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Construction Productivity Monitoring Techniques: A Review and Bibliometric Analysis

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***Abstract*—**

Despite previous attempts to alleviate the limitations of traditional monitoring methods, such as being time-consuming, labor-intensive, and error-prone, there still exists a gap in the domain of automated construction productivity monitoring. This study aims to evaluate various techniques employed for monitoring productivity within the context of building construction projects. To achieve this objective, a comprehensive methodology, integrating bibliometric analysis and systematic review, was employed. The investigation revealed that computer vision (CV) approach and photogrammetry are the prevailing methods for data acquisition in productivity monitoring of construction sites. Additionally, the integration of Building Information Modeling (BIM) with monitoring tools and technologies has been observed to enhance the effectiveness of automated monitoring in construction productivity. Nevertheless, it was observed that existing studies often do not cover the whole construction sites and are based on a limited sample of construction workers and machinery.

Keywords*— *Construction productivity, computer vision, monitoring technologies, effective decisions, project management.

I. INTRODUCTION

The role played by the construction industry in enhancing the economic development of both developed and developing countries is of great importance [1], [2]. On average, it contributes approximately 8% to 10% to the economy in different countries [3], [4]. Managing construction jobsites proves to be a challenging task due to their dynamic nature, involving multiple workers and machines working simultaneously [5], [6]. The most fundamental responsibilities of a construction manager in this context include tracking, monitoring, and ensuring that the project meets the predicted production rates [2], [7].

The unique characteristics of construction sites make it impractical to utilize industrial monitoring methods and systems in the construction sites [8]. The slow flow of information severely impedes managers' ability to monitor performance indicators of construction projects, thus reduce their ability to detect the inherent variability in project activities [9].

The practices of conventional methods for data collection and monitoring at construction sites exhibit various limitations, including high costs, inefficiencies, inaccuracies, and time-consuming processes [10]–[13]. However, automated data collection allows for the effective and real-time management and control of construction activities [8]. Various techniques such as tagged-studies, photogrammetry, and computer vision are employed for the monitoring of activities of construction sites [7], [14].

Monitoring productivity effectively is crucial in evaluating the resources performance and finding opportunities for improvement [15]. Selecting practical productivity monitoring tools is highly beneficial as it ensures the reliability of data collection and minimizes the likelihood of errors [2], [16], [17]. Insufficient monitoring of construction operations may potentially lead to the failure of the project, whereas proficient monitoring facilitates the prompt execution of remedial actions for delayed operations [18], [19]. Making the right choice of techniques and tools for monitoring purposes can have a substantial impact on construction productivity [20]–[22].

Consequently, the primary aim of this study is to assess and evaluate the knowledge domains of the existing literature regarding the utilization of productivity monitoring in construction projects. This assessment will be conducted by employing a mixed methodology that combines bibliometric analysis and systematic review. understanding various techniques for monitoring productivity in the construction of buildings is crucial, as it assists researchers in comprehending the diverse tools and techniques used for collecting and analysing data. Furthermore, it facilitates a comprehension of the activities that are monitored by each technique and the limitations associated with each technique. Additionally, the evaluation of effective techniques for monitoring productivity is great importance for construction managers. This evaluation allows them to understand the variability that is inherent in project activities, enabling them to make timely and accurate decisions. As a result, this leads to cost reduction, prompt corrective actions, reduction of errors, and ultimately, the success of the project.

II. Research Methodology

The systematic approach of the PRISMA protocol guidelines was utilized in conducting a literature search, complemented by bibliometric analysis. The PRISMA approach is renowned for its clarity and comprehensibility, as it encompasses both methodological and analytic processes [23]. Researchers can draw upon bibliometric methods to form their judgments, as these methods rely on bibliographic data from researchers who have expressed their perspectives through collaboration, citation, and writing [24].

