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BUILDING INFORMATION MODELLING FOR CONSTRUCTION PRODUCTIVITY MEASUREMENT

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ABSTRACT

Productivity is a critical performance indicator of the construction industry, and thus warrants effective and efficient construction productivity measurement (CPM). Building information modelling (BIM), a digital representation of the building process, plays a significant role in effective and efficient CPM. Considering the high mandatory requirements for enhancement in construction productivity measurement, this paper aims to review the state-of-the-art literature on BIM-integrated CPM, to identify gaps in the existing body of knowledge and explore future research trends. The aim is achieved through a systematic literature review and bibliometric analysis where the data are retrieved from Web of Science, Scopus, and Google Scholar and proposes future research directions. In total 260 publications were identified from the initial search, and 56 were shortlisted for full-text analysis after several levels of screening including duplication, title and abstract checking. Finally, 21 were narrowed yielded for detailed review for this study. The results mapped the yearly publication trend, publications by source and the co-occurrence of terms. The findings help to identify a suite of BIM-integrated CPM methods used in the construction industry and provide a foundation for future research in CPM. A framework is developed to illustrate the knowledge gap and future directions identified in this study. Accordingly, the findings revealed that existing studies on utilising BIM for CPM are limited to only 3D and 4D BIM. Further, there is a lack of studies on the feasibility of using BIM for CPM, fully automated BIM integrated CPM tools and real-time CPM through BIM.

Keywords: *Building Information Modelling; Construction Productivity Measurement; Systematic Review.*

1. INTRODUCTION

Productivity is a crucial concept since it plays a major role in evaluating the success of the construction industry through quantifying the relationship between construction inputs and outputs. Therefore, statistics on construction productivity are vital for understanding the construction industry in various aspects. Henceforth, productivity plays a major role in formulating and assessing government policy relating to the construction industry. The significance of construction productivity measurement (CPM) is linked to a widely recognised need for productivity improvement in construction at task, project and industry levels (Javed et al., 2018). Indeed, CPM is the first step for realise progressive improvement. Since construction productivity has been measured at different

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levels (e.g., task, project and industry) for various purposes (e.g., labour efficiency, construction efficiency, and economic efficiency) using various methods, such as Single Factor Productivity (SFP), Multi-Factor Productivity (MFP) and Total Factor Productivity (TFP), there is still no universally accepted CPM. Indeed, it is difficult to obtain a standard method to measure construction productivity because of the complexity and uniqueness of construction projects, the fragmented project-based nature of the industry, and the dynamic context of the built environment (Oglesby et al., 1989; Thomas & Mathews, 1986). Therefore, CPM is very elusive and difficult to be conducted.

Traditionally CPM was carried out through text-based manual systems (i.e., daily work reports) to record and obtain various on-site construction data (Cha and Kim, 2020; Ibrahim and Moselhi, 2014; Hildreth et al., 2005). However, the traditional method was considered a poor data capturing technique (Martínez-Rojas et al., 2015; Feng et al., 2010), mainly due to text based information storing system makes difficulty in determining the characteristics (Cha and Kim, 2020), difficulty in recording the information in detailed levels and leads to missing or avoidance of some important information (McCullouch and Gunn, 1993), and huge time and effort required for the on-site productivity data extraction (Xie et al., 2011; Oral and Oral, 2007) and to confirm the captured data is meaningful or useful along with all information (Cha and Kim, 2020).

Technological innovation has a vital impact on construction productivity (Zhan and Pan, 2020; Zhan et al., 2018; Pan et al., 2019). Similarly, advancements in innovation technologies significantly uplift the construction industry, CPM in specific. Various studies have focused on incorporating advanced technologies into the CPM methods to enable the automation of measurement (Arif & Khan, 2020; Ibrahim & Moselhi, 2014; Lee et al., 2017; Poirier et al., 2015a; Zhang et al., 2018). Building Information Modelling (BIM) is a digital representation of the building process and it has been highly acknowledged by researchers for the automation in CPM. Indeed, various studies have been carried out on the use of BIM in the construction process and visualisation, yet in a theoretical manner rather than practical applications. The implementation of BIM has been extensively researched and found to lead to substantial increases in productivity in the construction industry. Several studies have demonstrated the effectiveness of BIM in improving productivity and reducing inefficiencies in the construction process. For instance, a study by Wong et al. (2020) revealed that transitioning from traditional construction methods to a BIM-based approach resulted in substantial gains in productivity. The study found that BIM-based projects are more productive than traditional projects due to better planning, reduced rework, and improved collaboration. The use of BIM as a valuable tool for performance management in construction projects has been highlighted by Cha and Lee (2018). The use of BIM for CPM has also been explored by previous researchers and has been widely discussed in the literature.

