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Unraveling the Phenomenon of Construction Labor Productivity: A Cutting-Edge Bibliometric Analysis

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ABSTRACT

Construction Labor Productivity (CLP) is a critical factor in the construction industry that can significantly influence the success of a project. The lack of comprehensive knowledge and proficiency in CLP and its substantial impact on project outcomes is a significant concern. CLP is a highly effective concept that can significantly improve the overall efficiency of construction projects. While it has received considerable academic attention, it is still relatively underutilized in practice. This academic analysis aims to identify trends within the CLP as revealed by a comprehensive review of existing academic research. A bibliometric analysis, complemented by a descriptive quantitative statistical methodology, was utilized to evaluate the performance metrics and delineate the thematic landscape about the subject matter of CLP. Employing distinct keywords pertinent to the CLP phenomenon and applying specific criteria for metadata exploration facilitated a comprehensive search within the Scopus and Web of Science databases. The PRISMA flowchart was employed as a systematic approach for the identification, screening, and eligibility evaluation of metadata to be incorporated into this study. The study highlights growing CLP research, led by the US and the University of Alberta. Key trends include "improvement" and "construction equipment," with future focus on "machine learning" and "artificial intelligence." Despite their potential, data challenges limit their use. More research is needed in developing countries to enhance construction labor productivity.

Keywords: Productivity; construction labor; bibliometric analysis

INTRODUCTION

Construction Labor Productivity (CLP) is a critical subset of the comprehensive concept of construction productivity. CLP is critical in shaping any construction enterprise's profitability (Tam et al. 2021). The significance of CLP is predominantly since labor costs repeatedly constitute a substantial proportion of any project's total expenditure (Shoar & Banaitis 2019; Tam et al. 2021; Xue et al. 2018). Labor productivity measures the efficiency and effectiveness of labour executing construction activities (Wee et al. 2022; Ying et al. 2021). The efficiency and effectiveness of the labor are naturally assessed within a specified timeframe and against a predetermined level of quality. Hence, labor productivity reflects the labor's ability to accomplish tasks within the constraints of time and quality standards.

A high level of labor productivity indicates an optimized financial performance of the project (Calvetti et al. 2020; Liu et al. 2021; Shan et al. 2021). Such a situation implies that the labor can complete tasks efficiently, reducing the time and resources required (Dixit et al. 2022; Zhang & Tsai 2021). Efficient task completion can lead to cost savings and improved profitability. However, it is

essential to note that achieving high labor productivity is contingent upon many factors (Al Jassmi et al. 2019; C. Lee & Won 2021; Lin & Lai 2020). Issues influencing labor productivity can range from the skill level and experience of the labors to the availability and quality of tools and equipment and even the working conditions on the construction site (Albattah et al. 2022; Aldahash & Alshamrani 2022; Bangaru et al. 2022; Banobi & Jung 2019; Zhao et al. 2021). Therefore, strategies aimed at enhancing labor productivity must take a holistic approach, considering all these factors to yield the best results. CLP is a crucial determinant of the financial success of construction projects. Consequently, it is paramount for construction businesses to monitor and pursue methods to improve their labor productivity continually (Tam et al. 2021). Continual improvement ensures the financial viability of their projects and contributes to the business's overall growth and sustainability (Fernandez-Blanco et al. 2020).

Despite the critical role of CLP in the success of construction projects, it is observed that some stakeholders in the construction industry lack a comprehensive understanding and knowledge of CLP and its consequential impact on project outcomes (Abdullah et al. 2022; Abera 2021; Amani & Safarzadeh 2022; Wong et al. 2020). This lack of understanding often culminates in sub-optimal project results, particularly concerning project scheduling, cost management, and overall project success. The actual productivity achieved on construction sites often needs to catch up to the potential productivity that could be realized with a more informed approach to labor management (Schimanski et al. 2019). The gap between actual and potential productivity can negatively affect the project, particularly regarding scheduling and cost utilization (Begić & Galić 2021; Damara 2020; Isah et al. 2019). The underachievement in productivity can lead to delays in the project schedule, as tasks take longer to complete than initially planned (Dalouchei et al. 2022; Mohamed & Moselhi 2022). These delays, in turn, can lead to an escalation in project costs as resources are consumed for extended periods, and additional costs may be incurred due to the extended project duration.

Moreover, the overall success of the project can be compromised. Project success is typically measured in terms of meeting the project's objectives within the constraints of time, cost, and quality (Li et al. 2018). A shortfall in productivity can result in the project failing to meet these objectives, thereby deeming the project less successful. Therefore, all construction industry stakeholders must thoroughly understand CLP and its impacts on project outcomes (Khalil et al. 2021; Uddin et al. 2023). Understanding CLP would enable them to make informed decisions and implement effective strategies for labor management, thereby optimizing productivity and, ultimately, enhancing project success (Naseer et al. 2022).

The significance of the study lies in its potential to elucidate the intricacies of CLP, thereby serving as a valuable resource for more targeted and comprehensive investigations aimed at enhancing labor productivity. The research will comprehensively analyze the complexities of CLP with the ultimate goal of improving the performance of the construction industry. The research's objective is achieved by applying a science mapping approach to analyzing existing research literature.

METHODOLOGY

RESEARCH DESIGN

This study, which employed a descriptive quantitative methodology, used a bibliometric literature review as its primary investigative tool. A bibliometric review, which is a powerful tool, uses quantitative statistical analysis to evaluate the structure and content of published research articles (Bunjak et al. 2022; Gu et al. 2021; Shi & Ma 2022). A comprehensive and objective assessment of the research landscape is allowed through a bibliometric review. Elucidating the phenomenon of CLP through an in-depth analysis of existing research was the study's primary objective. Formulating specific research questions to uncover various aspects of CLP research to achieve the study's objective. These questions provided a holistic understanding of the research performance and science mapping in CLP topic.

The first set of research questions focused on the research performance on CLP topic. Included inquiries into the date of the first publication indexed, the types of documents published, the trend in publication production, the citation trend, the prominent authors, institutions, and countries in the field, the prominent sources of publication, the distribution of scientific publications, and the most cited publications in the field.

The second set of research questions aimed to map CLP topic scientifically. Involved in identifying the most frequently researched topics and discerning the research trends in the field. By answering these questions, the study aimed to provide a comprehensive overview of the CLP research landscape, thereby contributing to the understanding and advancement of the field.

DATA COLLECTION

The dataset for this investigation was derived from metadata extracted from previously published research

studies. In collecting the required metadata, a thorough search was conducted on two prominent academic databases, Scopus and Web of Science. The search strategy was designed with specific inclusion and exclusion criteria to ensure the relevance and specificity of the data collected. The search was not confined to a particular type of publication, thereby encompassing a wide range of sources, including, but not limited to, journal articles. The primary search term employed was "construction labor," with all other terms being excluded to maintain the focus of the study.

TABLE 1. Metadata search inclusion and exclusion criteria

Criteria	Inclusion	Exclusion
Source	Scopus database and Web of science core collection	all other databases
Type of Literature	All types of related literature	-
Subject Characteristics	construction labor, site labor, project labor, building labor, construction worker, site worker, project worker, bulding worker, construction workforce, site workforce, project workforce, building workforce	all other than construction laborers
Year of Publication	all time spans before August 4th, 2023	After the search date
Language	English	other than English
Phenomenon	productivity, efficiency, performance, output, effectiveness, capacity	all other than labor productivity

The temporal scope of the study was not restricted to a specific period. As such, all indexed publications related to the topic, from the earliest available to the search date of August 4, 2023, were included in the dataset. This approach ensured a comprehensive and historical perspective on the subject matter. The phenomenon under investigation was CLP. Consequently, the search was tailored to retrieve only those studies explicitly addressing this phenomenon, excluding all others. This focus allowed for a concentrated examination of the CLP phenomenon. The specific criteria employed in the search process are detailed in Table 1. These criteria served as a guide to ensure the systematic and objective collection of data, thereby enhancing the reliability and validity of the study.

