educational technology comprises the media or devices used in the educational process (Pinto et al., 2020). As such, the technology applied in the construction industry is very relevant when applied to the civil engineering teaching process.

Looking at education in general, the research of Huang et al. (2020) identified changes in educational research topics between 2000 and 2017. Other studies indicated that in the last decade, educational research has emphasized more innovative aspects, such as social media for learning and network-based

methodology (Tang et al., 2019). The interdisciplinary and multidisciplinary scope of education makes civil engineering education even more attractive because it focuses more on one engineering education discipline. Bibliometric studies within the scope of engineering education consisting of several specialization fields have been compared to determine which technologies were successful and truly impactful in engineering education. The specialization fields include computer science and software engineering, electrical and computer engineering, engineering education, mechanical and industrial engineering, telecommunication, and others (Martin et al., 2019). This means that research has yet to reveal the extent of the use of educational technology in the scope of civil engineering education.

There are three patterns in bibliometric study research based on educational technology. First, bibliometric studies capture large sets of data. For example, Ling et al. (2023) performed research regarding ICT in the educational environment over a very long period, namely from 1946 to 2022. Furthermore, Chen et al. (2019) studied educational technology in publications spanning over 40 years (1978–2018) utilizing the Web of Science (WoS) database, and Fauzan and Soegoto (2023) studied the same theme for the period 2017 to 2021 but used the Google Scholar database. Second, bibliometric studies focus on one technology. For example, Prahani et al. (2022) and Vazquez et al. (2021) did research on artificial intelligence (AI) and Hincapie et al. (2021) and Arici et al. (2019) on augmented reality (AR). Immersive technologies such as AR and VR are seen as practical applications of learning technology to support civil engineering education (Wang et al., 2022). They are considered very helpful in laboratory courses in civil engineering because they are seen as positive in promoting cognitive interest and accessibility (Try et al., 2021). Third, bibliometric studies focus on sources of information, either from journals or countries. Examples are the studies by Chen et al. (2020) and Bond et al. (2019) regarding educational technology sourced from one particular journal and the study by McGarr and Johnston (2021) regarding educational technology applied in a particular country.

Based on these descriptions, computational mapping of bibliometric analysis has been conducted in civil engineering education. In 2019, Zheng et al. evaluated construction education research from 1982 to 2017 using several relevant terminologies with a broader scope. Another study (Aliu & Aigbavboa, 2021) reviewed construction education research trends for the last decade, from 2010 to 2020. The current research is deemed necessary to complement these two studies, where research trends and educational technology in the scope of civil engineering education would be revealed. Limitations were not observed at the beginning of publication, leading to extension of the year for which data were collected, that is, 1967. We also used Scopus and WoS databases, and Biblioshiny, part of R software, as tools during data mining and analysis. R software is ecosystem software, which means that all functions are shared in an open-source environment with users (Dervis, 2019). Specifically, this research aims to analyze research trends and applications of educational technology in civil engineering education using bibliometric analysis. The following three research questions clarify the research objectives:

1) What are the research trends in civil engineering education from early publication until 2022?
2) Which authors, journals, and countries have published the most research on the course from early publication until 2022?
3) What are the educational technology trends in civil engineering education research?

The results of this study are expected to improve the quality of research and curriculum development at institutions providing civil engineering education.

2. Research Methods

This research aimed to analyze the trends in civil engineering education using bibliometric analysis, a rigorous method using large amounts of data (Donthu et al., 2021) and exploring a collection of publication metadata. In addition, Scopus and WoS were also used as databases for article exploration. This is because Scopus is the largest database of abstracts and citations, encompassing nearly 41,000 titles and more than 11,000 international publishers (Harzing & Alakangas, 2016). Meanwhile, WoS is the oldest and most widely used database of research publications and citations, with 34,000 journals (Birkle et al., 2020). The PRISMA (preferred reporting items for systematic reviews and meta-analyses) diagram was also employed to guide the identification of relevant research. It was responsible for determining and emphasizing the steps guiding various scholars in reporting systematic review articles (Page et al., 2021). In the initial stages, we established the topic, specifically "civil engineering education". This process involved data collection through various methods. Other terminology with similar interpretation was also emphasized, namely "building engineering and construction education". Moreover, the searches on Scopus and WoS used the string "civil engineer* education" OR "building engineer* education" OR "construction education". Inclusion criteria at the literature collection stage were: papers published until 2022; source type: journal; document type: article; and language: English. Meanwhile, exclusion criteria included papers published in 2023. Figure 1 illustrates the step-by-step processes conducted.

As seen in Figure 1, the search process was carried out on February 25, 2023, with the Scopus and WoS databases recording 502 and 243 publications, respectively. Of these, 200 duplicate records were excluded, leaving 545 publications for subsequent analysis. These records were exported into CSV format and contained several details, such as author, article title, affiliation, abstract, journal, year of publication, and keywords. Furthermore, Biblioshiny, a bibliometric software program, was used for relevant analysis. Biblioshiny is an interface application implemented to apply bibliometrics, a unique open-source tool for comprehensive science equity experiments which was integrated into R software (Aria & Cuccurullo, 2017).