Despite the great efforts of the previous studies of utilising BIM for CPM, none of them systematically reviewed the knowledge gap in utilising BIM for CPM. Thus, this present study aims to review the knowledge gap in the use of BIM for CPM by adopting a mixed review methodology of bibliometric analysis and systematic literature review. This study should help researchers to understand the knowledge gap in the use of BIM for CPM and guide future research on this important topic.

2. METHODOLOGY

A systematic literature review was adopted in this paper since it is often seen as an evidence-based approach, helping reduce researchers' subjectivity and biases. The Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) 2020 statement was used as a guideline for the systematic literature review. The PRISMA 2020 is a guideline not only to identify and screen the data set but also for transparent, complete, and accurate reporting of systematic reviews (Page et al., 2021).

Initially, a desktop search was conducted across various databases to identify the existing research papers on the domain of automation in CPM. However, this initial search revealed that most of the findings are covered by Web of Science (WoS) and Scopus databases. Various researchers have emphasised that WoS and Scopus are the largest and most robust citation and abstract databases with reasonable availability (Braun et al., 2019; de Oliveira et al., 2019). In addition to this, Alaloul et al. (2022) also used WoS and Scopus databases for a similar kind of study. In addition, a random search has been done in Google Scholar to obtain additional publications in the research context. Further, bibliometric methods were complemented with meta-analysis and qualitative structured literature reviews, so a better review and evaluation of scientific literature can be achieved.

A keyword search query was developed for WoS as "TS = ((BIM OR Building information modelling) AND (construction) AND (productivity) AND (measurement OR calculation OR assessment OR evaluation))" and for Scopus as "TITLE-ABS-KEY ((BIM OR Building information modelling) AND (construction) AND (productivity) AND (measurement OR calculation OR assessment OR evaluation))". Figure 1 illustrates the process involved in identifying the most suitable dataset for this paper.

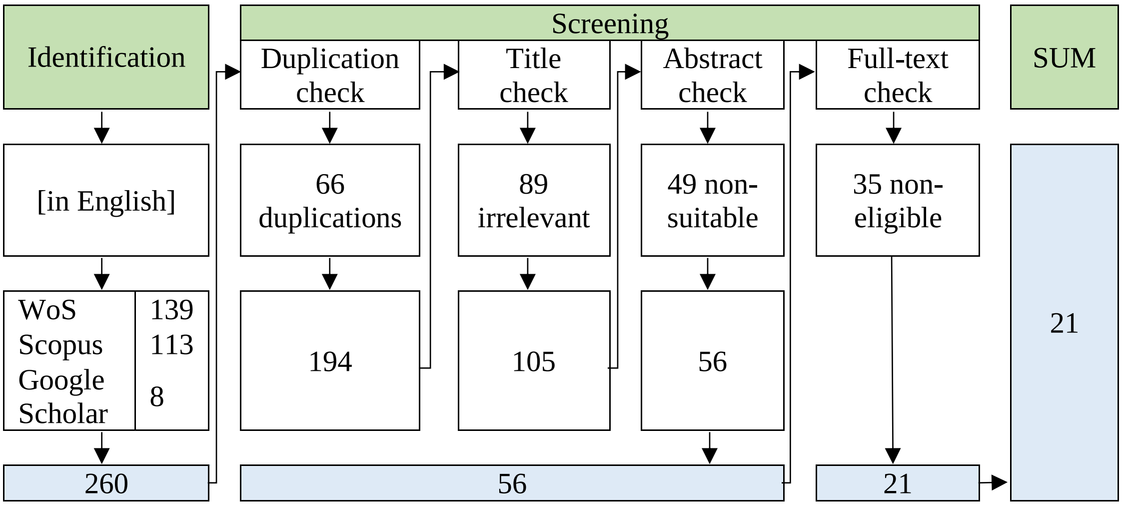

Figure 1: Flowchart of systematic literature review (Adapted from the PRISMA 2020 flowchart by Page et al., 2020)

Under the developed search string 139 and 113 publications were found from WoS and Scopus, respectively. In addition, 8 publications were obtained from a random search in Google Scholar for the publication in the relevant context. In both databases, results were limited to only 'English'. Accordingly, a total number of 260 publications were found from database searching. The initial screening revealed 66 duplicated publications in the findings, hence, at the end of duplication removal, a total number of 194 publications were obtained. The screening was continued with two further levels of filtering such as screening based on title and abstract, which resulted in 105 and 56 publications at the end of each stage respectively. Finally, at the end of a skim reading of the full text, 35 publications were removed, since non-eligible for the focused research domain. Therefore, in the end, 21 publications were found to be suitable for the detailed review of the literature.

