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A bibliometric review of lean principles in highway pavement for productivity improvement

Pooja P. Gohil[1], MohammedShakil S. Malek[2], Deep Shaileshkumar Upadhyaya[3]
[1]Department of Civil Engineering, Gujarat Technological University, Ahmedabad, India
[2]Om Institute of Technology, Gujarat Technological University, Ahmedabad, India
[3]Department of Civil Engineering, Government Engineering College, Godhra, India

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ABSTRACT

A past study of 25 years reveals the positive impact of lean principles on highway pavement productivity. This bibliometric review extracted 389 papers from the Scopus database that revolved around three terms, "lean principles," "highway pavement," and "productivity improvement," and used VOSviewer for scientometric analysis and scientific mapping. Study reveals that addressing this topic on a global scale is of chief significance, given the potential variations in indices of the issue across different countries or provinces. This research undertakes a comprehensive qualitative analysis that highlights diverse indicators that exert influence on the productivity of pavements. Additionally, this analysis also seeks to propose potential avenues for future research within lean construction. An intensive investigation provides four unique clusters of words that have been formed through the process of keyword science mapping within the context of the lean principles, which are road segment, techniques, productivity improvement, and lean. Last but not least, 4 pointers are recommended that will help stakeholders and policymakers assess pavement performance practices, identify areas for improvement, and execute targeted interventions to improve productivity.

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Corresponding Author:

MohammedShakil S. Malek
Om Institute of Technology, Gujarat Technological University
Ahmedabad, Gujarat, India
Email: shakil250715@yahoo.co.in

1. INTRODUCTION

The present study undertakes an inclusive bibliometric study to identify and retrieve patterns inherent in bibliographic data through a meticulous examination of quantitative values, which was lacking in the previous databank. Unlike past research. Here, in this study, we thoroughly scrutinized the available literature from the Scopus database and conducted a scientometric analysis for lean principles that are particularly used in highway pavement with emphasis on improving productivity. Following the above course, a comprehensive qualitative discourse was undertaken, wherein the outcomes were meticulously synthesized and incorporated as an indispensable facet of our scholarly inquiry.

Apart from facets, the bibliographic data encompasses the quantification of published papers, the progression of the scholarly literature, and the discernible pattern of publication dissemination [1]. We further conducted a comprehensive scientometric analysis to examine the scholarly landscape of the research topic at hand. This involved a meticulous examination of relevant literature, including academic articles, conference papers, and other scholarly publications. The objective was to gain a deeper understanding of the existing body of knowledge and identify key themes and trends that were missing in previous theories.

The research scope of the paper revolves around three terms “lean principles,” “highway pavement,” and “productivity improvement”. Lean principles being top approaches are one of the key tactics for enhancing an organization's productivity and, hence, competitiveness [2]. A lean construction method is the only way that proves betterment in quality, time, and cost simultaneously [3]. Talking about productivity, it plays a vital part in construction and is one of the crucial problems in developed as well as developing countries. “Productivity” defines the affiliation between inputs and outputs [4]. Highway pavements are made up of layers of processed materials laid over a natural soil subgrade. They are considered a critical part of the infrastructure development as they carry traffic. Therefore, the expected service life of a particular highway pavement is for a longer duration. The core purpose of highway pavement is to dispense applied vehicle loads to the subgrade. It decreases the wheel loads suitably to a level within the subgrade’s bearing ability [5].

2. PROPOSED METHODOLOGY

We conducted a thorough scrutiny of the available literature from the Scopus database and conducted a scientometric analysis for lean principles used in highway pavement for the improvement of productivity. For phase 1, the bibliographic data was accessed on September 25, 2024, encompassing a comprehensive range of documents published within the time frame spanning from 2000 to 2024 (last 25 years). The selection of this option was substantiated by the findings of prior research conducted by Chadegani *et al*. [6] and Hong *et al.* [7], which underscored the prompt expansion and escalating appeal of Scopus as a digital repository. The introductory investigation resulted in the identification of a cumulative body comprising 9,499 textual records. The comprehensive scope of the research ought to have encompassed a wide range of sources, including but not limited to duplicate documents, incomplete materials, non-English texts, conference papers, and book chapters. The exclusion of conference papers was motivated by the limited scope of their content. Under the scholarly work of Chellappa and Salve [8], a comprehensive assortment of 389 scholarly articles composed in the English language and about the subject matter under investigation was meticulously chosen to undertake a meticulous scientometric examination.