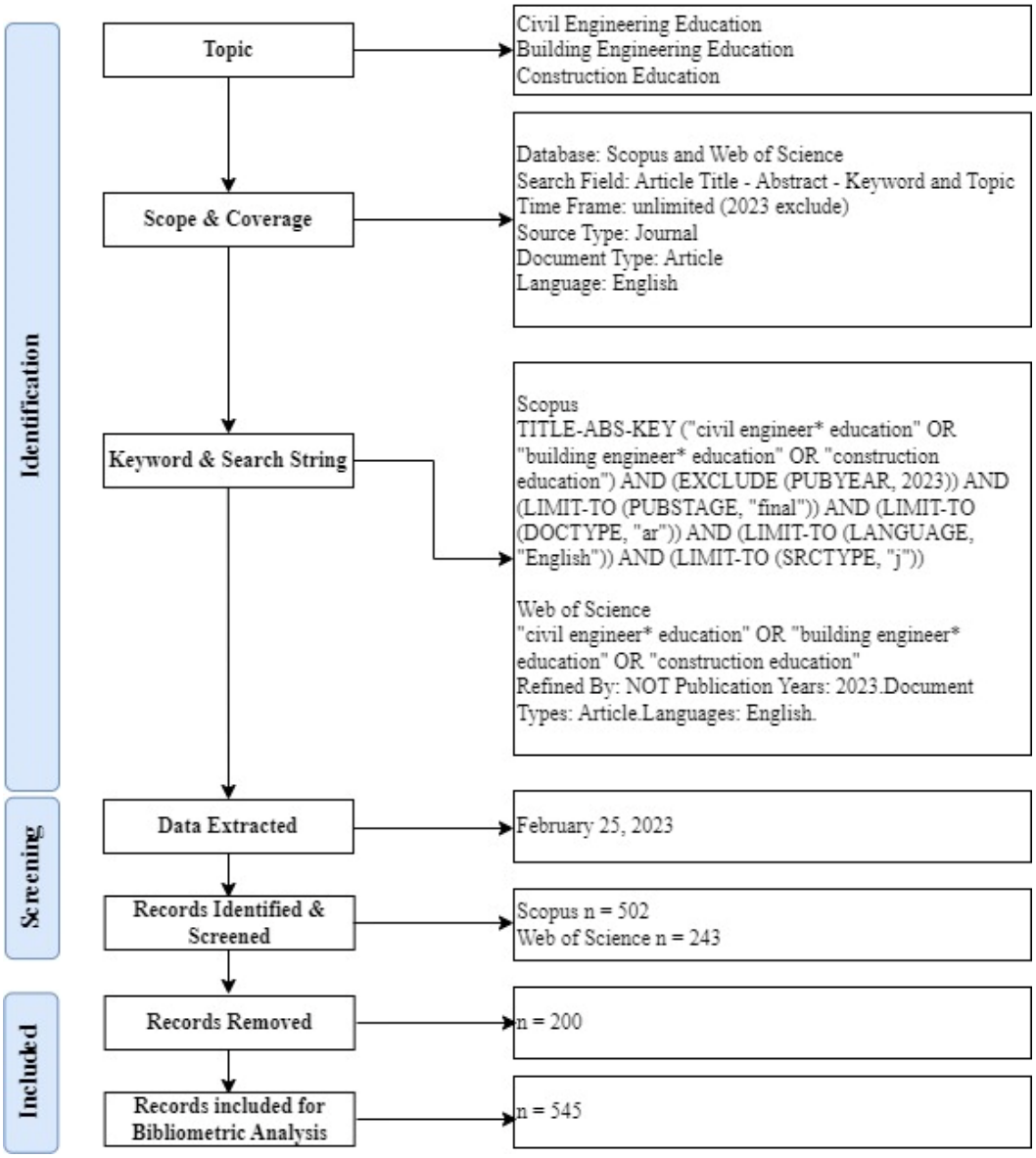

Figure 1: PRISMA flow diagram

We used two analysis processes. The first is performance analysis, which utilizes article metadata, such as author, journal source, and country of origin. In the second, thematic analysis and WordCloud analysis, selected papers on the topic of educational technology were analyzed. Bibliometrics allow researchers to review the literature comprehensively and systematically in civil engineering education. Although this approach cannot provide in-depth insights for each publication, using bibliometric analysis can identify trends, themes, and patterns in the literature without relying on other analysis techniques.

3. Bibliometric Results

3.1 Research Trends in Civil Engineering Education from Early Publication until 2022

Research trends in civil engineering education were determined by recording all papers published from 1967 until 2022. Table 1 summarizes the metadata statistics used as the database.

Table 1: Publication data research outputs

Timespan 1967−2022	**Sources** 172	**Documents** 545	**Annual growth rate** 6.73%
Authors 1099	**Single-authored publications** 166	**International co-authors** 0.9174%	**Co-authors per publication** 2.54
Author's keywords 969	**References** 14,303	**Average age of publications** 15.8	**Average citations per publication** 10.54

As seen in Table 1, 545 publications were obtained, with 1099 authors in total. Regarding the number of publications per year, the number increased from 1 article in 1967, 1971, and 1972, to 36 articles in 2022, with an average annual growth rate of 6.73%. The average age of the publications was 15.8 years, the average citations per publication was 10.54, and the publications cited 14,303 references in total. Since the number of publications increased from 1 article in 1967, 1971, and 1972 to 36 in 2022, the theme of "civil engineering education" has increasingly attracted the interest of various scholars yearly. The 6.73% annual growth rate over the 55-year timespan highlights that the theme of the course was becoming increasingly important and highly considered by several research experts. In addition, the average publication age was 15.8 years and average number of citations per document, 10.54, showing frequent interest and citation by various scholars. In addition, the total of 14,303 references that were used in these publications shows that the theme of civil engineering education was continuously developing and becoming highly considered in relevant educational fields. The high annual growth rate emphasizes the progress of the analysis, leading to new publications yearly. The relatively high average age of publications also indicates that this theme has a lengthy concern.

The number of publications yearly shows an increase or decrease in research trends, providing valuable insight into civil engineering education research themes. Figure 2 presents the annual distribution of the publications.