It is crucial to establish guidelines for formulating search strings to ensure the extraction of the most pertinent results from the database. These guidelines encompass the use of synonyms, specific word combinations (which are enclosed in quotation marks), truncation symbols (represented by an asterisk), and boolean operators such as AND and OR. These elements are strategically combined to construct comprehensive search strings. These search strings are then input into the search boxes of library databases and search engines, serving as the primary tool for data retrieval. The specific search strings utilized in this study are outlined in Table 2 for reference.

In the context of this study, these search strings were applied to the Scopus database for the title, abstract, and keywords (under the search parameter TITLE-ABS-KEY). Similarly, these strings were used for topics (under the search parameter TS) for the Web of Science database. This approach ensured a thorough and targeted search, enhancing the relevance and comprehensiveness of the results obtained.

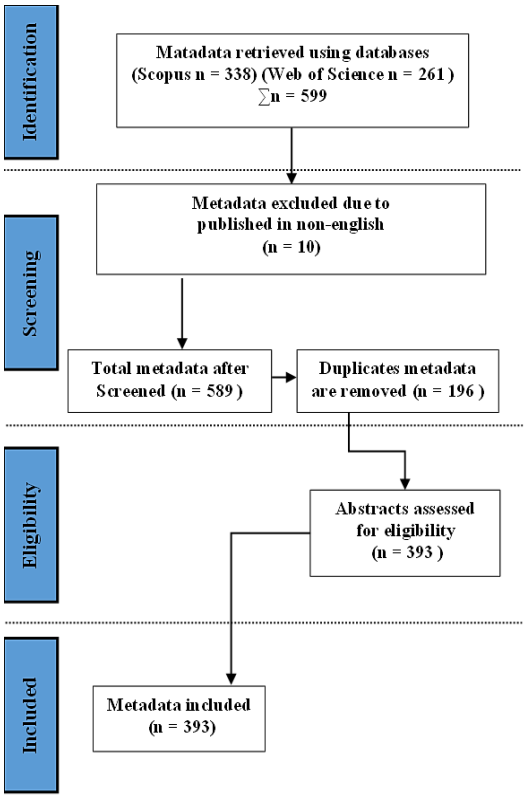

FIGURE 1. PRISMA flowchart

The database search resulted in the retrieval of 599 publication metadata pertinent to CLP, with 338 sourced from the Scopus database and 261 from the Web of Science database. Prior to the execution of the bibliometric analysis on the identified metadata, a rigorous screening process and eligibility assessment were undertaken to ascertain the metadata that were appropriate for inclusion in the analysis process.

This process was conducted following the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines (Moher et al. 2009; Page et al. 2021), which provide a robust and systematic approach to the identification, screening, and eligibility assessment of studies for inclusion in a systematic review or meta-analysis (Magano et al. 2023). Figure 1 shows the PRISMA flow chart, which visually represents the process and illustrates the progression of studies through the various stages of the review process. This rigorous approach ensured the comprehensiveness and reliability of the data included in the bibliometric analysis.

The screening process was conducted in two distinct stages. Initially, the language of the article was used as a criterion for screening, resulting in the exclusion of 10 metadata that needed to be composed in English. Subsequently, a second layer of screening was implemented to eliminate duplicate metadata, removing 196 duplicated entries from the metadata set. Consequently, 393 metadata successfully passed through this rigorous two-tiered screening process.

TABLE 2. Search string for metadata collection in CLP topic

Database	Search String
Scopus and Web of Science Core Collection	((“construction labo* productivity” OR “site labo* productivity” OR “project labo* productivity” OR “building labo* productivity” OR “construction worker productivity” OR “site worker productivity” OR “project worker productivity” OR “building worker productivity” OR “construction workforce productivity” OR “site workforce productivity” OR “project workforce productivity” OR “building workforce productivity”) OR (“construction labo* efficiency” OR “site labo* efficiency” OR “project labo* efficiency” OR “building labo* efficiency” OR “construction worker efficiency” OR “site worker efficiency” OR “project worker efficiency” OR “building worker efficiency” OR “construction workforce efficiency” OR “site workforce efficiency” OR “project workforce efficiency” OR “building workforce efficiency”) OR (“construction labo* performance” OR “site labo* performance” OR “project labo* performance ” OR “building labo* performance ” OR “construction worker performance ” OR “site worker performance ” OR “project worker performance ” OR “building worker performance ” OR “construction workforce performance ” OR “site workforce performance ” OR “project workforce performance ” OR “building workforce performance ”) OR (“construction labo* output” OR “site labo* output” OR “project labo* output” OR “building labo* output” OR “construction worker output” OR “site worker output” OR “project worker output” OR “building worker output” OR “construction workforce output” OR “site workforce output” OR “project workforce output” OR “building workforce output”) OR (“construction labo* effectiveness ” OR “site labo* effectiveness” OR “project labo* effectiveness* ” OR “building labo* effectiveness* ” OR “construction worker effectiveness ” OR “site worker effectiveness ” OR “project worker effectiveness ” OR “building worker effectiveness ” OR “construction workforce effectiveness ” OR “site workforce effectiveness ” OR “project workforce effectiveness ” OR “building workforce effectiveness”) OR (“construction labo* capacity” OR “site labo* capacity” OR “project labo* capacity” OR “building labo* capacity” OR “construction worker capacity” OR “site worker capacity” OR “project worker capacity” OR “building worker capacity” OR “construction workforce capacity” OR “site workforce capacity” OR “project workforce capacity” OR “building workforce capacity”))

The bibliometric analysis of these metadata provided a comprehensive overview of the evolution and development of literature related to CLP. However, it is essential to note that due to the absence of a detailed feasibility assessment, all metadata from the previous process were included in the analysis. This approach ensured an inclusive perspective on the subject matter, enhancing the bibliometric analysis’s comprehensiveness.

The process of amalgamating and filtering publication metadata from the Scopus and Web of Science databases was facilitated by the Bibliometrix R-package within the R-Studio application. The Bibliometrix R-package, an open-source tool developed by Aria and Cuccurullo, is specifically designed to conduct comprehensive science mapping analyses (Aria & Cuccurullo 2017). This tool provides a robust and systematic approach to managing and analyzing bibliometric data (Aria & Cuccurullo 2017). Figure 2 presents the specific code utilized in R-Studio for the combination and filtration of metadata, illustrating the practical application of the Bibliometrix R-package in this research process (Aria & Cuccurullo 2017).

Metadata files with the “BibTeX” extension, sourced from the Scopus and Web of Science databases, were consolidated using the code “Merge-Database =

mergeDbSources(Scopus, Wos, remove.duplicated = TRUE)". This code was executed to eliminate duplicated metadata, ensuring each data entry's uniqueness. The consolidated file was subsequently saved with an "xlsx" extension using the code "write.xlsx(Merge-Database, file = 'merge-file-name.xlsx')." This step was undertaken to facilitate research performance analysis. The Bibliometrix R-package within the R-Studio application was utilized to execute these processes.

Furthermore, the Merge-Database was saved as a file with a "txt" extension using the code "write. table(Merge-Database, 'merge-wosvos-file-name.txt,' sep = '\t,' row. names = FALSE, col. names = TRUE, quote = FALSE)". This step was performed to enable the analysis of science mapping with the VosViewer application. This comprehensive approach to data management and analysis ensured the thoroughness and accuracy of the subsequent bibliometric analysis.

```
setwd("directory folder")
library(bibliometrix)
Scopus = convert2df("scopus-file-name.bib", dbsource = "scopus", format = "bibtex")
Wos = convert2df("wos-file-name.bib", dbsource = "wos", format = "bibtex")
Merge-Database = mergeDbSources(Scopus, Wos, remove.duplicated = TRUE)
dim(Merge-Database)
library(openxlsx)
write.xlsx(Merge-Database, file = "merge-file-name.xlsx")
# write the data frame to a scopus format file
write.table(Merge-Database, "merge-scopusvos-file-name.csv", sep = ",", row.names = FALSE, col.names = TRUE, quote = FALSE)
# write the data frame to a WoS format file
write.table(Merge-Database, "merge-wosvos-file-name.txt", sep = "\t", row.names = FALSE, col.names = TRUE, quote = FALSE)
```

FIGURE 2. R-Studio code for combining and filtering metadata

DATA ANALYSIS

A comprehensive research performance analysis was undertaken to trace the trajectory of this research from its inception to the present. This analysis utilized a range of metrics, which were quantitatively computed using the Bibliometrix R-package tool within the R-Studio application (Aria & Cuccurullo 2017). These metrics served as robust measures of research performance, providing a quantitative assessment of the research's impact and reach.