The search strategy employed was based on query strings:

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(TITLE-ABS-KEY ("LEAN CONSTRUCTION”) OR TITLE-ABS-KEY ("highway pavement")
OR TITLE-ABS-KEY ("productivity improvement")) AND PUBYEAR > 2003 AND
PUBYEAR < 2025 AND (LIMIT-TO (SUBJAREA,"ENGI")) AND (LIMIT-TO
(DOCTYPE,"ar")) AND (LIMIT-TO (LANGUAGE, “English")) AND
(EXCLUDE (EXACTKEYWORD, "Manufacture”) OR EXCLUDE (EXACTKEYWORD, "Architectural
Design”) OR EXCLUDE (EXACTKEYWORD, “Decision Making”) OR EXCLUDE
(EXACTKEYWORD, "Life Cycle”) OR EXCLUDE (EXACTKEYWORD, "Surveys")
OR EXCLUDE (EXACTKEYWORD, “InformationTheory”) OR EXCLUDE
(EXACTKEYWORD, "Information Management")) AND (LIMIT-TO (OA, “all”))
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Phase 2 research involved the implementation of a scientometric analysis, employing the esteemed scientific mapping tool known as VOSviewer. It is a widely utilized software tool and has gained prominence in the field of construction health and safety for its efficacy in conducting scientometric analyses and scientific mapping research [9]–[11]. The present study explores the potential of VOSviewer software [12]–[14] in facilitating the creation of graphical and bibliometric networks. This software allows for the analysis of various factors, such as the frequency, co-authorship, and co-occurrence of significant phrases. It helps in gaining valuable insights into the structural patterns and relationships within a given field of study. The present investigation aims to facilitate a comprehensive understanding of the intricate relationships and discernible patterns inherent within the meticulously analyzed dataset. According to Eck and Waltman [15], VOSviewer is positioned as a more accessible alternative to conventional visualization tools.

Scopus offers a vast bibliographic database encompassing scientific and engineering journals from reputable publishers worldwide, with complete author and affiliation information, including citation statistics. With access to a diverse dataset of academic papers, researchers can study cooperation patterns, author productivity, and institutional influence. The Scopus API allows researchers to programmatically access scholarly knowledge, enabling rapid and automatic data retrieval, data collection automation, and effective management of large datasets. Moreover, Scopus’s global repository of intellectual publications from prominent scholars and organizations provides a multinational perspective, unveiling trends and studies related to the study. Using Scopus ensures the credibility and reliability of the bibliometric investigations [16], [17]. Figure 1 represents two-phase methodologies for the undertaken study.