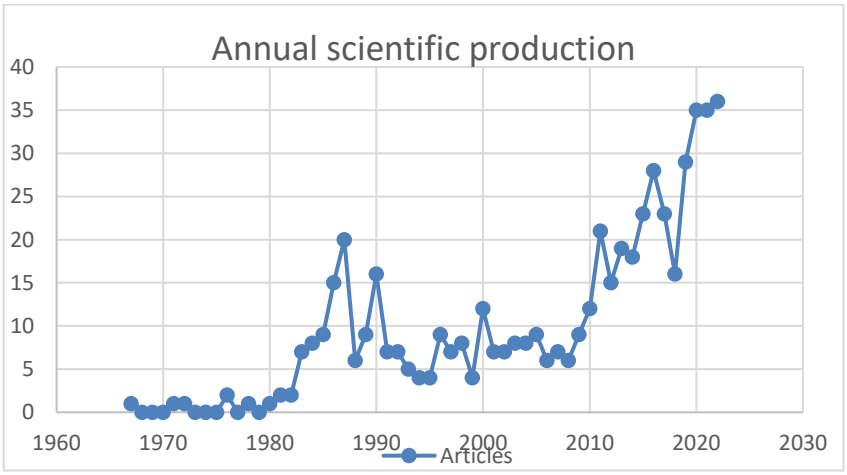

Figure 2: Distribution of annual scientific publications

As shown in Figure 2, the theme of civil engineering education significantly increased in the last 3 years of the study period, with 35/36 publications for 2020, 2021, and 2022. However, research in civil engineering education experienced several fluctuating phases. Production in 1967 to 1982 is referred to as the initial phase, where for these 16 years, no more than 2 papers were published per year. This indicates that civil engineering education was not yet an interesting topic to research in this time. Between the 26 years from 1983 to 2009, publications on civil engineering education increased slightly, yet with fluctuations from year to year. This shows that researchers were starting to realize the importance of pedagogical aspects in civil engineering and were supported by technological developments that could be applied in civil engineering courses. After this, from 2009 until 2022, although the number of publications on civil engineering education per year did not increase consistently, the numbers are very satisfactory compared to those of the first phase. This means that civil engineering education researchers are showing increasingly strong and diverse interests in the field.

Figure 3 shows the average number of citations per year of the reviewed publications.

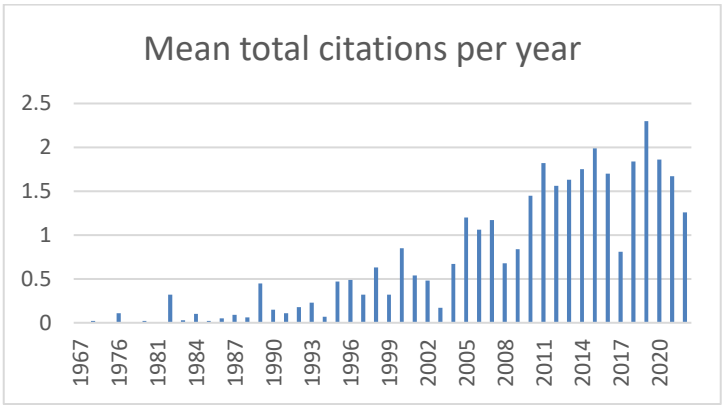

Figure 3: Mean total citations per year

As seen in the figure, the 2019 publications were the most cited, with an average of 2.3 citations per year. The 29 articles that were published in 2019 had an average of 11.52 citations per publication. Until 2004, citations were still very low, that is, at an average of less than one per publication per year. Biblioshiny was employed to determine which of the publications were most cited globally. Results show that Teizer et al. (2013) and Kartam (1999) were the most cited articles globally and locally on civil engineering education. Most publications with a high citation rate are related to improving design technology and data visualization. Another type of publication with a high citation rate pertains to technology in the construction industry as applied in civil engineering classes, both for students and construction workers.

3.2 Authors, Journals, and Countries that Published the Most Research on Civil Engineering Education from Early Publication until 2022

3.2.1 Top authors

The selected publications on civil engineering education involved 1099 authors, of which 919 authored 1 paper, 152 authored 2 or 3 papers, 25 authored 4 to 6 papers, and only 3 authored more than 6 papers. Figure 4 illustrates the research production of the most prevalent authors over time.

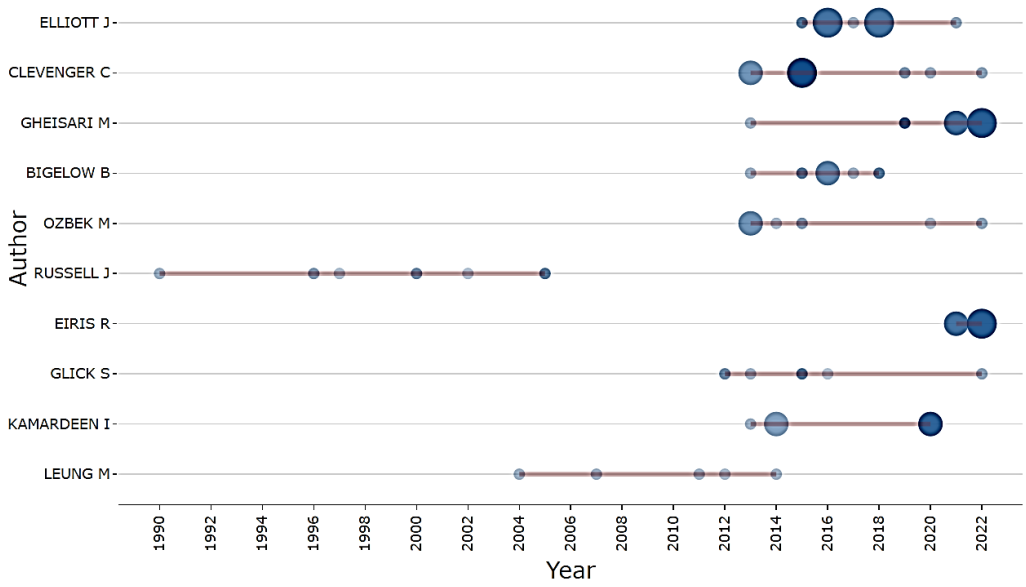

Figure 4: Authors' research production over time

In Figure 4, the line shows the period between the author's first and last publications, while the size of the circle shows the number of articles published. The top three authors were Elliott, J., Clevenger, C., and Gheisari, M., who published nine, eight, and seven articles, respectively. Elliott, J. focused on gender themes in construction education (Thevenin & Elliott, 2018), specifically regarding female students' self-efficacy, motivation, and behavior in construction management programs. Clevenger, C. tested learning methods and tools for civil engineering students, such as collaborative learning, work−life balance, BIM-based learning, and sustainability competencies (Clevenger et al.,

2019). Gheisari, M. focused on using VR and other technological tools in construction education (Eiris et al., 2022).