The metadata sets generated from the previous process were subjected to an in-depth analysis. This analysis yielded statistical tabulations on various aspects, including the overall characteristics of the research, the categories of documents produced, trends in publication output and citation, prominent authors, institutions, countries, and sources, the distribution of scientific output, and the most frequently cited works. These tabulations provided a comprehensive overview of the research landscape, highlighting key trends and patterns.

Furthermore, the data visualization application SCImago Graphica was employed to aid readers in their understanding of the CLP phenomenon. SCImago Graphica is a user-friendly tool that facilitates the creation of intricate and visually appealing visualizations without programming (Yusef et al. 2022). This tool served as a valuable resource in presenting the research findings enhancing the accessibility and comprehensibility of the data (Yusef et al. 2022).

Sciene mapping analysis is a method that employs co-occurrence analysis to scrutinize the textual content of publications, intending to discern the relationships between topics within a specific research area. Co-occurrence analysis is typically derived from "Author Keywords." However, in the absence of these, significant words can also be extracted from the "Article Title," "Abstract," and "Full Text". The underlying assumption of co-occurrence analysis is that words frequently appear together and are likely related in subject matter.

The visualization of the relationships between topics within the research area is facilitated by using the VOSviewer application. This application employs visualization techniques that have become a reliable approach to bibliometric network analysis, thereby aiding in science mapping (VanEck & Waltman 2014). Furthermore, the application was utilized in this review to generate clear and dynamic visualizations, enhancing the comprehensibility and accessibility of the data (VanEck & Waltman 2014).

RESULTS AND DISCUSSION

The bibliometric review of CLP topic yielded a range of results. The research performance analysis provided an overview of the main attributes of the research metadata collection, including the types of scientific publications, trends in scientific publication production, citation trends, prominent authors, institutions, and countries, the worldwide distribution of scientific publications, prominent sources, and the most frequently cited scientific publications.

Furthermore, the science mapping of CLP topic encompassed a co-occurrence network, co- co-occurrence overlay, and occurrence density. These elements provided a comprehensive understanding of the relationships and patterns within the research area, thereby contributing to the overall understanding of the CLP phenomenon. This rigorous and systematic data analysis approach ensured the research findings' comprehensiveness and reliability.

OVERVIEW OF KEY ATTRIBUTES

The metadata set on publications on CLP topic is comprehensively detailed in Table 3. This table presents the main attributes, further categorized into four sub-attributes: critical data information, document content, authors, and author collaboration. The primary dataset spans 1972 to 2023 and encompasses 226 scientific sources. These sources include various materials such as journals, books, and other relevant publications. The analysis recorded 393 scientific documents, reflecting an annual growth rate of 4.99% over 51 years. The average age of the documents is 8.5 years, indicating a robust body of both contemporary and historical research. Furthermore, the average number of citations per document stands at 19.72, demonstrating these publications' significant impact and reach within the academic community. The total number of references across all documents is 1663, highlighting the extensive network of knowledge and research that underpins the study of CLP topic.

The content of the documents reveals that there are 1,969 additional keywords and 932 author keywords available for use in the keyword co-occurrence analysis. This wealth of keywords provides a robust basis for the analysis, enabling a comprehensive exploration of the thematic landscape of the research. A total of 1,044 authors have contributed to scientific publications on the topic of CLP, demonstrating the breadth of scholarly engagement with this topic. Within this cohort, 41 authors have produced single-author works, as categorized in the author sub-attribute.

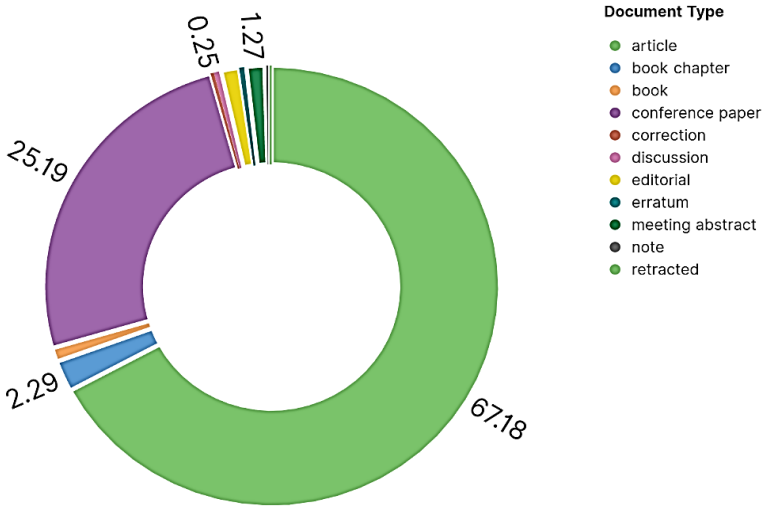

FIGURE 3. Types of scientific documents on CLP topic (1972-2023)

The author collaboration sub-attribute reported 48 collaborative affiliations in single-author documents, indicating a significant level of collaborative engagement even among single-author works. Furthermore, each document has an average of 3.5 collaborative affiliations among co-authors, highlighting the collaborative nature of research in this field. In addition, the rate of collaborative writing between countries stands at 4.3%, suggesting a degree of international collaboration in the study of CLP topic. This international collaboration enriches the research, bringing together diverse perspectives and approaches.

Out of the 393 scientific publications analyzed in this review, a majority of 268 (67.18%) were journal articles. It was followed by 99 (25.19%) scientific meeting articles, contributing to a significant portion of the publications. A smaller number of 9 (2.29%) were book chapters, while 5 (1.27%) were classified as meeting abstracts and editorials. Books accounted for 4 (1.02%) of the publications, and 2 (0.51%) were discussions and errata, respectively. The remaining publications, constituting 1 (0.25%) of the total, were corrections, notes, and retracted publications. The distribution of these document types is visually represented in Figure 3.

TABLE 3. Key attributes of metadata search results on CLP topic

Description	Results
MAIN INFORMATION	
Timespan	1972:2023
Sources (Journals, Books, etc)	226
Documents	393
Annual Growth Rate %	4.99
Document Average Age	8.5
Average citations per doc	19.72
References	1663
DOCUMENT CONTENTS	
Keywords Plus (ID)	1969
Author's Keywords (DE)	932
AUTHORS	
Authors	1044
Authors of single-authored docs	41
AUTHORS COLLABORATION	
Single-authored docs	48
Co-Authors per Doc	3.5
International co-authorships %	4.326

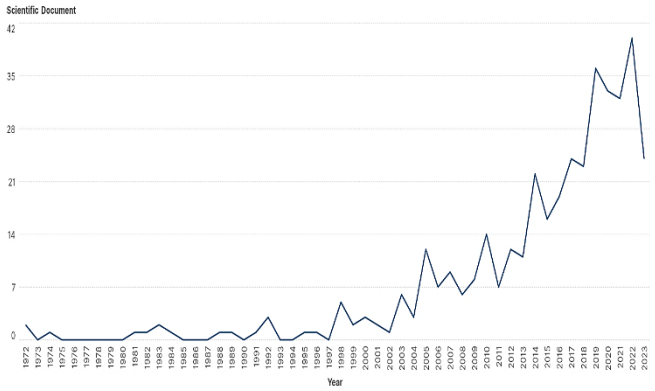

FIGURE 4. Trend of scientific publication production each year in CLP topic (1972 - 2023)

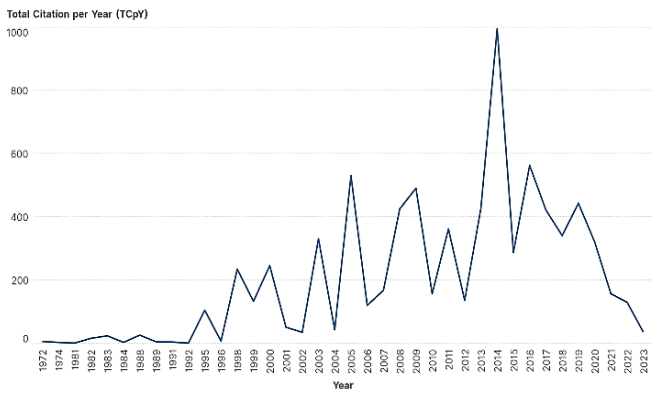

FIGURE 5. Trend of total citations per year of scientific publications in CLP topic (1972 - 2023)