To gather comparative studies that were accessible, two databases were selected: Web of Science (WoS) and Scopus. The decision to choose these databases was based on their esteemed reputation as the primary sources of citations and abstracts in the peer-reviewed literature within the domains of technology, science, and related fields [25]. Table 1 presents the combination of keywords employed in this investigation to identify relevant publications, as well as the number of publications extracted and the pertinent publications after screening.

TABLE I. Key words combination number of relevant studies.

Database	Duration	Keywords combination	collected papers	Relevant papers
Scopus	2010-2022	((automat* AND (project OR construction OR build*) AND (vision) AND (monitor* OR track* OR updat* OR detect*)))	47	5
WoS	2010-2022	(automat* AND (project OR construction OR build*) AND (vision) AND (monitor* OR track* OR updat* OR detect*))	66	6

The content of the paper and author's research areas are among the subjects explored in the bibliographic analysis [26]–[28]. In this study, the selected literature was evaluated by means of the keywords employed by the author and the methodologies utilized for monitoring the productivity within the construction domain. Finally, the selected literature was analysed by taking into account the title and abstract, with the intention of visualizing the connections between the different terms and identifying the most commonly occurring terms.

III. Result and Discussion

A. Bibliometric Mapping

Given the growth of visualization, scientific indices, and the information technologies, the utilization of the bibliometric method provides scholars with a highly valuable instrument to visually represent and comprehend the patterns and correlations within the scholarly literature. The bibliometric method delves into latent associations through the examination of the bibliographic records of published works [29]. In order to view the connections and trends among the chosen studies, bibliometric mapping was employed for keyword analysis.

The analysis of keywords was done using the VOSviewer software, a freely available program specifically designed for the visualization and construction of bibliometric maps.

Fig. 1 depicts the visualization of co-occurring keywords. The keywords "construction productivity," "outdoor construction," "indoor construction," and "CV" exhibited the highest frequency of occurrence.

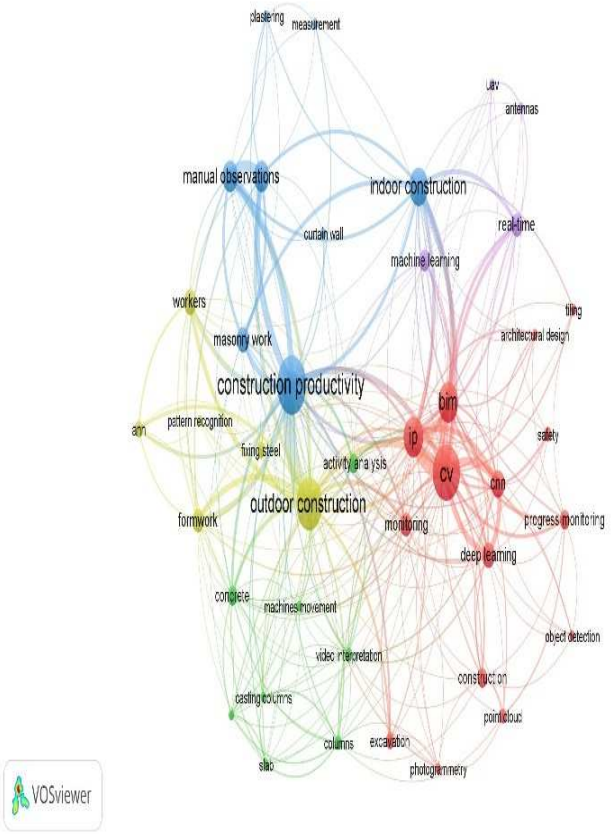

Fig. 1. Keywords analysis

B. Tools used for Monitoring Productivtiy

Productivity within the construction sector is widely recognized as an indicator of the reliability and effectiveness of construction companies. Extensive research has been conducted to analyse, measure, and monitor productivity data, driven by the increasing interest in enhancing productivity within the construction field [30]. The monitoring and measurement of construction productivity play a critical role in ensuring the projects' success [31]. The majority of factors impacting construction productivity can be effectively addressed through diligent monitoring efforts [32]. Based on relevant studies, monitoring methods can be categorized into automated and traditional methods. Traditional methods rely on statistical techniques and manual observations to collect and analyse productivity data [33]. On the other hand, automated methods leverage cutting-edge technologies to monitor construction operations [7], [34]. Table 2 illustrates the methods employed and the activities monitored in these research efforts.