Initially, the selected 21 publications were analysed according to the publication year and source. Bibliometric analysis is carried out based on the title and abstract to visualise the connections between terms and the most cooccurred terms. Content analysis of each paper has been done to identify the existing use of BIM in CPM.

3. RESULTS AND DISCUSSION

3.1 PUBLICATIONS DISTRIBUTION BY YEAR AND JOURNAL/CONFERENCE

Figure 2 illustrates the yearly publications output of the publication achieved from WoS, Scopus and Google scholar databases. A maximum number of publications were found in 2016 and 2018. Whereas there was no publication in 2013. The R-square value of the trend line (based on the "Total", y= 0.2333x + 1.1667) was found as 0.3267, which is not sufficient to show the significance. However, since 2016, there is a considerable increase in publications compared to previous years. Even though there were no limitations added to the year of publication in the search string, publications were obtained since 2011 only.

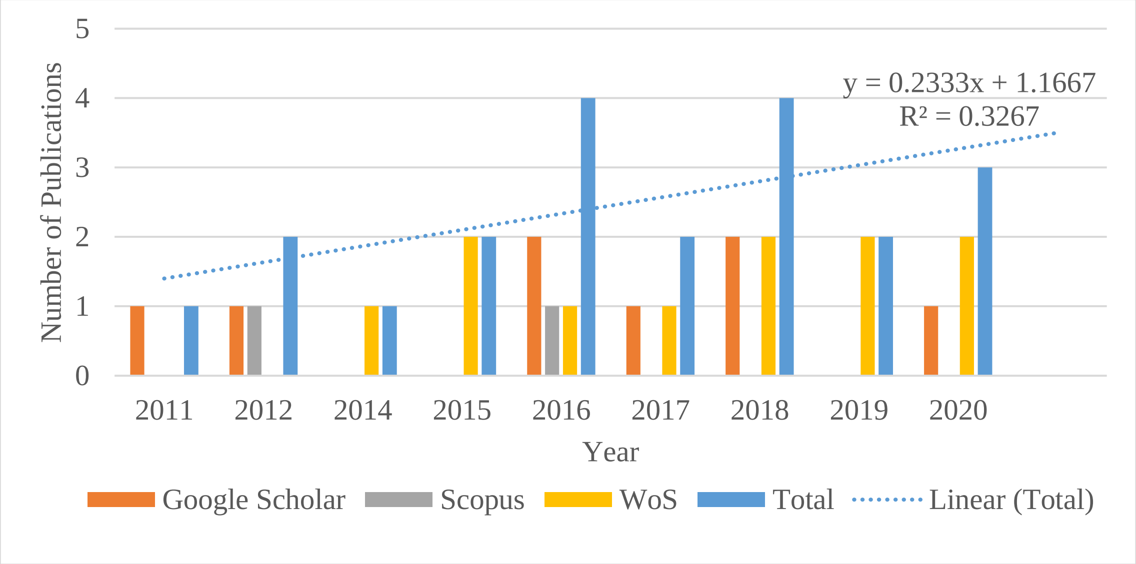

Figure 2: Number of publications from the selected databases over the period 2011-2020

Publications were also analysed based on the sources as illustrated in Figure 3. Accordingly, 21 publications were found from 15 sources, among which 2 were conference papers and the remaining were journal articles. The highest number (6) of publications was found in "Automation in Construction", followed by "Journal of Asian Architecture and Building Engineering" (with 2 records), with the rest of the sources having one record in each only.