Table 2 presents the top six most productive authors and their respective h-index.

Table 2: Top six most productive authors on civil engineering education in the study period

Author	Articles published	h-index	Total citations
Elliott, J.	9	5	86
Clevenger, C.	8	6	92
Gheisari, M.	7	5	49
Bigelow, B.	6	5	73
Ozbek, M.	6	3	46
Russell, J.	6	4	157

From the context, an h-index was observed for each author (third column: Table 2). The h-index is an author-level indicator used to measure the output of scientists/scholars and the impact of citations on their publications. Table 2 also indicates the number of publications and total citations per author. The results show that Elliott, J. received the top position due to being the most prolific author, with nine publications. Second was Clevenger, C. with eight articles.

Based on the results, Figure 5 was designed to graphically illustrate collaborations between the top authors and other authors in the reviewed publications.

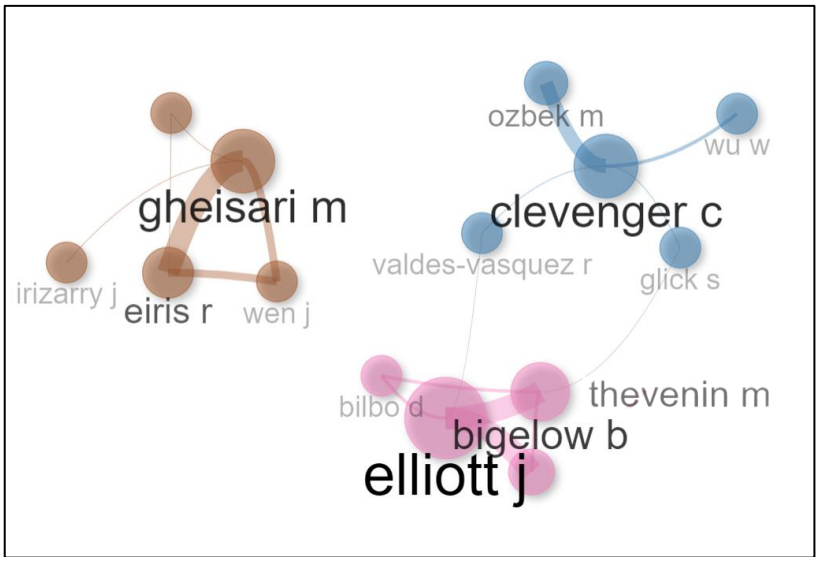

Figure 5: Author collaboration networks

As the author with the most publications, Elliott, J. collaborated most often with Bigelow, B. and Thevenin, M. (thicker lines). Clevenger, C. had the most

extensive author network, collaborating with seven other authors. Interestingly, these two authors, namely Elliott, J. and Clevenger, C., originated from the same affiliation and country, that is, Colorado State University, United States of America.

3.2.2 Most influential sources

The most influential sources were identified by reviewing the number of publications (NP) and total citations (TC) (cluster determination indicators), and through the SCImago Journal Rank (SJR), that is, the standard metrics used to measure the quality and reputation of scientific journals. SJR was published by SCImago Lab, a Spanish research institute, whose work in scientometrics involves quantitatively studying science, technology, and innovation. SJR was used to measure the citation frequency of a journal in other publications within the last three years. Despite this, the metric still calculated the quality of citations by considering the reputation of the involved journals. Based on metric data, the top three relevant publishers on the topic of civil engineering education are as follows: (1) Journal of Construction Engineering and Management, (2) International Journal of Construction Education and Research, and (3) Journal of Civil Engineering Education. However, the journal that observed the most publications and total citations was the Journal of Professional Issues in Engineering Education and Practice. This journal focuses on professional and ethical issues in civil engineering education and practice, curriculum development, and teaching methods, and highlights its relevance to the analysis of the course.

Table 3 indicates the top nine journals in each cluster on civil engineering education. Nine journals were observed, with the top three exhibited in clusters 1, 2, and 3. This cluster division was calculated according to the NP and TC. In this case, the journals in Cluster 3 did not necessarily have a lower impact factor (IF), CiteScore, and SJR value than those in Cluster 1.

Table 3: Top nine journals in each cluster on civil engineering education

Journal	NP	TC	SJR 2021
Journal of Professional Issues in Engineering Education and Practice[1]	102	1560	-
International Journal of Construction Education and Research	63	633	0.43
Journal of Construction Engineering and Management	19	299	1.07
Journal of Construction Education[2]	14	81	-
International Journal of Engineering Education	13	113	0.44
Journal of Civil Engineering Education[3]	10	66	0.53
Computer Applications in Engineering Education	3	43	0.59
Computers and Education	3	9	3.68
Construction Economics and Building	3	28	0.34

Note: 1 = discontinued in Scopus since 2019. 2 = discontinued in Scopus since 2003. Taken over by Taylor & Francis, the name of the journal became International Journal of Construction Education and Research. 3 = The previous name was Civil Engineering Education.

Even the journal with the most NPs (Journal of Professional Issues in Engineering Education and Practice) was discontinued by Scopus since 2019. The results also show that four of the nine journals were in Quartile 1, namely (1) Journal of Construction Engineering and Management, (2) Journal of Civil Engineering Education, (3) Computer Applications in Engineering Education, and (4) Computers and Education. From this context, the journal with the lowest SJR value was in the third quartile, namely Construction Economics and Building.