TREND OF SCIENTIFIC PUBLICATION PRODUCTION AND CITATION

Scientific publications on CLP commenced in 1972, and over five decades, there has been a discernible upward trend in these publications. In the initial decade (1972 - 1982), a modest number of 5 scientific publications were indexed. The subsequent decade (1983 - 1992) witnessed a slight increase, with nine scientific publications. This upward trajectory continued into the third decade (1993 - 2002), which saw 15 scientific publications. A significant surge was observed in the fourth decade (2003 - 2012), with the number of scientific publications escalating to 84. The current decade has seen an intensified focus on CLP, with substantial growth in CLP exploration from 2013-2023, resulting in 280 scientific publications in the past decade. These trends underscore the ongoing interest and active debate surrounding CLPs within the research community. For a comprehensive visual representation of the evolution of scientific publications on CLP, please refer to Figure 4.

Citation trends for scientific publications on CLP topic exhibit variation across different publication years. Over 51 years, 393 scientific publications have collectively garnered 7,751 citations. An average of 19.72 citations per document indicates these publications' significant impact and reach within the academic community. The publication that received the maximum number of total citations was published in 2014, amassing a remarkable 995 citations. The citations underscore the enduring relevance and influence of this particular publication within the field of CLP. The annual trend of these citation patterns is visually represented in Figure 5. The fluctuations observed in these trends underscore the continued interest and active engagement with the topic of CLP among researchers. This ongoing interest suggests that CLP remains a vibrant and evolving area of research.

PROMINENT AUTHORS, INSTITUTIONS, COUNTRIES

An author's productivity in the field of CLP can be gauged by the number of articles they have produced on the topic, as indicated by the available statistics. Figure 6 delineates the most prominent authors in the realm of CLP, as ranked by this review. Emerging as the most prolific author to date is Aminah Robinson Fayek, who has made a significant contribution to the field with a total of 18 scholarly articles on CLP topic since 2005. Fayek holds a professorship in the Department of Civil and Environmental Engineering at the University of Alberta in Edmonton, Canada. Her areas of expertise encompass a range of subjects, including artificial intelligence, fuzzy logic, fuzzy hybrid systems, and simulation in construction management. This diverse array of specializations underscores her comprehensive understanding of the field and her substantial contribution to the discourse on CLP.

In parallel with the prominent authors, the prominent affiliations are institutions that have effectively produced scientific publications on CLP topic. The University of Alberta emerged as the most productive affiliation, contributing 26 scientific publications. The University of Wisconsin-Madison followed this with 20 articles, Harvard Medical School and the University of Texas-Austin, each with 17 articles, and the University of Washington with 12. The University of Sydney made further contributions with 11 articles, AARHUS University with nine articles, Nelson Mandela University with eight articles, and Lamar University and the University of Johannesburg with seven articles. These institutions represent the forefront of research in the field of CLP, contributing significantly to the body of knowledge on the topic. The visualization of these prominent affiliations is presented in Figure 7.

The prominent countries regarding the productivity of author affiliations publishing scientific articles on CLP topic are as follows. The United States stands at the forefront with the highest productivity, contributing 139 articles to the field. Australia follows it with 57 articles, Canada with 33, South Africa with 28, and Malaysia with 22. India has made further contributions with 21 articles, China with 17 articles, South Korea and the United Kingdom with 13 articles, and Turkey with 12 articles. These countries represent the global leaders in research on CLP topic, contributing significantly to advancing knowledge in this field. A visualization of these prominent countries in CLP research is provided in Figure 8.

Figure 9 presents the distribution of author affiliations concerning CLP topic. Among the 48 countries represented, Western developed nations such as the United States, Australia, and Canada demonstrate a pronounced focus on this subject matter. Simultaneously, developing nations such as South Africa, Malaysia, India, and Turkey, along with Eastern developed countries like China and South Korea, are also prominently engaged in discussions related to CLP. This global distribution underscores the widespread interest and active research in CLP across diverse geographical and developmental contexts.

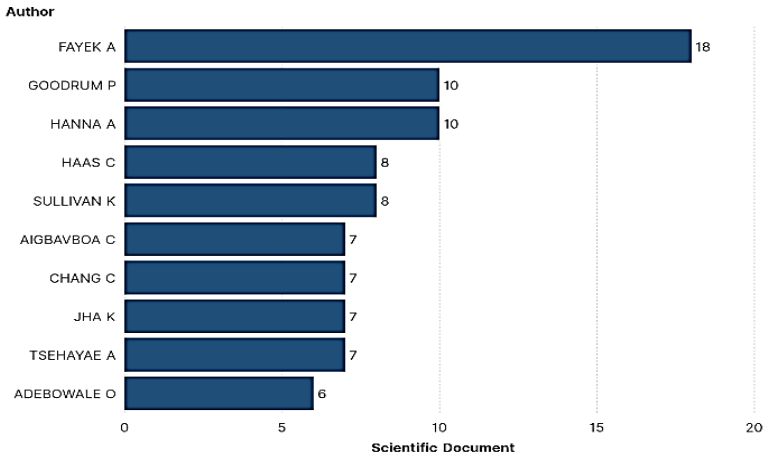

FIGURE 6. List of ten prominent authors on CLP topic (1972 - 2023)

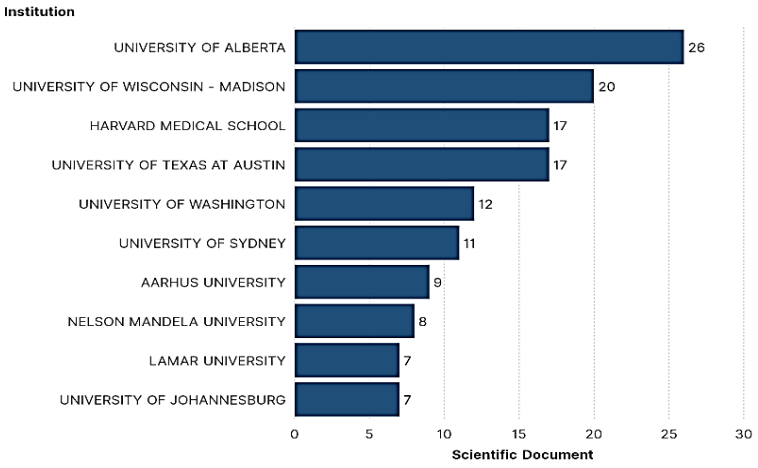

FIGURE 7. List of ten prominent institutions on CLP topic (1972 - 2023)

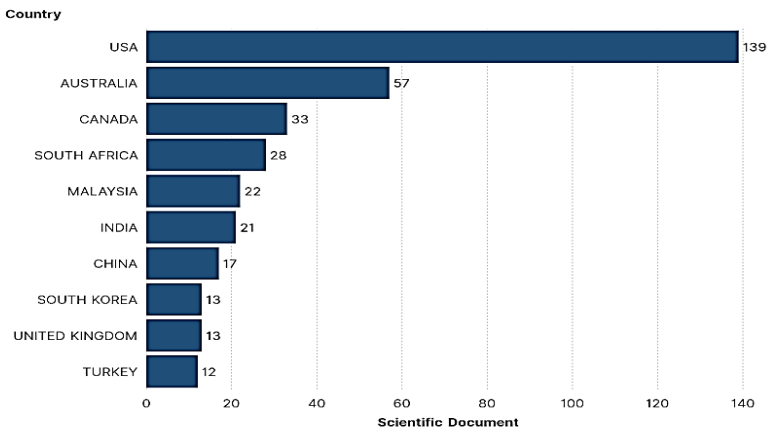

FIGURE 8. List of ten prominent countries on the topic of CLP (1972 - 2023)