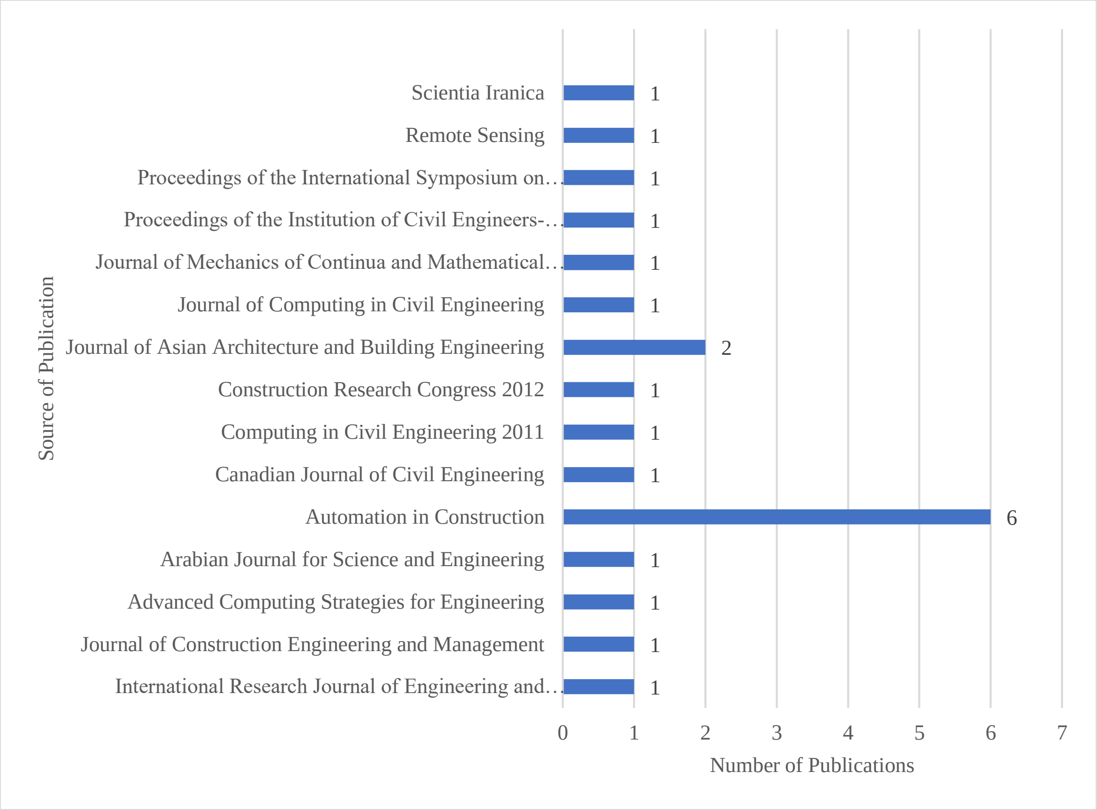

Figure 3: Number of publications per journal/conference

3.2 BIBLIOMETRIC MAPPING

The co-occurrence of text data of publications was analysed using VOSviewer software, to show the inter-closeness among them. Figure 4 illustrates the co-occurring of 26 terms found in the publications.