3.2.3 *Scientific production by country*

Dozens of countries in America, Europe, Africa, and Asia contributed to civil engineering education research from 1967 to 2022, showing that civil engineering education became a global research theme. Figure 6 shows the top 10 countries that contributed most to this research theme. The United States was found to be a leader in the theme of civil engineering education research because it published 332 of the 545 papers during the study period. Other countries, including the United Kingdom, Australia, and China, published less than 40 papers each. Also in this list is Indonesia, the country with the fourth largest population, who only had eight publications. Indonesia must focus more on improving the quality of civil engineering learning because, in this way, the quality of prospective construction workers in the country can compete with that of foreign workers. The civil engineering education study programs at 14 state universities in Indonesia are important capital for increasing the scientific production of civil engineering education.

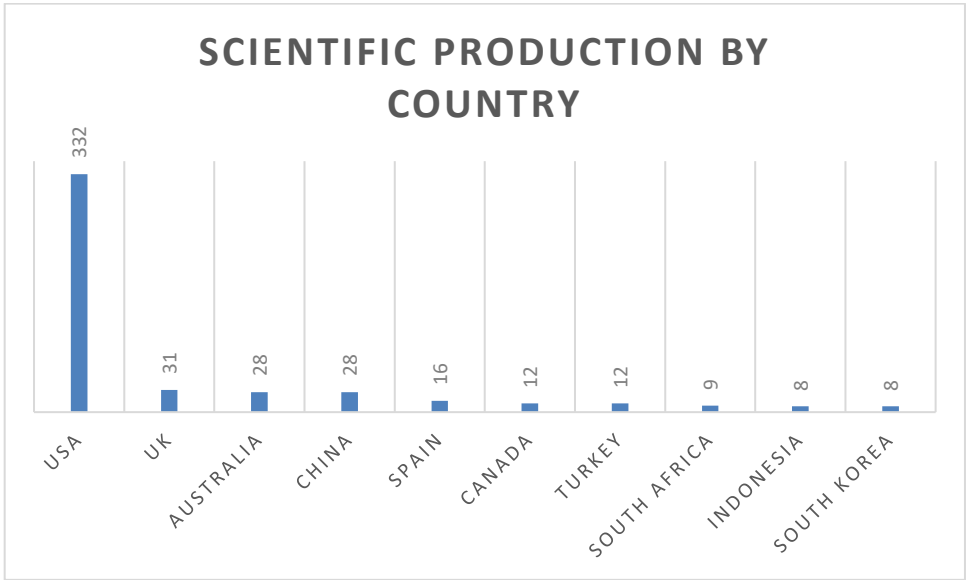

Figure 6: Contributions of the top 10 countries on civil engineering education

Figure 7 illustrates the research collaboration network between countries. The bigger the circle, the higher the number of publications produced.

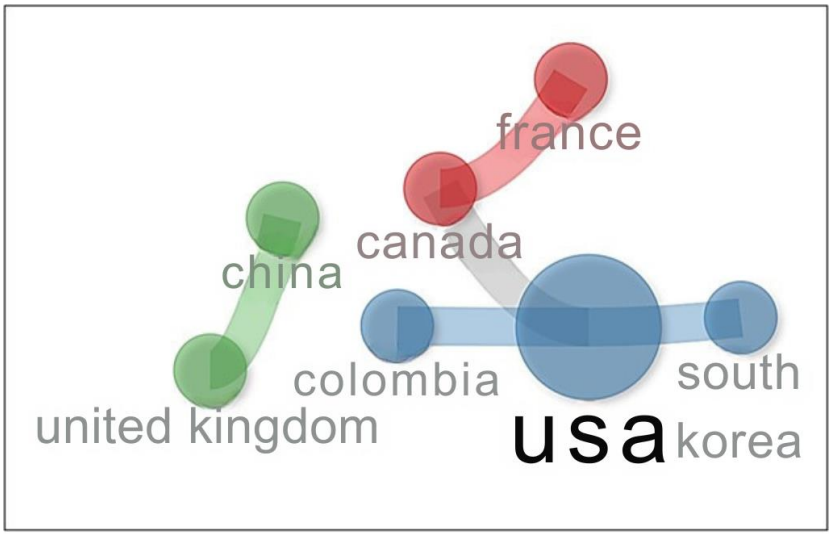

Figure 7: Collaboration network among countries

The United Kingdom, China, Colombia, Canada, France, and South Korea were the countries involved in the scientific production of civil engineering education, although their total number of contributions combined do not exceed that of the United States in the field of civil engineering education. In this regard, various implications and improvements were observed for the position of the USA as a global leader in civil engineering education. For other countries, the research contributions also served as a model for increasing the productivity and quality of research in similar fields. Scientific publications can be increased by collaborating with researchers from other countries. As shown in Figure 7, we could conclude that only three collaborative network clusters from dozens of countries were involved in the scientific production of civil engineering education. Cluster 1 was the USA, Colombia, Canada, and South Korea, Cluster 2 was Canada and France, and Cluster 3 was the United Kingdom and China. This means that most of the research relied on individuals or local collaborations.

3.3 Educational Technology Trends in Civil Engineering Education

Thematic analysis was employed to analyze the educational technology trends in civil engineering education. This helped to identify the division of themes and developments in educational technology applied to civil engineering education. Thematic analysis identified the keywords that appear and had become trending topics yearly. The 6 themes that emerged over the 55-year study period are indicated in Table 4.