TABLE II. SUMMARY OF MONITORING TOOLS AND TECHNIQUES IMPLEMENTED FOR CONSTRUCTION PRODUCTIVITY MONITORING

Key emphasis	Year	Method	Activities	Reference
Analysing Activities to Improve productivity in Construction Projects	2011	Manual observations	Workers	[35]
A method for the rapid analysis of construction productivity is proposed, which is based on object tracking, recognition, and contextual reasoning for video interpretation	2011	CV	Slab, Earthmoving, Scaffolding, Column pouring	[36]
A model for analysing and collecting productivity of construction workers utilizing image processing technologies	2014	CV, BIM	Formwork, workers	[30]
Analysis of construction activities from jobsite video streams through crowdsourcing	2015	CV	Concrete work	[37]
Photogrammetry and video analysis employed for the purpose of assessing the productivity of earthwork processes.	2017	Photogrammetry	Excavation	[38]
Automated tracking of construction equipment	2017	CV	Excavation machine	[39]
Workforce activity assessment using CV in construction	2018	CV	Steel fixing activities	[10]
Monitoring construction site activities an automated photogrammetry-based approach	2018	Photogrammetry, BIM	Column	[12]
Productivity assessment in prefabricated timber construction	2019	CV	crane cycles	[40]
Performance assessment model for building construction using 3D/BIM-based.	2020	BIM, manual observation	Steel fixing activities	[41]
Automated progress monitoring of indoor construction activities.	2022	CV	Evaluate the wall construction progress (plastering)	[42]

TABLE III. COMPARISON OF MONITORING METHODS

Method	Covered range	Weather	Computational time	Intrusiveness	Accuracy	Testing environment	Activities
Photogramm etry	Within cameras view	Affected	Fast	Non	High	Main structures/ outdoor	Reinforced column and excavation operations
CV	Within cameras view	Affected	Fast	Non	High	Main structures/ outdoor	concrete works, crane cycles, and excavation equipment
Traditional techniques	Wide range	Affected	Slow	Non	High	Indoor/ Main structures/ outdoor	All activities

In order to overcome the limitations inherent in conventional monitoring approaches, numerous studies have undertaken valuable efforts by embracing artificial intelligence to supervise, quantify, and analyse the productivity of construction projects [43], [44]. Presently, contemporary new monitoring technologies utilized in construction are helping users in resolving issues such as time-consuming processes, labour-intensive practices, and the high costs associated with data collection [45]. Also, the introduction of high-capacity databases and the availability of the Internet has brought about a significant transformation in the methods used to monitor ongoing construction operations. This transformation can be understood as a paradigm shift. Consequently, there has been a notable increase in the popularity and growth of studies focused on computer vision-based techniques in the field[46], [47]. These techniques are employed by researchers to effectively monitor construction activities [48].

CV refers to the extraction of information from images automatically. The information that can be extracted encompasses a wide range of aspects, including camera positioning, 3D models, object detection, as well as image content grouping and searching [49]. CV are utilized to monitor construction productivity of various activities combining with BIM. Examples of such activities include excavation operations, concrete work, earthmoving machines, and concrete work [40]. Despite the advancements achieved through the utilization of these techniques, it is important to acknowledge that the accuracy of construction productivity monitoring is hindered by the challenging environment that construction sites present. Issues such as congestion, occlusions, and illumination variations are known to affect the accuracy of these techniques [10], [50].

Photogrammetry is a technique that extract three-dimensional geometrical data from a series of digital two-dimensional images [51]. When combined with Building Information Modeling (BIM), photogrammetry can be applied to monitor activities like the pouring of reinforced concrete columns [12] and excavation operations' productivity [38]. While this approach offers superior accuracy and is considered a cost-effective monitoring technique in comparison to other methods [14], it is susceptible to adverse weather conditions and poor visibility caused by occlusions, resulting in increased errors [12], [38].