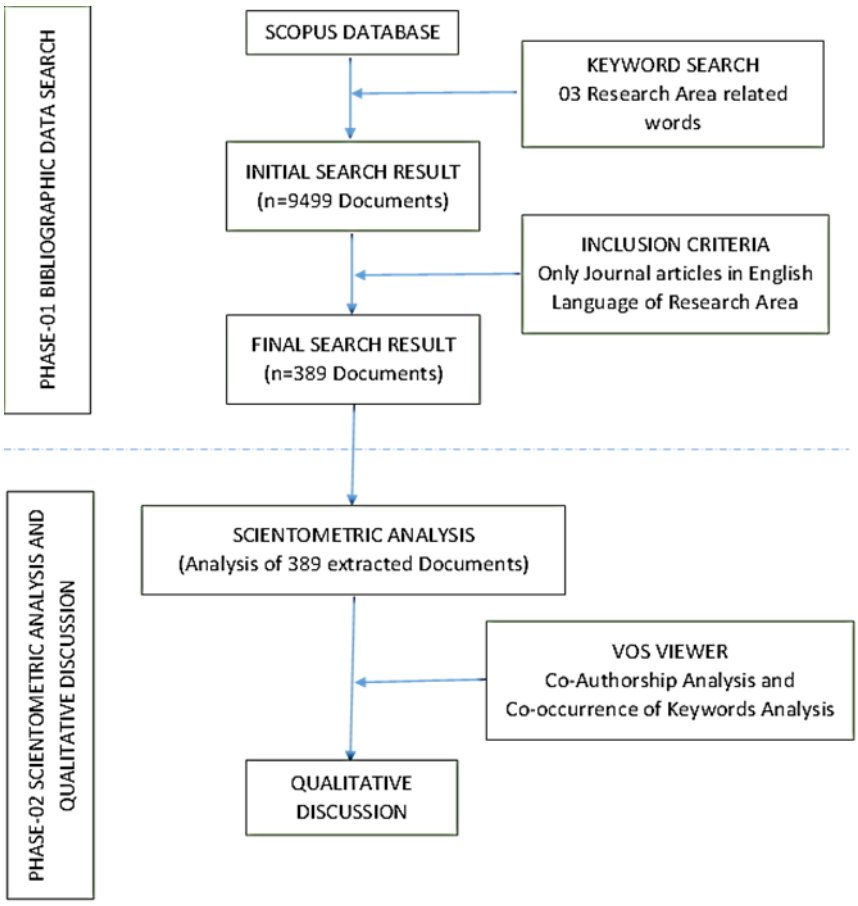

Figure 1. Proposed methodology for the undertaken study

3. RESULTS OF THE SCIENTOMETRIC ANALYSIS

3.1. Distribution of lean construction publications yearly and growth trend

The graphical depiction in Figure 2 shows the chronological distribution of scholarly publications over the widespread time frame beginning from 2002 and concluding in 2024. Based on the comprehensive analysis of the Scopus database, Figure 2 visually represents the formative inception of scholarly publications within the domain of lean construction in the year 2002. In that year, a solitary document served as the pioneering contribution.

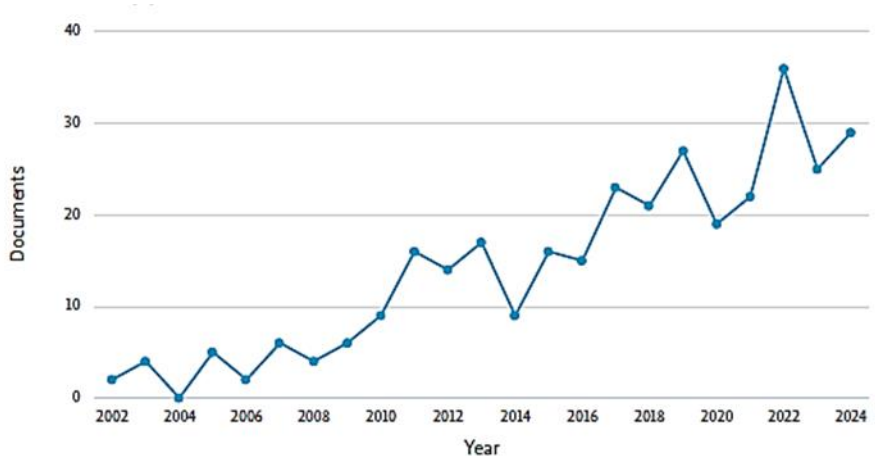

Figure 2. Distribution of lean construction publications yearly and growth trend

Following the year 2007, a discernible increase in the number of published documents was observed, totaling six. Moreover, the statistics, as mentioned earlier, experienced a notable increase, reaching a total of 16 by the year 2011. The count of publications slowed down, leading to only 9 publications in the year 2014. Lean construction witnessed an increase in the number of scholarly articles published within its domain during the period spanning from 2015 to 2024. The observed upward trajectory in the number of published papers represents a notable milestone, as it reflects the highest recorded number of publications since the inception of the research endeavor. The peak in the count of scholarly articles published in the lean construction domain is achieved in the year 2022, which is 37 publications, indicating that the comprehensive collection of academic literature for this particular year is the highest of all time. In summary, it can be inferred that the persistent pursuit of research holds significant importance within the context of lean construction despite its tendency to deviate from a strictly linear progression.

3.2. Distribution of lean construction publications by country/territory

The countries/territories that circulated lean construction constituents were identified through an inclusive assessment of the number of documents they published. Utilizing the analytical capabilities of VOSviewer, an all-inclusive selection of scholarly articles, was acquired, ensuring a minimum of five publications per nation. The visual representation in Figure 3 provides a comprehensive overview of the scholarly papers published in countries/territories associated with the revered lean construction across the globe. The data presented in this study were compiled utilizing the iMAP builder, an advanced online map editor software tool.