Table 4: Theme division based on keyword trends from 1967 to 2022

Theme 1: Engineering education	Theme 2: Civil engineering education	Theme 3: Fields of civil engineering
Engineering education − computer applications Engineering education − teaching Engineering education Personnel training	Civil engineering − education Civil engineering students Construction engineering Construction education	Buildings Civil engineering Structural design Structural analysis Civil engineers Construction industry

Curriculum Teaching Professional development Higher education Learning Undergraduate students Surveys Learning systems Education Curriculum Body of knowledge Students		Industrial management Construction management Project management Sustainable development Professional aspects
Theme 4: Technology in engineering education	**Theme 5: Global & social aspects**	**Theme 6: Other**
Computer-aided instruction Computer software Virtual reality Mixed reality E-learning Building information modeling Technical presentations	Leadership World Wide Web Societies and institutions Social aspects Climate change	Engineering research Research Design Problem-solving Employment Management Accreditation Strategic planning

As seen in the table, civil engineering education is part of engineering education, which is also Theme 1, with keywords such as engineering education, curriculum, teaching, and students. Theme 2 is civil engineering education, the main terminology used in this research. Another terminology that is often used is construction education. Technicalities in civil engineering could not be denied, even though we are discussing the pedagogical aspect. Therefore, Theme 3 describes the field of civil engineering, with concepts such as structural design, structural analysis, and project management. This means that technical aspects closely related to the field become material content in the pedagogical aspect. Theme 4 is technology in engineering education, which is also the main theme in the discussion. This theme is related to the development of increasingly intelligent digital technology in engineering education. Theme 5 is related to social and global aspects, a theme that made civil engineering education research themes increasingly diverse. Keywords that appear in this theme include leadership, social aspects, and climate change. Finally, Theme 6 is a mixture of keywords not included in the first five themes.

Furthermore, technological developments applied in civil engineering education were divided into five eras: 1) simple software era (1976–1990); 2) geographic information systems (GIS) and VR era (1991–2000); 3) multimedia and e-learning era (2001–2010); 4) BIM era (2011–2022); and 5) the forthcoming era (2023–future). To understand technological developments in these eras, we specifically mapped research that utilized educational technology from year to year. In addition, mapping was done with WordCloud analysis using keywords divided by era (see Figure 8). Specifically, the forthcoming era is explored in the discussion section.

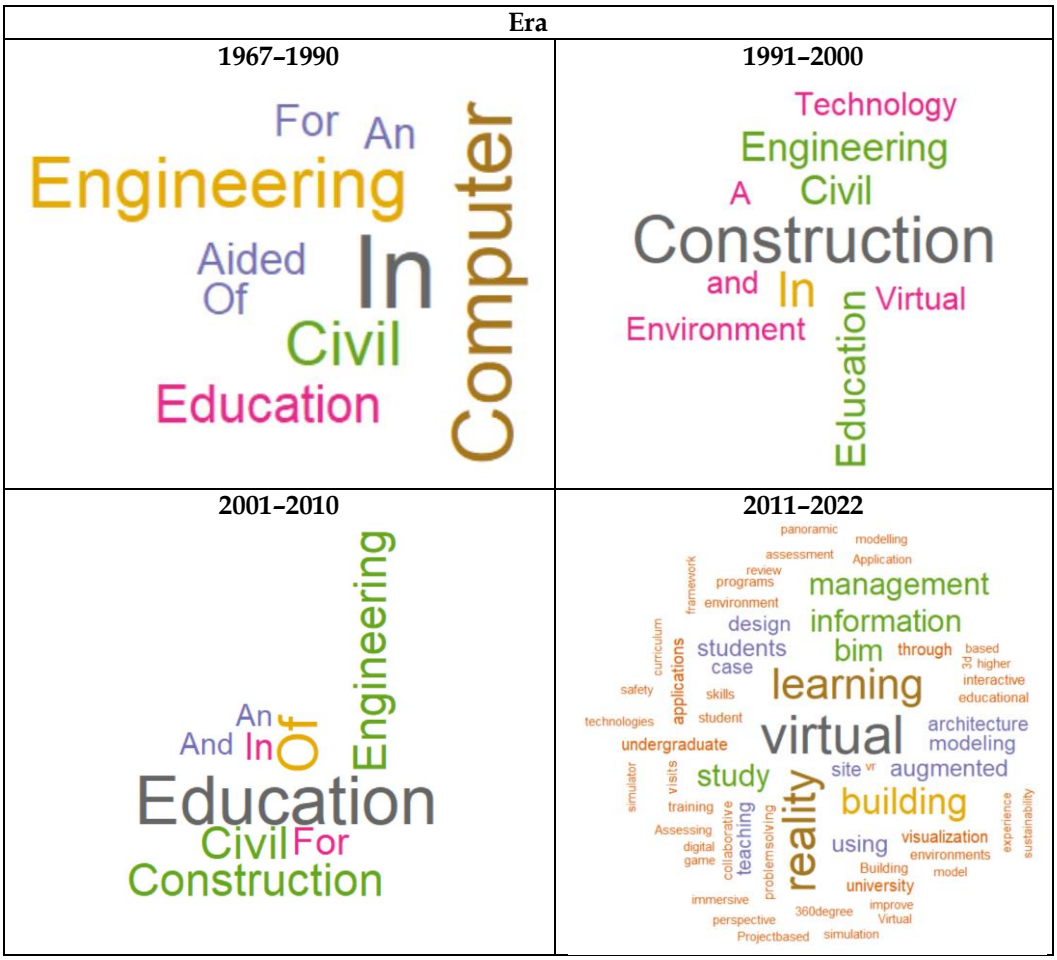

Figure 8: WordCloud of publication titles regarding educational technology by era

In the 1976 to 1990 era, the use of computers and simple software began to be applied to civil engineering education. A publication by Abbott in 1976 emphasized using computers in hydraulics. It was considered a solution to the problems of pseudo-dispersion and pseudo-radiation, mass falsification, and other violations of physical laws (Abbott, 1976). In the 1980s, computer capabilities were enhanced with graphics that better supported the learning of civil engineering students (Shephard, 1981). Software in the field of civil engineering was starting to be applied to learning. These include computer-aided instruction for the design of steel (CAIDS) (Katona et al., 1986), computer support for civil engineering graduates concentrating on water resources engineering (Mantz, 1986), Turbo Pascal for computer-aided instruction (CAI) of the mechanics of materials (Adeli & Chen, 1989), as well as the use of microcomputers in survey learning (McDonough, 1985). In this era, computers supported learning for prospective civil engineers. In the early 1990s, the need for computers in civil engineering education became increasingly important for design, interpretation of analysis results, and understanding the concept of structural analysis (Hoadley & Buckner, 1990). Obstacles and problems using computers in civil engineering education were also faced and researched during this period.