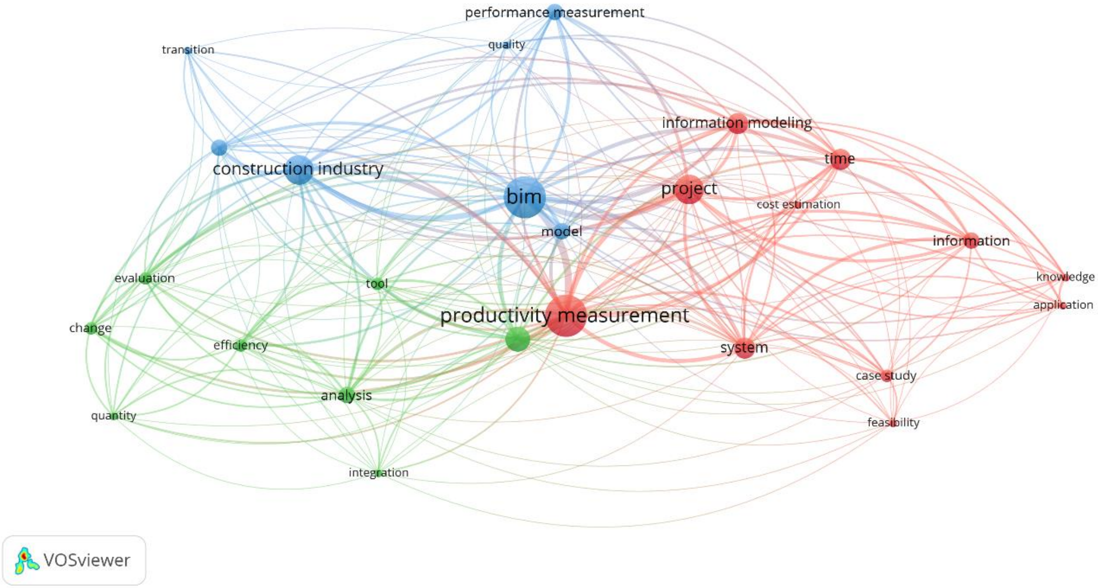

Figure 4: Co-occurrence mapping of terms in title and abstract of publication

By reviewing the bibliometric database files, the minimum occurrence of a text was set to two, 26 terms meeting the threshold point. Instead of analysing the co-occurrence of keywords, the co-occurrence of text data was analysed, since it enables to cover title and abstract of publications. BIM and productivity have the highest occurrence as the node reflects a visual representation of the occurrence of a given term. The thickness of the connecting lines between the nodes indicates the interconnectedness between the terms which indicates the significance of the integration of BIM for productivity.

3.3 BIM FOR PRODUCTIVITY MEASUREMENT

The use of BIM for CPM has been explored by previous researchers and has been widely discussed in the literature. Table 1 summarises the use of BIM for productivity measurement found in the 21 publications considered in this study.

Table 1: Studies on using BIM for productivity measurement

Source	Use of BIM
Abedi et al. (2016)	The proposed CACCBIM can be used as an effective tool for the data collection for the CPM
Arif and Khan (2020)	Typical total station, cloud and BIM integrated framework for real-time productivity measurement
Chan and Kim (2020)	Link 3D objects with a spreadsheet containing detailed daily progress information
Fang et al. (2016)	BIM and cloud-enabled RFID localisation systems enable productivity monitoring through worker location identification and data visualisation
Heigermoser et al. (2019)	The tool allows for a systematic evaluation and analysis of the construction planning in terms of productivity and manpower allocation
Heydarian and Golparvar-Fard (2011)	Framework for monitoring and controlling construction productivity of excavation. Machine learning approach to measure productivity and 4D BIM for a visual representation of the productivity
Khan et al. (2019)	BIM accurately estimates the bill of quantity and cost of the project. Well-documented reports are also generated in the BIM tool (Robot) for the model.
Kim et al. (2020)	Evaluation of project progress was performed through the 3D point cloud and the 4D attributes of BIM
Lee et al. (2014)	New algorithms are proposed for the acquisition of labour data, measurement and analysis of LP, and BIM models were employed for the creation of the LP database
Lee et al. (2017)	Proposed a BIM-based model that could be used for measuring daily LP progress and productivity best-fit line using the proposed BIM-based model
Lin and Golparvar-Fard (2018)	BIM for capturing, communicating, and analysing construction performance
Menon and Varghese (2018)	LP data acquisition method using 3D BIM model. 3D BIM model is used to take off quantities and enhance the accuracy of the LP measurement
Nath et al. (2016)	Fuzzy triangular function to measure construction productivity. Automated scheduling and automated quantity takeoff will automate the productivity measurement
Poirier et al. (2015b)	The findings suggest that BIM has had a positive impact over time on predictability for indicators such as total project cost and labour cost
Poirier et al. (2015c)	Productivity indicator predictability (labour productivity in specific) is becoming easier with BIM implementation
Shan et al. (2012)	BIM as a platform to perform labour productivity studies
Turkan et al. (2012)	3D object recognition technology with schedule information into a combined 4D object recognition system with a focus on progress tracking.
Yarmohammadi and Castro-Lacouture (2018)	A novel approach for automated design productivity measurement, using an API-enabled approach to collect real-time data directly from BIM software

Source	Use of BIM
Yarmohammadi et al. (2016)	Purpose of design log files including information about modelling activities (modeller's interactions with the software) during design sessions
Yarmohammadi et al. (2017)	Extract implicit process information from design log data by implementing a tailored sequential pattern mining approach
Zhang et al. (2018)	Proposed pattern retrieval algorithm which allows identifying the design sequential pattern that is most frequently used in building projects

3.3.1 3D BIM for CPM

Predictability of productivity indicators, especially labour productivity (LP) has been identified as becoming easier with BIM implementation compared to non-BIM implemented projects, thus positively impacting the LP prediction (Poirier et al., 2015b, 2015c). The findings indicate that the use of BIM has a significant positive impact on the accuracy of predicting the LP, compared to projects that have not implemented BIM. Similarly, a fuzzy mapping technique has been proposed and utilised to measure productivity improvement in a BIM-based workflow compared to a precast workflow (Nath et al., 2016). The findings of this study revealed that BIM enables automated scheduling and quantity take-off, which has the potential to automate CPM. This is because the quantity of work done can be used as an output for the CPM. Therefore, BIM allows for accurate estimates of the bills of quantities and costs of the project (Khan et al., 2019). Kim et al. (2020) also highlighted the use of BIM for monitoring the overall project status, such as productivity analysis, progress rate and quality verifications.