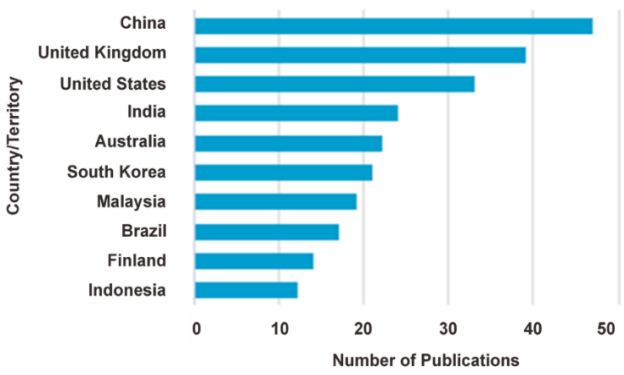

Figure 3. Distribution of lean construction publications by country/territory

China has attained the foremost position in terms of publications within the lean construction, with a notable count of 48 scholarly documents. In alignment with the scholarly output of the United Kingdom, the United States, India, and Australia, each of these nations has contributed a total of 114 publications to the academic treatise. In the empire of scholarly publications, South Korea has demonstrated a commendable level of academic output, boasting a total of 21 publications. Contradictory, Canada, another prominent player in the academic field, has not at all contributed in this arena. The countries of Malaysia, Brazil, Finland, and Indonesia exhibited varying levels of scholarly output, as evidenced by their respective publication counts of 19, 18, 12, and 11.

The graphical representation in Figure 3 illustrates the existence of ten sovereign states originating from distinct continents, thereby highlighting the global diversity of nations. Nevertheless, it is imperative to acknowledge that the corpus of identified publications does not encompass any sources originating from the regions of South America, Africa, or Antarctica. The analysis of the data set reveals that the presence of lean construction has been duly acknowledged across diverse geographical regions, namely Asia, Europe, North America, and Australia. The importance of participation in lean construction holds immense value in the pursuit of achieving the utmost on-site health and safety standards within the construction sector. Therefore, it is of utmost importance for continents and nations that require additional written documentation in relation to this field to cultivate such resources.

3.3. Lean construction author and co-author network publication

The present study hired the VOSviewer software to generate an inclusive network diagram that visually represents the collective efforts of playwrights involved in collaborative research for the lean

construction. The collective count of authors, comprising the primary author as well as co-authors, reached a count of 410 individuals, which is presented in Figure 4. Figure 5 offers a comprehensive compilation of esteemed researchers in the field of lean construction. Notably, Daniel and Seppanen have produced five documents each, which have garnered an impressive citation. Similarly, Abdullah, Alarcon, Junnonen, Keskiniva, Peltokorpi, and Saari have also authored four documents each, which have received significant recognition. These findings shed light on the scholarly contributions of these authors and highlight their substantial impact within their respective fields of study.