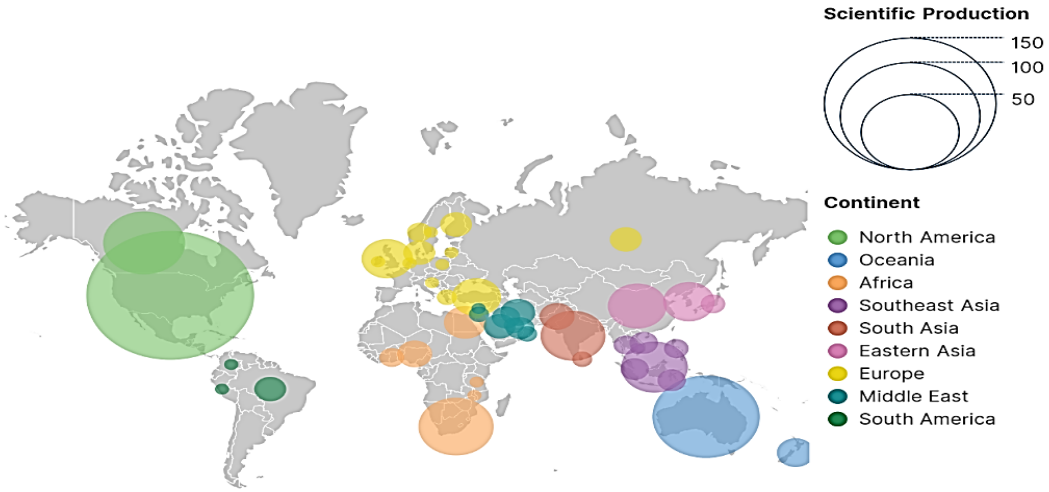

FIGURE 9. Global distribution of scientific publications on CLP topic (1972 - 2023)

PROMINENT SOURCES AND MOST INFLUENTIAL ARTICLES

The Journal of Construction Engineering and Management, published by the American Society of Civil Engineers (ASCE) in 1982, emerged as the most prominent source on CLP topic. It has contributed to 48 publications, boasting a Citation Score of 8.0. The International Journal of Construction Management followed this with 17 articles, the Journal of Management in Engineering with 11 articles, and Construction Management and Economics with 10 articles. Automation in Construction made further contributions in Construction with eight articles, the International Journal of Productivity and Performance Management with seven articles, and Engineering, Construction, and Architectural Management with six articles. Additionally, Buildings contributed five articles, while Building and Environment and Construction Innovation each contributed four articles to the discourse on CLP. The ranking of these sources is visually represented in Figure 10. This distribution underscores the diverse sources contributing to the research and discourse on CLP topic.

Since the publication of seminal works such as "Boosting Construction-Worker Productivity" by Schrader in 1972 and "On-Site Labor Productivity in Home

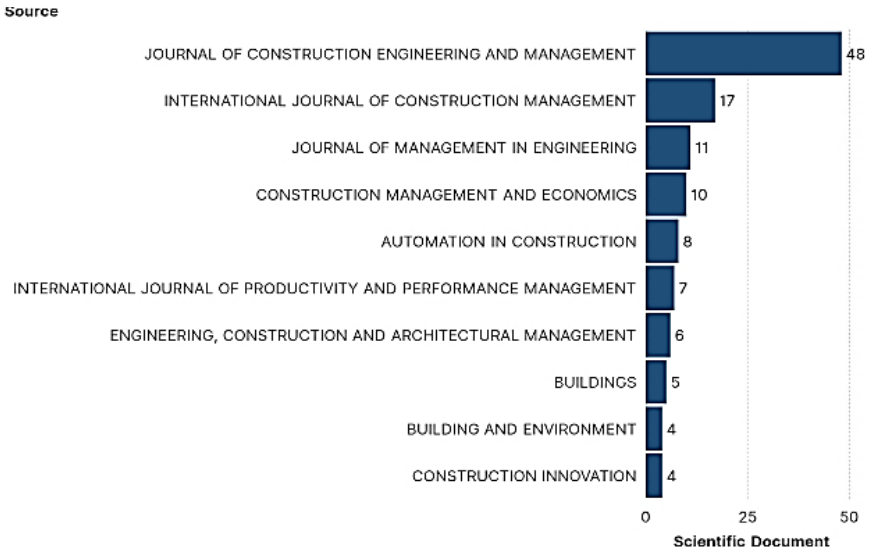

FIGURE 10. List of ten prominent sources on CLP topic (1972 - 2023)

Building" by Behman in the same year, CLP has garnered significant attention. Table 4 enumerates the most cited and influential articles on this subject. Topping the list is the article "Reductions in labor capacity from heat stress under climate warming," published in the journal Nature Climate Change in 2013, which has received a remarkable 362 citations. It is followed by "Critical Review of Labor Productivity Research in Construction Journals," which has amassed 268 citations, and "Factors Affecting Construction Labor Productivity in Kuwait," which has garnered 252 citations. These articles have substantially contributed to the discourse on CLP, shaping the understanding and exploration of this topic.

TABLE 4. List of ten prominent publication on CLP topic (1972 - 2023)

Author	Source	TC	TC per Year
(Dunne et al. 2013)	Nature Climate Change	362	32.91
(Yi & Chan 2014)	Journal of Management in Engineering	268	26.80
(Jarkas & Bitar, 2012)	Journal of Construction Engineering and Management	252	25.20
(Kadir et al. 2005)	Structural Survey	180	9.47
(Allmon et al. 2000)	Journal of Construction Engineering and Management	180	7.50
(El-Gohary & Aziz, 2014)	Journal of Management in Engineering	160	16.00
(Kazaz et al. 2008)	Journal of Civil Engineering and Management	154	9.63
(Hanna et al., 2005)	Journal of Construction Engineering and Management	144	7.58
(Sonmez & Rowings 1998)	Journal of Construction Engineering and Management	133	5.12
(Durdyev & Mbachu 2011)[in]	Australasian Journal of Construction Economics and Building	125	9.62

CO-OCCURRENCE AND TREND ANALYSIS OF RESEARCH

Co-occurrence analysis, a component of the science mapping technique, is employed to examine the relationship between topics within a research field. This technique analyzes publications' written content to discern current and future trends in the research field (Emich et al. 2020). The underlying assumption of co-occurrence analysis is that words frequently appearing together are likely to be thematically related (Donthu et al. 2021).

The VOSviewer application created network, overlay, and density visualizations of the prepared scientific publication metadata. The network visualization depicts the frequency of word usage, the interconnections between words, and the clustering of words by theme. This visualization serves as a comprehensive map of the thematic landscape of the research field. The network visualization of keyword co-occurrence on CLP topic over 51 years is depicted in Figure 11. This network comprises nodes and edges, each serving a specific function in the visualization.

The overlay visualization presents the clustering of words based on the time of occurrence, providing a temporal perspective on the evolution of themes within the research field. Additionally, the density visualization illustrates the frequency density of commonly used words, highlighting the most prominent themes within the research field. These visualizations collectively provide a comprehensive and nuanced understanding of the research field.

Nodes represented as circles, correspond to keywords. The size of each circle is proportional to the frequency of the corresponding keyword's appearance in scientific publications related to CLP topic. Thus, larger circles indicate keywords that occur more frequently. Edges, represented as lines, signify the relationships between nodes. The proximity of one node to another, connected by an edge, indicates a higher degree of relationship. It implies that the corresponding keywords often appear together in scientific publications. Colors are used to denote keyword clusters based on themes. This color-coding provides a visual representation of the thematic organization of the keywords, thereby enhancing the comprehensibility of the network visualization.

Conducting a cluster analysis of keywords from paper abstracts retrieved from metadata is crucial for identifying emerging trends and potential research directions. VOSviewer, a robust keyword visualization tool, facilitates understanding relationships between significant terms within a specific research area (VanEck & Waltman 2023).

From the metadata set, 138 keywords (with a frequency of 5 or more) were identified. This set was subsequently filtered down to 132 keywords, as some were deemed irrelevant for analysis (such as "na," "article," "Ghana," "Australia," "India," and "China"). These keywords were then clustered into seven theme clusters, each represented by a distinct color in the keyword co-occurrence network visualization depicted in Figure 11.