To ensure the effective implementation of each methodologies on construction sites, five crucial performance metrics need to be met [7]: (1) computational efficiency, (2) accuracy, (3) necessary equipment, (4) weather, and (5) monitored activities. Additionally, non-intrusiveness towards workers (addressing privacy concerns) and the adaptability of these methods to both indoor and outdoor environments should be considered [50].

Table 3 offers a comparative analysis of these methods based on the selected research. Traditional monitoring techniques have historically covered a wide array of construction activities but are plagued by limitations such as time-intensive data collection, the need for skilled personnel to monitor and analyse productivity, and high costs, making effective decision-making challenging. CV has significantly expanded the range of monitored activities, offering high accuracy, cost-effectiveness, and rapid data extraction. However, it relies on fixed cameras, limiting its coverage area and susceptible to occlusion caused by moving objects and personnel. Photogrammetry also achieves high accuracy, cost-effectiveness, and efficient data collection and analysis but faces constraints related to view range due to its reliance on fixed cameras.

Based on an extensive review of the literature, a conceptual framework was formulated and is depicted in Fig. 2. The framework illustrates the interconnection between monitoring productivity, productivity enhancement, informed decision-making, and success of construction projects.

The framework shows that the utilization of monitoring technologies for productivity results in a more effective monitoring process. This, in turn, facilitates accurate, efficient, and real-time data collection from construction sites, helping management in making well-informed decisions. Effective decision-making leads to cost reduction, timely corrective actions, and error reduction. These elements collectively enhance the likelihood of successful project outcomes. Consequently, considerable emphasis must be placed on effective construction productivity monitoring and the adoption of novel techniques, directly correlated with productivity improvements and the ultimate success of construction projects.

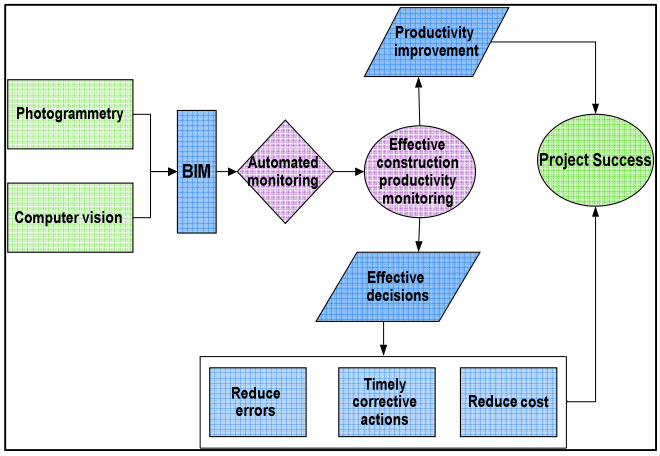

Fig. 2. Conceptual framework

IV. Conclusions

Productivity within the construction serves as a fundamental gauge of the efficiency and reliability of construction companies. The selection of the most effective techniques for monitoring construction productivity is of paramount importance for the success of construction projects. Automated methods, specifically CV-based and photogrammetry techniques, demonstrating their potential in offering highly accurate, rapidly accessible, and cost-effective results. However, it should be noted that these automated methods often rely heavily on fixed cameras, which may restrict their field of view.

To enhance monitoring of construction productivity, researchers have integrated BIM with monitoring techniques and technologies. This integration aims to improve monitoring performance and increase automation in the field. It's worth noting that existing studies have primarily focused on specific and isolated construction tasks performed by a limited sample of construction workers and machines.

Future research efforts may concentrate on more comprehensive monitoring of entire construction sites,

encompassing multiple workers and machines operating concurrently. The advancement of CV applications in construction is a critical area, necessitating the provision of training, workshops, and conferences tailored to construction professionals to ensure their familiarity with the latest developments in communication and information technologies.

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