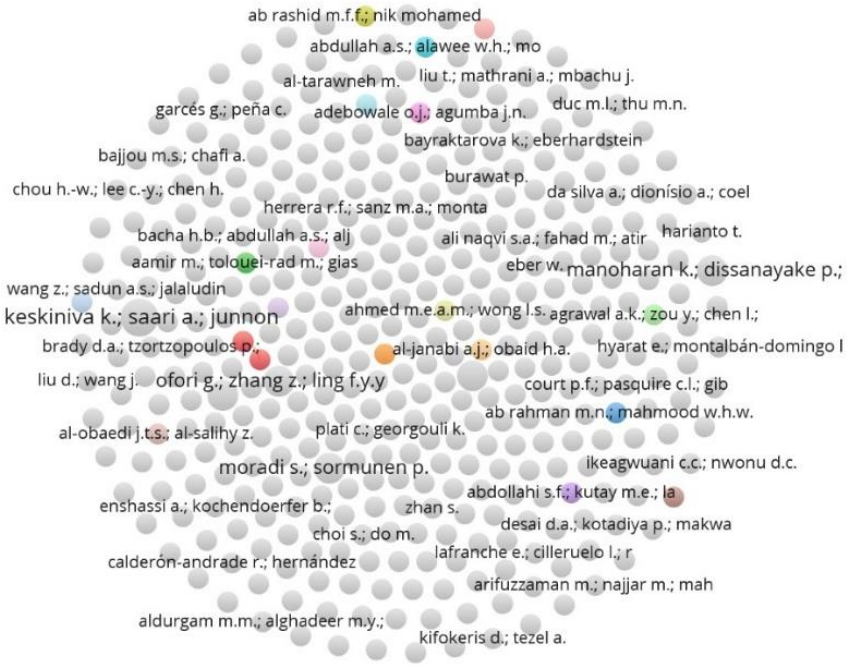

Figure 4. Lean construction author and co-author network publication

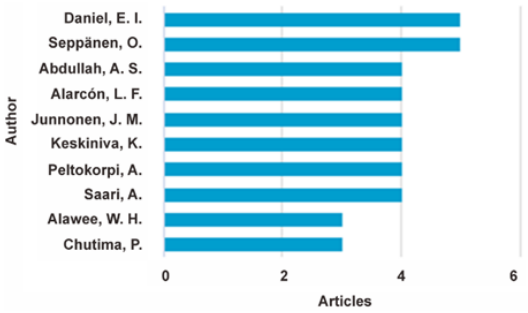

Figure 5. Number of articles per author

In the present study, a scrutiny was carried out employing VOSviewer, a widely utilized software tool for visualizing bibliometric networks. The findings of this investigation revealed that a total of 6 authors demonstrated commendable adherence to the stipulated criteria, which necessitated the possession of no less than two documents. Table 1 highlights those researchers who have not only achieved a significant number of citations but have also contributed substantially to the body of literature within the domain of lean construction. The present study aims to identify and analyze the authors who have exhibited exceptional levels of productivity and impact within the academic realm, as evidenced by their document output and citation count. Zhang, along with Kapoor, has published 2 documents that have received significant recognition with 49 citations. Following them in work are Moradi and Sormunen, having 2 documents in publication with citation number 18. The highest number of documents are published by Keskiniva, Saari, and Junnonen, which is 3 having citation of 10.

Table 1. Articles by authors with citations

Authors	No. of articles	Citations
Keskiniva, Saari, and Junnonen	3	10
Manoharan, Dissanayake	2	7
Moradi and Sormunen	2	18
Ofori, Zhang, and Ling	2	16
Sutantio, Anwar, and Wiguna	2	3
Zhang and Kapoor	2	49

In the undertaken study, Figure 6 showcases a compilation of six linkages, each possessing a distinct level of link strength. The cumulative link strength of these six linkages is quantified to be 13. In accordance with the scholarly findings of Eck and Waltman [18], it has been established that authors who maintain strong affiliations with their peers are likely to exhibit a commensurate level of co-authorship potency. The network diagram serves as a visual representation of the intricate interconnections existing among authors, effectively illustrating the magnitude of their collaborative efforts and the geographical dispersion of their respective clusters. The present study has successfully identified the existence of co-authorships within a total of six distinct and separate clusters.

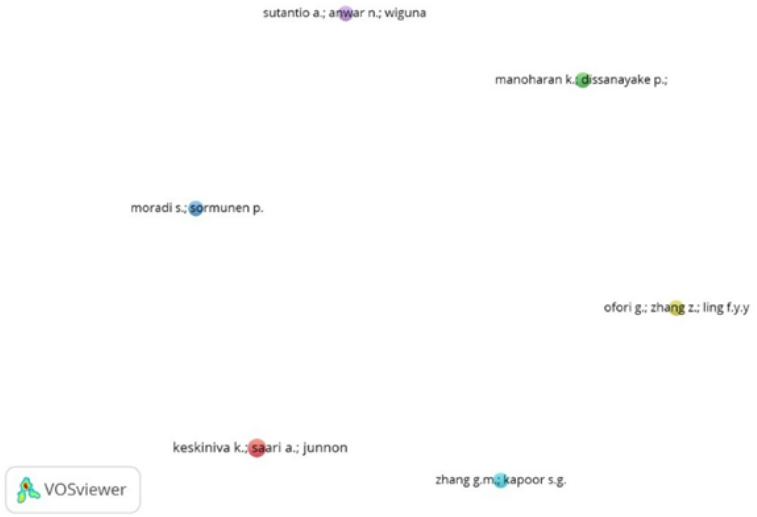

Figure 6. Co-authorship visualization network for lean construction

3.4. Co-occurrence study of lean construction terms

The comprehension and explication of topics within a scholarly article are enhanced through the utilization of keywords, which serve as pivotal terms that act as markers of significance [19], [20]. In recent years, there has been a notable surge in scholarly attention towards the multifarious determinants that exert an impact on the health and safety conditions prevalent at construction sites. Here, the VOSviewer was used to extract bibliographic data from the Scopus database. The purpose of this data extraction was to create a comprehensive visual representation of the co-occurring terms within the domain of lean construction. In accordance with a predetermined threshold of 5, the initial pool of keywords comprised a total of 2,935 distinct terms. Among the available options, a mere 70 keywords were found to meet the predetermined threshold.