The unit of analysis encompasses all keywords contained in the title, abstract, author keywords, and additional keywords in the metadata of scientific publications. Detailed information regarding the clustering of keyword co-occurrence on CLP topics is presented in Table 5.

Cluster 1, represented in red and comprising 35 items, is situated on the right side of the network visualization. This cluster appears distinct from the rest, suggesting that it represents a common theme related to the CLP topic. This cluster encompasses themes related to "Workforce and Health Optimization." Cluster 2, represented in green and comprising 23 items, pertains to the "Construction and Productivity Analysis" theme. Cluster 3, represented in blue and comprising 23 items, is associated with the theme of "Construction and Innovation Research." Cluster 4, represented in yellow and comprising 17 items, corresponds to the "Construction Productivity and Technology" theme.

Similarly, Cluster 5, represented in purple and comprising 17 items, relates to the theme of "Construction Industry and Economics." Cluster 6, represented in cyan and comprising 13 items, is associated with the "Construction Management and Efficiency" theme. Lastly, Cluster 7, represented in orange and comprising four items, pertains to the theme of "Labor Productivity in Construction." These clusters collectively provide a comprehensive thematic overview of the field of CLP.

The term "productivity" emerged as the most frequently occurring word, appearing 184 times. It was followed by "construction industry" (125 times), "labor productivity" (98 times), "construction" (74 times), "project management" (62 times), "labor productivity" (45 times), and "construction labor productivity" (40 times), among other keywords with a frequency of occurrence of 5 or more. These themes represent the main topics that frequently appear in studies.

The overlay visualization, as depicted in Figure 12, was selected as a more reliable tool for reviewing recent academic trends. This tool allows for categorizing keywords by time frame, thereby providing a temporal perspective on the evolution of themes within the research field (Shvindina 2019). The color coding of the visualization is based on the year of publication. In this review, keywords from recently published articles are represented in a more yellowish color, with the year of publication being 2018. The darker the color of the circle, the longer ago the keyword was published. Conversely, the lighter the color, the more recent the topic has been discussed among researchers. This color-coding scheme enhances the comprehensibility of the visualization, providing a clear and intuitive representation of the temporal trends in the research field.

As depicted in Figure 12, the "labor productivity" theme is closely related to other themes. Themes such as

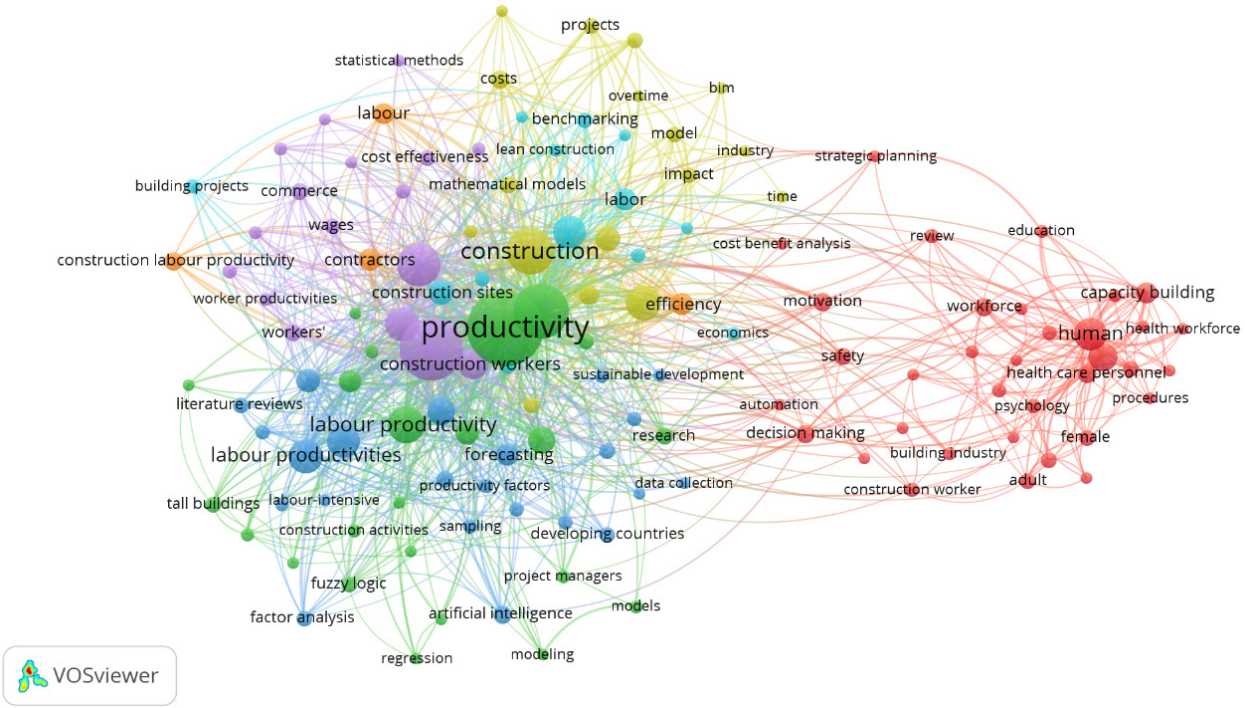

FIGURE 11. Visualization of keyword co-occurrence network on CLP topic (1972 - 2023)

"project management," "personnel," "building materials," "cost," "labor cost," "cost-effectiveness," "scheduling," "schedule acceleration," "mathematical model," "neural network," and "regression analysis" are themes that researchers in the CLP field have been debating for over a decade.

More recent trending themes include "improvement," "construction equipment," "impact," "sustainable development," "forecasting," "influencing factors," "artificial intelligence," "efficiency," "fuzzy logic," "work performance," "factors," "wages," "relative importance index," "sampling," "questionnaire surveys," "motivations," "economics," "industry," "productivity factors," "construction productivity," and "building projects."

TABLE 5. Clustering co-occurrence of keywords on CLP topic (1972 - 2023)

Cluster	Co-occurrence Keywords
Cluster 1 (red) 35 items *"Workforce and Health Optimization"*	adult, automation, building industry, capacity building, construction worker, cost benefit analysis, decision making, education, ergonomics, female, health care, health care personnel, health care quality, health personnel, health workforce, human, humans, laboratory, male, middle aged, motivation, organization and management, priority journal, procedures, psychology, public health, public health service, quality control, review, safety, standardization, strategic planning, workforce, workforce development, working conditions
Cluster 2 (green) 23 items *"Construction and Productivity Analysis"*	construction activities, construction equipment, construction management, construction productivity, construction project, fuzzy logic, fuzzy systems, labor productivity, labour productivity, learning algorithms, modeling, modelling, models, productivity, productivity rate, project managers, project performance, regression, regression analysis, research, risk assessment, system dynamics, tall buildings
Cluster 3 (blue) 23 items *"Construction and Innovation Research"*	accident prevention, artificial intelligence, construction labours, data collection, design/methodology/approach/, developing countries, factor analysis, forecasting, human resource management, influencing factors, labour productivities, labour-intensive, literature reviews, machine learning, neural networks, occupational risks, productivity factors, questionnaire surveys, sampling, structural design, surveys, sustainable development, work sampling
Cluster 4 (yellow) 17 items *"Construction Productivity and Technology"*	bim, construction, construction labor productivity, costs, impact, improvement, industry, management, mathematical models, model, overtime, performance, projects, schedule acceleration, schedulling, technology, time
Cluster 5 (purple) 17 items *"Construction Industry and Economics"*	building materials, commerce, competition, construction industry, construction projects, construction workers, cost effectiveness, employment, factors, labor costs, project management, relative importance index, statistical methods, wages, work performance, worker productivities, workers'
Cluster 6 (cyan) 13 items *"Construction Management and Efficiency"*	benchmarking, budget control, building projects, civil engineering, contruction companies, construction sites, economics, industrial management, labor, lean construction, personnel, productivity improvement, variability
Cluster 7 (orange) 4 items *"Labor Productivity in Construction"*	construction labour productivity, contractors, efficiency, labour

Post-2018 trends encompass themes such as "fuzzy system," "learning algorithm," "factor analysis," "machine learning," "developing countries," "safety," "human resource management," "tall building," "modeling," "work sampling," "technology," "bim," "budget control," "construction companies," "decision making," and "labor-intensive".