In the 1991 to 2000 era, the use of computers began to be integrated with other technologies, such as multimedia learning, websites, GIS, construction automation, and robots. In addition, virtual reality (VR) began to be used toward the end of the 90s and beginning of the 2000s. This was influenced due to the start of Internet usage in education. Dymond (1996) practiced using websites and multimedia at the University of Wisconsin—Platteville, Platteville, United States. The basics of automation and robotics became new course topics in this era at several universities in the United States (Boles & Wang, 1996). Several experts in this era discussed integrating technology into civil engineering education. For example, integrating GIS into civil engineering curricula faced financial and technical challenges (Easa et al., 1998). However, the case was different with the use of VR. In 1997, the research team at National Chiao Tung University in Taiwan succeeded in implementing VR in learning structural analysis in civil engineering education (Chou et al., 1997). It can thus be concluded that in this era, the use of computers became more sophisticated than in the previous era, and that new technology started to be integrated into the civil engineering education curriculum.

The 2001 to 2010 era was an era of learning using multimedia and e-learning. The increasingly widespread Internet made integrated web-based learning easier to use. Multimedia development was included in computer-aided learning (CAL) and was applied to civil engineering learning. Moreover, virtual reality modeling language (VRML) was developed (Turk, 2001). The integration between 2D and 3D digital whiteboards produced VizClass, a classroom equipped with a visualization environment for civil engineering and computer graphics education (Grimes et al., 2006). Even though educational technology advanced increasingly in this era, the success of multimedia and e-learning in civil engineering education depended on student learning behavior (Liu et al., 2010). Therefore, it can be concluded that the 2001 to 2010 era was a continuation of the previous era in terms of the use of VR and multimedia.

In the 2011 to 2022 era, BIM began to be implemented in civil engineering education. In the previous era, 2D and 3D computer-aided design (CAD) was a long-lasting trend. However, BIM was slowly replacing this trend because of its wider reaching capabilities. In 2011, the Department of Building and Real Estate of the Hong Kong Polytechnic University (PolyU) included BIM in its construction management, building technology, and quantity surveying curricula (Wong et al., 2011). Leading universities were increasingly serious about including BIM in their civil engineering education curriculum. For example, Fuzhou University in China expanded BIM education from a single BIM course in the early undergraduate years to a final semester project in the senior year, designed to enable BIM utilization in various construction tasks (Wang et al., 2020). Apart from BIM, the use of AR, VR, and e-learning, such as massive open online courses (MOOC), also grew in this era (Llanos & Barroso, 2020). Integrating several design and visual technologies presents the virtual construction site as an innovative and intelligent technological tool in construction education (Terentyeva et al., 2020).

The 2011 to 2022 era was an era of integration between BIM, immersive technology (AR, VR), and e-learning. This collaboration made civil engineering education increasingly more realistic in facing conditions in the field. 2021 was the technological peak of Industrial Revolution 4.0, characterized by automation and innovation. Even though the technology used was the same as in the previous era, such as BIM, AR, and VR, the innovation applied was more advanced and used for wider benefits. For example, DroneSim, a VR-based flight simulator mediated by drones in the real world, is used to inspect buildings (Albeaino et al., 2022). Drones or UAVs could be used in conjunction with 4D BIM in order to assess project progress and verify the compliance of geometric design models (Elghaish et al., 2021). Another example is the use of VR in construction safety training (Zhang et al., 2022). AI is also applied as interdisciplinary learning in civil engineering education. Shortly, AI will become a necessity for universities based on the development of the construction industry (Chiang, 2021). This means that in this era, the road to digitalization in the construction industry is accelerating, supported by technological innovation that continues to develop.

4. Discussion

Over the 55-year study period (1967–2022), publications on civil engineering education increased at an average of 6.73% per year, as calculated form the 545 reviewed publications from reputable journals, with a total of 5747 citations and 10.54 per publication. This indicates that research produced many reputable publications and significantly impacted the scientific community. Research interest in civil engineering education or construction education began in the early 1920s, but research interest has increased since the beginning of the 21st century (Zheng et al., 2019). Regarding the continuous development of publications, the interest and analytical focus were continuously improving. This proves that technological advances significantly impacted the development of the building construction industry (Li et al., 2022). Technology-based and interdisciplinary approaches characterize current research trends in civil engineering education. Technology from Construction 4.0 applied in construction projects is being brought into higher education to facilitate student learning activities (Chacon, 2021). Using Construction 4.0 technology in universities impacts interdisciplinary learning approaches in civil engineering education. For example, AI is having an impact on sustainable development in the field of civil engineering (Manzoor et al., 2021). In summary, the research trend in civil engineering education has been ongoing for more than five decades and has been accelerating since the beginning of the 21st century. The current research trend in civil engineering education leans toward a technology-based and interdisciplinary approach.

Based on the number of publications, most citations, and author productivity in the study period, the USA was highly dominant in civil engineering education research. This is proven by the most prolific authors on the topic, namely Elliott, J. and Clevenger, C., being academics in the USA. The most productive institution also originated from the USA, namely Colorado State University.

Similarly, the USA was home to leading publishers on civil engineering education, such as the Journal of Professional Issues in Engineering Education and Practice published by the American Society of Civil Engineers (ASCE) (see Table 3). This journal was the most prominent in publishing research in the field of engineering (Zheng et al., 2019). Besides the USA, several countries also had major roles, such as the United Kingdom, Australia, and China. These results contradict those of Salunkhe et al. (2022) regarding the research trends of image processing applications in civil engineering. These authors stated that the research productivity of the USA was below that of China, with 60% and 20% of scholars originating from China and the USA, respectively. Other research (Zheng et al., 2019) also supported this finding, indicating that China was the most influential country in construction education research due to its development of stable collaborations with scholars from different countries. Meanwhile, the finding of this research is that the USA was the most productive country in collaborative research on construction education.