It was imperative to refine these initial filtered keywords further. The consolidation of the terms "construction companies," "construction firms," "construction sector," and "construction industry" into a unified term has been undertaken. The process of amalgamating the synonymous terms 'lean construction' and 'lean principles' was undertaken. The scientific cartography illustrated in Figure 7 has successfully delineated a comprehensive network comprising a total of 8 clusters, with the highest noticeable cluster of 12 pivotal keywords. The terminologies above have been extensively referenced by scholars associated with lean construction in their prior scholarly pursuits. The visual representation of font size serves to depict the relative frequency of a term within a specific corpus of literature. The primary emphasis of the network lies in the intricate interplay among the concepts of "lean construction," "productivity," and "pavements," which forms the fundamental underpinning for all other associated terminologies.

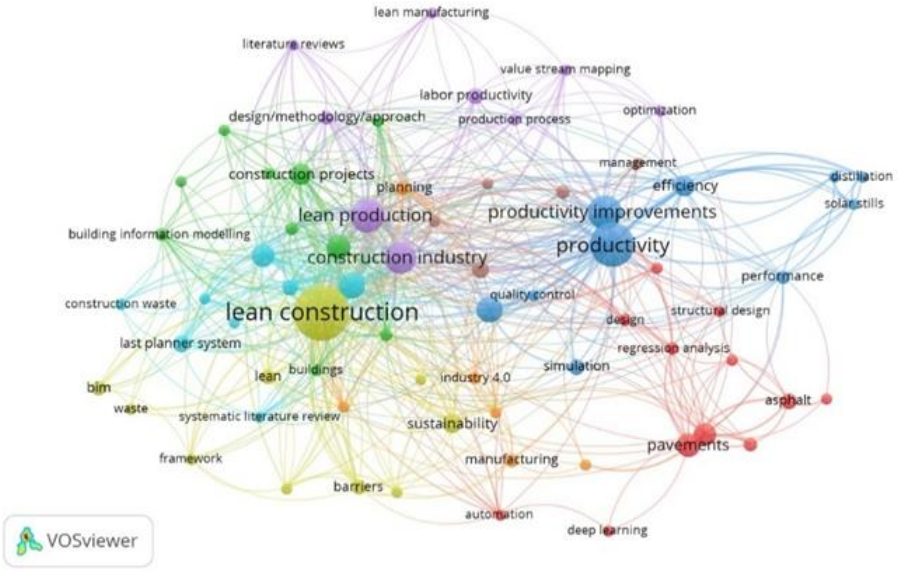

Figure 7. Science mapping of keywords for lean construction

Upon vigilant analysis of inter-connecting lines exemplified in Figure 7, a conspicuous observation emerges, namely, the distinct manifestation of the degree of proximity existing between two keywords. The inherent correlation between "leading indicators" and "project management" suggests that the recognition and mitigation of leading indicators that influence pavement productivity are encompassed within the purview of the project management process. The construction industry places considerable emphasis on the concept of "productivity". The present study aims to explore the robust association between lean construction and productivity. Table 2 provides a terse presentation of the keywords exhibiting the highest level of activity.

The visual representation in Figure 7 showcases the presence of eight obvious clusters, wherein each cluster is distinguished by its unique node color, which is determined by the frequency of the corresponding terms. The keywords pertaining to the road sector, as discerned within the red cluster 1, are typically classified as pavement factors. Within this specific crimson cluster, there exists an aggregate total of 12 discrete linguistic entities. Cluster 2 encompasses a total of 10 keywords, all of which fall under the category of green keywords, characterized explicitly by their techniques. One notable example is cluster 3 (blue), which encompasses terms related to productivity, while cluster 4 (yellow) encompasses keywords associated with lean.