The findings of this review provide an enlightening insight into the topic of CLP by utilizing the combination of the keywords mentioned above. This comprehensive overview of the thematic landscape of CLP research underscores this field's dynamic and evolving nature.

A density visualization was employed to identify regions of high and low density to enhance the analysis of keyword co-occurrence. Regions of high density indicate high saturation, signifying that the corresponding themes have been extensively discussed among researchers. Conversely, regions of low density represent low saturation, suggesting that these themes have yet to be widely debated and thus may represent potential future research gaps.

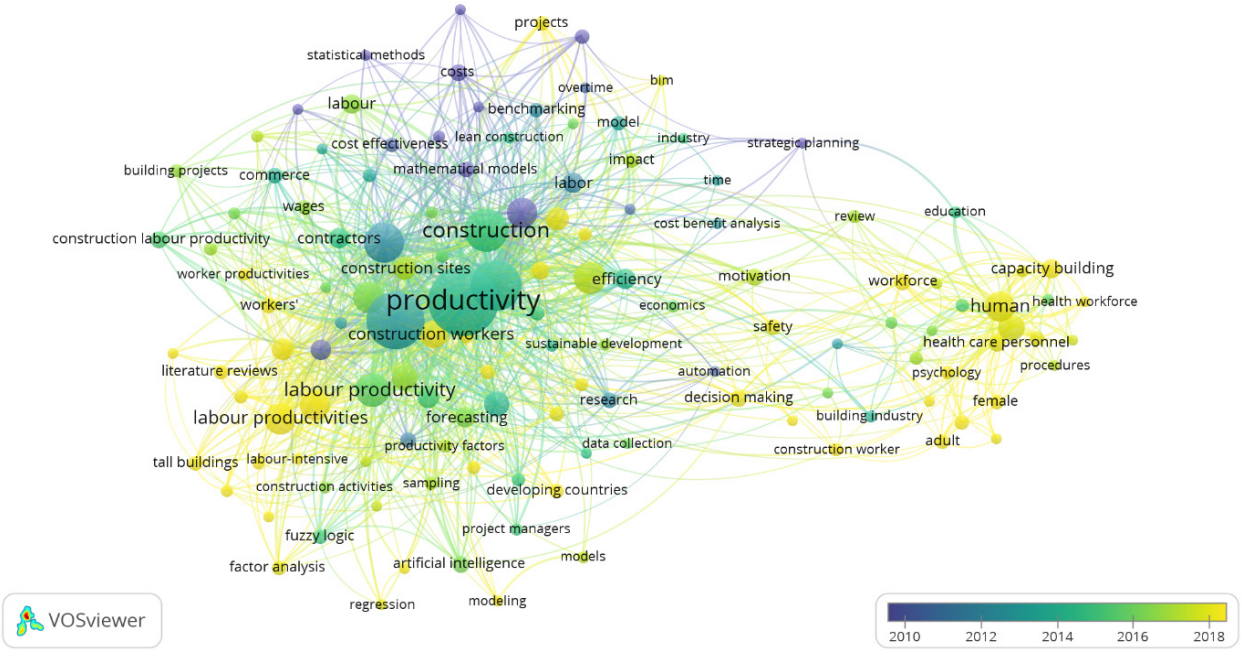

FIGURE 12. Visualization of co-occurrence overlay of keywords on CLP topics (1972 – 2023)

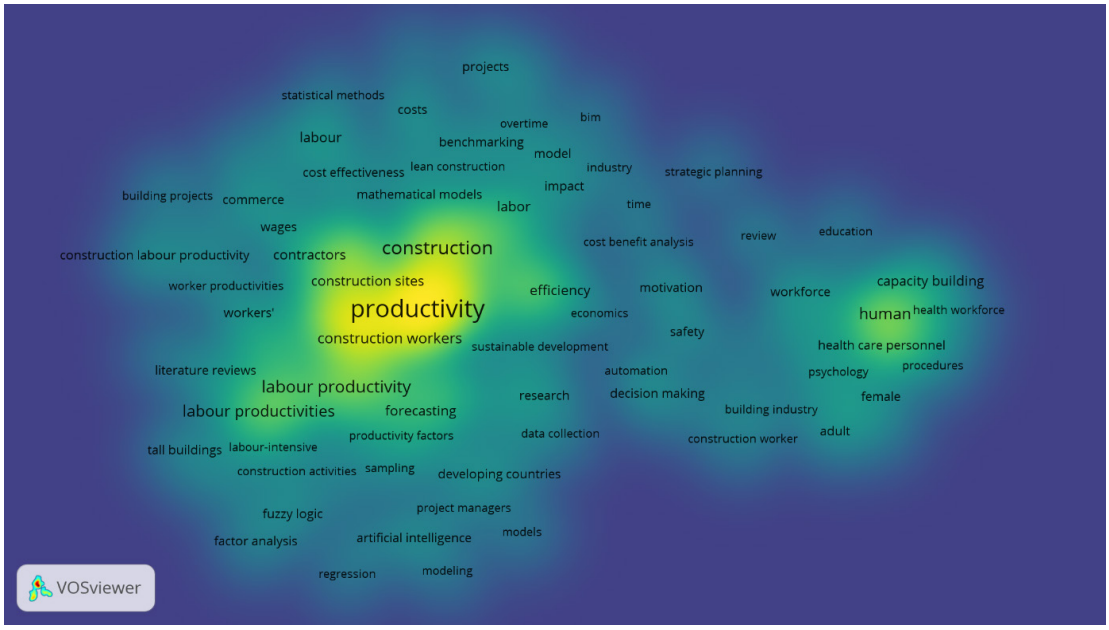

FIGURE 13. Visualization of co-occurrence density of keywords on CLP topics (1972 – 2023)

Figure 13 presents the results of the keyword co-occurrence analysis, visualized through the density of themes in CLP topic. The intensity of the yellow color around the theme area indicates the theme's density. Themes such as "productivity," "construction workers," "construction," "construction sites," "contractors," and "labor productivity" are often discussed among researchers in the field of CLP.

On the other hand, themes such as "machine learning," "artificial intelligence," "fuzzy logic," "regression," "modeling," "productivity factors," "developing countries," and "labor-intensive" are enclosed in green areas. These areas indicate low density and potential gaps in CLP topic, suggesting areas for future research exploration.

The systematic organization of key research trends and publications is a crucial step in the research process. It provides researchers with a comprehensive understanding of the current state of their field and helps them identify areas that are ripe for further investigation. This process is exemplified in Table 6, which presents potential themes and content derived from selected papers related to CLP.

In the dynamic environment of a construction site, where numerous activities are occurring concurrently, monitoring all construction activities can pose a significant challenge (Sherafat et al. 2020). The complexity of construction activities is further compounded by the fact that low labor productivity can negatively impact their overall performance. Particularly when considering cost and scheduling aspects, it is essential to note that labor costs account for 30 - 50% of total project costs. (Gunduz & Abu-Hijleh 2020; Jang et al. 2011; Jarkas & Bitar 2012).

Traditional monitoring methods, such as manual data collection through direct observation and questionnaires, have inherent limitations. These methods are often subjective, prominent to concerns about their efficiency and reliability (Akhavian & Behzadan 2015; Cheng et al. 2013; Weerasinghe et al. 2012). As a result, there has been a growing interest in exploring automated monitoring solutions as an alternative.

Automated monitoring solutions offer the ability to collect and analyze data on the two primary resources that drive construction productivity: people and equipment (Al Jassmi et al. 2021). These solutions leverage advanced technologies to provide objective, real-time insights into construction activities, thereby enhancing the accuracy and efficiency of monitoring efforts. By doing so, they hold the potential to significantly improve labor productivity and, consequently, the overall performance of construction projects. Enhancing productivity and project performance underscores the importance of continued research and innovation in this area, as it could lead to substantial advancements in construction management.

The implementation of automated monitoring in construction projects encompasses several key areas, including activity recognition (Al Jassmi et al. 2021), activity tracking (Akhavian & Behzadan 2018; Al Jassmi et al. 2021), and performance monitoring (Al Jassmi et al. 2019; Sherafat et al. 2020). These areas represent the core components of a comprehensive monitoring system designed to provide real-time insights into construction activities.