Forthcoming educational technology trends in civil engineering education are evolving rapidly to prepare students for a more modern world of construction work. Although these technologies have surfaced only recently, integration and wider use thereof will develop in the coming years. The first form to be integrated is VR technology. VR is an interesting innovation applied in the construction world. The technology developed increasingly due to the digital improvements in the last two to three years. The increasing development is also because of its ability to combine with other technologies, such as BIM (Strand et al., 2022). Moreover, the use of VR in civil engineering education was very helpful for appropriate understanding of students. This involved the performance of several experiments, such as comparing the use of VR-aided learning (VRAL) and video-aided learning (VAL) (Try et al., 2021), game development using VR for civil engineering education (Dinis et al., 2017), interactive building modeling with VR (Sampaio et al., 2013), etc. In the future, VR topics should expand with related equipment, including (1) more affordable head-mounted displays (HMDs), (2) the combination of VR with AR and mixed reality (MR), and (3) the use of VR in e-learning (Lai et al., 2020). This indicates that VR is capable of becoming an important educational technology for advancing civil engineering education.

The second technology to be integrated is BIM technology. The use of BIM in civil engineering education and training started in the early 2000s and increased after 2011. Many academics have developed a BIM-based curriculum and learning media in the last decade. In the future, incorporating BIM technology will complement the sophistication of educational technology in civil engineering education. Technology development and collaboration with BIM can include technologies such as digital twins, GIS, virtual design and construction (VDC), and integrated design and delivery (IDD). In addition, the combination of the Internet of Things (IoT) and deep learning technologies has shown the future experimental potential of BIM (Choo et al., 2019). The use of BIM is increasingly in demand because collaborative BIM learning can improve students' professional practical experience (Olowa et al., 2023). In short, combining BIM technology with other technologies will become an educational technology trend.

The identified educational research and technology trends have implications for curriculum development, teaching practices, and future research directions. The civil engineering education curriculum must continue to be updated and adapted to the latest developments to overcome the challenges in the field. Zhang et al. (2016) emphasized integrating sustainability education and industry needs into civil engineering education curriculum planning, with Martin et al. (2021) highlighting the importance of civil engineering education that is aligned with Sustainable Development Goals (SDGs). This means covering the cutting-edge knowledge and skills required for future civil engineers. According to Hammi and Bouras (2018), future civil engineering education curricula must incorporate new technologies, such as integrating cyber security and blockchain features in the BIM curriculum.

Given their dominance of research in this field, the teaching practices and educational approaches of civil engineering in the United States could be adopted. The future of civil engineering education will likely focus on technology integration, project-based learning, and integration with industry through hands-on instruction. Meanwhile, awareness of sustainable education will drive future research.

Sustainability and sustainable development also became trends in the last two decades, specifically in civil engineering education (Menon et al., 2022). In this case, the concept of sustainability was integrated into engineering education as being the responsibility of prospective engineers to protect future generations with more environmentally friendly development (Menon et al., 2022). Several themes were discussed, namely (1) integration of the sustainability concept into the civil engineering education curriculum (Antaya et al., 2013), and (2) experience in implementing sustainability in civil engineering education (Svennevig & Hjelseth, 2017), including the practice of sustainable activities through construction waste (Ivannikov et al., 2019). Therefore, for the achievement of SDGs, sustainability should be futuristically determined with the use of collaborative technology.

Ultimately, this research realized the limitations of bibliometric analysis, as there was potential bias in selecting the reviewed literature. However, to mitigate limitations in this regard, the most relevant and reliable databases were used, and several terminologies related to civil engineering education were used in the search string. Thus, this research provides valuable insight into research and technology trends in civil engineering education and can be a strong starting point for further study for researchers and academics to formulate strategies and policies in future civil engineering education.

5. Conclusion

This research examined the development of civil engineering education research from a bibliometric perspective. Analysis of data taken from 545 publications from Scopus and WoS over 55 years (1967–2022) revealed research themes and the evolution of educational technology in civil engineering education. The

average volume of literature published in the last decade showed a fourfold increase from the average of the previous four decades. The primary growth occurred in 1987, 2000, 2011, and 2022. The United States led in the number of publications published globally, with more than 60% of the reviewed publications attributed to the USA. The United Kingdom, Australia, and China also contributed to civil engineering education research but, on average, each produced only 5% of the publications. The United States increasingly showed itself as a global leader in civil engineering education research, as evidenced by the top-ranking authors and journals also being from the United States.

Analysis of articles based on keywords showed six trending themes in civil engineering education research. These were engineering education, civil engineering education or construction education, fields of civil engineering, technology in engineering education, global and social aspects, and other. The evolution of educational technology within the scope of civil engineering education was described in five eras, namely: 1) simple software era; 2) GIS and VR era; 3) multimedia and e-learning era; 4) BIM era; and 5) the forthcoming era. Other technologies, such as AR, VR, UAVs, and AI, were becoming increasingly sophisticated and interconnected, increasingly helping civil engineering education in analysis and visualization.

The findings of this study have several important implications. First, research trends in civil engineering education show that this field is developing, which has implications for research needs that will become increasingly innovative and competitive. Second, the finding that the United States dominates civil engineering education research suggests they have supportive research and educational infrastructure. Further research on contributions from other countries from different regions is needed to ensure diversity in civil engineering education research. Third, the finding that educational technology in civil engineering is developing very quickly shows that technology and innovation play a crucial role and will continue to be essential factors in the development and evolution of civil engineering education.

This research could ultimately provide academics with an overview of research trends and the evolution of educational technology in civil engineering education and serve as a guide for relevant future analysis. Future research must combine other bibliometric tools, such as VOSviewer and Pajek, to obtain more complete results. Apart from that, a more focused topic can include the collaborative learning and team-based projects that are applied in universities and vocational schools in civil engineering. Another recommended topic is sustainable construction education. These two suggested topics will offer discussions that will enrich the breadth of the field of civil engineering education.

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