Table 2. Most active keywords based on their occurrences

Keyword	Occurrence
Lean construction	121
Productivity	76
Productivity improvements	47
Lean production	45
Construction industry	40
Project management	28
Highway pavement	21
Construction management	20
Construction project	18
Efficiency	17

3.5. Analysis of publication sources

The present study encompasses an examination of publishing sources, with a particular focus on the assessment of annual papers and documents published in accordance with their respective country or region which as shown in Table 3. Among the pool of 60 journals that were subjected to analysis, a total of 15 journals were found to meet the predetermined criteria. These criteria encompassed two key aspects, namely the presence of a sufficient number of articles and a minimum threshold of citations, as determined by the employment of VOSviewer. In this scholarly article, we present, which offers a comprehensive

compilation of the 15 sources that have garnered the highest number of citations. The findings of the analysis indicate that buildings and energy journals have garnered the most substantial number of citations.

Table 3. Analysis of publication sources

Sources	Publications	Citations
Buildings	42	730
Construction Management and Economics	7	129
Construction Innovation	7	219
Construction Economics and Buildings	6	155
Journal of Civil Engineering and Management	5	113
Applied Sciences (Switzerland)	18	263
Revista Ingenieria de Construccion	9	88
South African Journal of Industrial Engineering	6	45
Energies	9	474
Civil Engineering Journal (Iran)	6	30
Engineering Journal	6	34
Baltic Journal of Road and Bridge Engineering	7	65
IEEE Access	7	59
International Journal of Innovative Technology and Exploring Engineering	5	9
Journal of Marine Science and Engineering	5	10

4. DISCUSSION OF QUALITATIVE DATA

This present discourse undertakes a comprehensive qualitative analysis that highlights diverse indicators that exert influence on the productivity of pavements. Moreover, this discourse presents recommendations for prospective research undertakings predicated on the utilization of bibliographic data for science mapping and scientific examination of the selected documents. The following exposition pertains to the four clusters that have been observed in Figure 7.

4.1. Pointers for road segment

The cluster, visually emphasized in the color red, comprises a total of 12 keywords that pertain to the domain of the road sector. These keywords encompass a wide range of topics. These include but are not limited to the asphalt, asphalt pavement, automation, lean tools, deep learning, design, highway pavement, machine learning, pavements, regression analysis, and structural design.

In this assemblage of concepts, it becomes apparent that the primary focus resides within the realm of construction. The present study examines the relationship between lean construction and productivity for highway pavement. Drawing upon the works of Daniel and Seppanen, it is postulated that a greater emphasis on applying lean principles may result in productivity improvement in the road segment.

4.2. Pointers of techniques

The accumulation, denoted as the ‘green cluster,’ encompasses a total of 10 discrete keywords that encompass a diverse array of subjects. These subjects include but are not limited to agile manufacturing, building information modelling, buildings, construction, construction projects, integrated project delivery, supply chain, waste management, and lean management. The improvement on construction sites is primarily attributed to modern techniques used on-site. The examination of waste management systems and lean management has reaped significant attention in emerging techniques. In their study, Gohil *et al.* [21] emphasized the importance of lean management and its impact on the behavior of pavement.

4.3. Pointers for productivity improvement

The assemblage, denoted as the blue cluster, encompasses a total of 10 isolated keywords, namely distillation, efficiency, performance, productivity, productivity improvement, quality control, simulation, solar heating, and solar stills. The productivity improvement can be achieved through the implementation of rigorous lean principles. The influence of the lean principles on pavement performance has been extensively discussed in the literature. Ghate *et al.* [22] have contributed to this body of knowledge. The studies have shed light on the significance of considering the productivity measurement factor when assessing pavement performance in the construction industry.

4.4. Pointers for lean

The accumulation of the yellow spectrum encompasses a compilation of 10 pivotal barriers: building information modeling (BIM), construction 4.0, framework, sustainability, waste, lean, lean thinking, lean construction, and lean implementation. Koskela [23] introduced the concept of lean in construction. The implementation of this practice may potentially improve construction projects in various ways. The scholarly

literature suggests that it is advisable to use modern techniques and tools, including but not limited to the last planner system, BIM, construction 4.0, and other similar methods for the ease of construction [24]. To ensure the optimal performance of pavement, it is of utmost importance for the contractor to not only provide and maintain pavement but also to impart comprehensive training to their esteemed staff members regarding the proper usage of lean principles [25].