Moreover, the integration of technology into theoretical models for forecasting and optimizing CLP has become a focal point of research (Ebrahimi et al. 2021; Efekan et al. 2023; Elshaboury 2022; Sarihi et al. 2023). Technology integration reflects the growing recognition of the potential benefits of leveraging advanced technologies in construction management.

Despite the promising developments in this field, the practical application of artificial intelligence, machine learning, and fuzzy logic for forecasting and optimizing CLP still needs to be improved in the construction industry, particularly compared to other industries. One of the primary challenges in this regard is the fragmented nature of the construction industry, which poses significant obstacles to data collection and storage (Regona et al. 2022).

Data acquisition, which involves collecting data from various sources such as sensors, cameras, and other devices, and data storage, which pertains to the storage and management of this data, are particularly problematic in this context. Data acquisition and storage are especially true for small and medium-sized companies that dominate the industry and still rely on manual and traditional processes.

There are no established applications for integrating these advanced technologies into construction project practices (Sherafat et al. 2020). The absence of applications for advanced tech in construction practices presents a significant opportunity for researchers to contribute to advancing the field by developing solutions to address these challenges and fill the existing gap. Such efforts could revolutionize the construction industry by enhancing productivity, reducing costs, and improving the overall efficiency of construction projects.

While numerous studies have investigated the factors influencing labor productivity, research in the context of developing countries still needs to be more extensive (Palikhe et al. 2019). This gap in the literature underscores the need for further exploration of this topic within these specific geographical and socio-economic contexts.

A handful of studies have been conducted on CLP in developing countries such as Indonesia (Handoko et al. 2020), Malaysia (Momade et al. 2022), India (Sathvik et al. 2023), Iran (Goodarzizad et al. 2023), and Ghana (Bamfo-Agyei et al. 2021), among others. These studies

provide valuable insights into the unique challenges and opportunities associated with improving labor productivity in these regions.

However, a comprehensive review study that analyzes the differences in CLP findings across different regions still needs to be improved (Momade et al. 2023). Such a study could offer a more nuanced understanding of the factors influencing CLP and highlight the potential for region-specific strategies to enhance productivity.

The perspective of developing countries is crucial to refine and strengthen the results of previous research. Considering these countries' diverse socio-economic and cultural contexts allows for a more inclusive and comprehensive understanding of CLP.

TABLE 6. Potential themes and insights from several authors on CLP topic

Theme	Insight	Authors
Machine Learning (ML) (method)	ML model for improving CLP forecasting	(Elshaboury 2022)
	Real-time labor performance monitoring for tracking progress	(Al Jassmi et al. 2021)
	Hybrid model to optimize CLP factors	(Ebrahimi et al. 2021)
	Wearable sensors for measuring worker happiness and CLP	(Al Jassmi et al. 2019)
Artificial Intelligence (AI) (method)	AI-based inference models for predicting and optimizing CLP	(Efekan et al. 2023)
	Fuzzy Inference System (FIS) for estimating CLP accurately and interpretable	(Sarihi et al. 2023)
Fuzzy Logic (method)	Predicting productivity through internal factors	(Chaudhari & Bhangale 2023)
	Developing a predictive model of multifactor productivity	(Malara et al. 2019)
	Equipment productivity prediction with fuzzy dynamics	(Nima & Fayek 2018)
	Fuzzy system for uncertain labor productivity improvement	(Nojedehi & Nasirzadeh 2017)
Regression (method)	Reinforcement quantity, rebar diameter, congestion enhance productivity; work duration hinders it.	(Arora et al. 2023)
	Predictive models for the relationship between rework and labor productivity in plastering, brick works, and ceramic works	(Mahamid 2020)(2
Developing Countries (Geographical Context)	Lack of incentives, tools, meetings, and safety hampers productivity	(Palikhe et al. 2019)
	Fatigue, motivation, skill drive productivity; delays, cost inflation affected most.	(Jalal & Shoar 2019)

Future studies focusing on a diverse range of developing countries will significantly enrich the body of work in CLP. They will not only fill existing gaps in the literature but also provide practical insights that can inform policies and practices aimed at enhancing labor productivity in the construction industry within these countries. The need for more CLP studies in developing countries highlights the importance and urgency of further research in this area.

Many studies have been undertaken to comprehend, plan, measure, control, and forecast the optimization of CLP. This review is designed to delineate the current research performance and provide a science mapping of CLP topic, employing a statistical quantitative approach.

Historically, CLP has been the focus of several bibliometric reviews. For instance, Hire & Sandbhor (2020) reviewed the application of artificial neural networks in CLP. They utilized the Scopus database, spanning the years 1996 to 2020, to gather and analyze metadata. The authors leveraged previous research as a blueprint to construct a research methodology using artificial neural networks.

Similarly, Adebowale & Agumba (2022) employed metadata from the Scopus database to conduct a bibliometric analysis of CLP for 2012-2021. They identified key areas that contributed to enhancing productivity in construction work. More recently, Lee et al. (2023) provided insightful data on CLP monitoring. They extracted metadata from the same database as the previous authors, covering an extensive period from 1967 to 2022.

These studies underscore the importance of bibliometric reviews in understanding the evolution of CLP research. They provide a valuable foundation for future research, offering insights into the methodologies, themes, and trends that have shaped the field. Furthermore, they highlight the potential of artificial neural networks and other advanced technologies in optimizing CLP, pointing to promising avenues for future exploration. avenues for future exploration.

CONCLUSION

The metadata on CLP over the past five decades shows a steady growth in research interest, with a diverse range of documents from various sources. The average age of these documents is less than a decade, indicating the relevance and timeliness of the research. Many authors have contributed to this field, with a notable international collaboration rate. Most of these publications are journal articles and scientific meeting articles, highlighting the academic focus of this research. The most cited publication, from 2014, has many citations, demonstrating its influence in the field. Aminah Robinson Fayek is the most prolific author, and the University of Alberta leads in affiliations. The United States leads in productivity, contributing a significant number of articles. The Journal of Construction Engineering and Management is the prominent source on CLP topic. These findings underscore the ongoing interest and global distribution of CLP research, reflecting its importance in improving construction practices worldwide.

The metadata set identified 132 CLP-related keywords grouped into seven theme clusters. The most frequent keyword was "productivity". The overlay visualization showed the evolution of themes in the CLP research field, with "labor productivity" being closely related to themes like "project management" and "personnel." Recent trends include "improvement" and "construction equipment." In contrast, post-2018 trends encompass "fuzzy system" and "learning algorithm." The density visualization highlighted high-density regions representing extensively discussed themes and low-density regions indicating potential research gaps, such as "machine learning" and "artificial intelligence." These findings underscore the dynamic and evolving nature of the CLP field and potential areas for future exploration.

The dynamic nature of construction sites and the impact of low labor productivity on performance make monitoring activities challenging. While traditional methods have limitations, automated monitoring solutions using advanced technologies are gaining interest. These solutions provide real-time insights into activities, enhancing labor productivity and overall performance. However, the practical application of technologies like artificial intelligence, machine learning, and fuzzy logic is limited in the construction industry due to data acquisition and storage challenges. Limited technology use in construction due to data issues presents an opportunity for researchers to develop solutions to these challenges, potentially revolutionizing the industry by improving productivity, reducing costs, and enhancing efficiency.

While numerous studies have investigated labor productivity, research in the context of developing countries still needs to be more extensive. A few studies have been conducted on CLP in developing countries such as Indonesia, Malaysia, India, Iran, and Ghana, providing insights into these regions' unique challenges and opportunities. However, a comprehensive review of CLP findings' differences across different regions still needs to be completed. This perspective is crucial to refine and strengthen the results of previous research, allowing for a more inclusive understanding of CLP in diverse socio-economic and cultural contexts. Future studies focusing on a diverse range of developing countries will significantly enrich the body of work in CLP, filling existing gaps in the literature and providing practical insights to inform policies and practices that enhance labor productivity in the construction industry within these countries.

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DECLARATION OF COMPETING INTEREST

None

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