5. CONCLUSION

The contemporary study utilized a science mapping methodology, integrating bibliometric search, scientometric analysis, and wide-ranging qualitative discourse, to scrutinize a total of 389 research publications in the field of lean construction. Based on the existing data, a notable surge in the number of scholarly articles within this specific realm was observed during the preceding epoch. The findings of the investigation unveiled a notable prevalence of publications originating from economically advanced countries. In the context of less developed countries, it is evident that a substantial reservoir of untapped potential for economic and social advancement exists. Moreover, a surfeit of scholarly journals has meticulously disseminated comprehensive research within this specific domain. In addition, the present study investigated the identification of the most prolific authors and co-authors in the kingdom of lean-related research. This identification was accomplished by considering both the quantity of publications and the number of citations reaped by these researchers. A comprehensive examination of keywords was conducted to ascertain the prevailing terms employed in research conducted within the realm of lean construction. This research paper intends to explicate the various indicators that exert an impact on the lean principles within the construction industry, which are herein denoted as 'keywords.' The present learning has successfully categorized the insights above into eight discrete clusters of keywords. The conducted scientometric analysis has provided significant insights that can inform and dictate future research happenings.

6. FUTURE SCOPE

The active research methodology eases the identification of the key factors that wield the most significant influence, as evidenced by the clusters mentioned before. The improvement of productivity in highway pavements is intrinsically linked to the identification of lean principles pertaining to the construction of pavements. The hunt for novel indicators and the establishment of models, along with the prioritization of the most noteworthy indicators based on the discoveries are authoritative in this context. The consideration of addressing this topic on a global scale is of chief significance, given the potential variations in indices of the issue across different countries or provinces. In accord with the set criteria of this study, solely scholarly articles composed in the English language and obtained from the Scopus database were included. The exclusion of definite recent research findings, which have been published in languages other than English or non-academic publications like trade periodicals, is a remarkable aspect that authorizes consideration.

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AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
Pooja P. Gohil	✓	✓			✓	✓	✓	✓	✓	✓			✓	✓
MohammedShakil S. Malek	✓	✓					✓	✓		✓	✓	✓	✓	✓
Deep Shaileshkumar Upadhyaya		✓	✓	✓		✓	✓			✓	✓		✓	✓

C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

INFORMED CONSENT

We have obtained informed consent from all individuals included in this study.

ETHICAL APPROVAL

We ensure that all research conducted will respect participant confidentiality, adhere to ethical guidelines, and contribute to the academic community with honesty and integrity.

DATA AVAILABILITY

The data that support the findings of this study are available from the corresponding author, [PPG], upon reasonable request.

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BIOGRAPHIES OF AUTHORS

Pooja P. Gohil is pursuing her Ph.D. in civil engineering at Gujarat Technological University, Chandkheda, Ahmedabad, Gujarat. She did her M.Tech. with a specialization in construction project management from CEPT University, Ahmedabad. She completed her bachelor's degree in civil engineering at Birla Vishvakarma Mahavidyalaya Engineering College, Sardar Patel University, Vallabh Vidyanagar. She has industrial experience of 3 years and academic experience of more than 4 years. She can be contacted at email: 199999912503@gtu.edu.in.

MohammedShakil S. Malek is a Principal at Om Institute of Technology, affiliated with Gujarat Technological University, Ahmedabad, Gujarat. He completed his Ph.D. from CEPT University, Ahmedabad, and M.E. in civil engineering (construction engineering and management) from Birla Vishvakarma Mahavidyalaya Engineering College, Sardar Patel University, Vallabh Vidyanagar, securing a gold medal. He has presented/published more than ninety articles in various international journals/conferences. He has 16 years of teaching, industrial, and research experience. He has published three books and around 75 research articles. He is also a life member of the Indian Society of Technical Education (ISTE). He also serves as a distinguished reviewer for various prestigious journals indexed in Scopus and WoS. He can be contacted at email: shakil250715@yahoo.co.in.

Deep Shaileshkumar Upadhyaya has completed his Ph.D. in civil engineering at Gujarat Technological University, Chandkheda, Ahmedabad, Gujarat. He is an assistant professor at Government Engineering College, Godhra, in the Department of Civil Engineering. He has presented/published more than eight articles in various international journals/conferences. He has more than 16 years of teaching experience. He is also a life member of the Indian Society of Technical Education (ISTE) and the Institute of Engineers India (IEI). He can be contacted at email: deep.upadhyaya@gtu.edu.in.