Lee et al. (2014) and Lee et al. (2017) conducted research centred around the utilisation of BIM as a tool for collecting data related to productivity measurement. To enhance the recognition of construction site images captured through video, Lee et al. (2014) developed innovative algorithms. These algorithms aimed to improve the recognition of construction site images to better measure the LP and establish a corresponding database. Importantly, BIM models were employed for the creation of the LP database, thus this study primarily focused on using BIM for the creation of an LP database rather than for the direct measurement of LP. In contrast, Lee et al. (2017) proposed a BIM-based model that could be used for measuring daily LP progress. This model was accompanied by a detailed explanation of the prototype. The study also went on to generate a productivity best-fit line using the proposed BIM-based model. While this study was significant in that it directly examined the use of BIM for CPM, it was limited in its scope as it only considered 3D BIM.

In addition, BIM has been utilised for the on-site performance measurement for building construction projects (Cha & Kim, 2020). This system is unique in its ability to link 3D objects with a spreadsheet containing detailed daily progress information, which can provide an accurate and comprehensive view of the project's progress. The proposed database is designed to enhance traditional CPM by incorporating the use of 3D BIM. However, it should be noted that the study by Cha and Kim (2020) is limited in scope, and only focuses on the use of 3D BIM for CPM, similar to the study conducted by Lee et al. (2017). Despite this limitation, the results of these studies demonstrate the potential for using 3D BIM to improve on-site performance measurement. In light of the similar limitations of previous studies, Menon and Varghese (2018) conducted a study that utilised a 3D BIM model for the measurement of LP in a commercial construction project. The study proposed a field LP data acquisition method that integrated the 3D BIM model, which was primarily used to take off quantities and enhance the accuracy of the LP measurement.

3.3.2 BIM Integrated with Other Technologies for CPM

Abedi et al. (2016) proposed a cloud-integrated BIM for precast supply chain management, named context-aware cloud computing building information modelling (CACCBIM). This proposed tool enabled efficient monitoring of the precast supply chain and it can be used to collect data for the CPM. Similarly, BIM has been integrated with cloud and Radiofrequency Identification (RFID) to collect worker location data in an indoor construction environment (Fang et al., 2016). The BIM-enabled system enables data visualisation and offers situational awareness of workers' locations. In addition, this system is capable of storing the historical location data on the server for further data analyses if necessary. Similarly, Arif and Khan (2020) proposed a BIM-based real-time productivity tracking framework that utilises a typical total station and cloud technology. This framework is capable of generating an as-built model for an ongoing construction project through the use of Dynamo programming on a BIM platform and measuring real-time productivity through data-driven BIM models. However, similar to previous studies in this area, Arif and Khan (2020) focused solely on the use of 3D BIM technology, neglecting the potential benefits of incorporating other BIM dimensions, into the framework.

3.3.3 4D BIM for CPM

BIM has been uniquely combined with machine learning to enable monitoring and controlling of productivity in construction excavation operations (Heydarian & Golparvar-Fard, 2011). The authors integrated the use of 4D BIM to provide a visual representation of the productivity of each planned construction activity. Additionally, they applied a machine learning approach to measure productivity. BIM and 4D schedule simulation is also used for labour studies to visually compare the schedule performance as a result of using quick connection systems (Shan et al., 2012). Similarly, the use of BIM for dividing construction projects into work zones, obtaining a fully automated quantity take-off, and offering a colour-coded 4D construction simulation is highly emphasised (Heigermoser et al., 2019). Moreover, location-based 4D BIM models are used to benchmark and monitor workers' location and to document worker hours per task per location (Lin & Golparvar-Fard, 2018). In addition, 4D BIM is integrated with 3D object recognition technology with a focus on progress tracking (Turkan et al., 2012).

3.3.4 BIM for CPM at Design Stage

Productivity measurement at the design stage is comparatively more complex than measuring the construction stage productivity, due to the complexity and variability of the design process, as well as the challenges associated with data collection and analysis (Zhang et al., 2018). Several researchers came up with various methods for the design stage productivity measurement including design hours, number of drawings, number of contractual documents, and project size and type (Thomas et al., 1999).

Even though these methods help to measure the effectiveness of resource utilisation, typically, data collection was manual, which is time-consuming, complex, error-prone, etc. Meanwhile, the integration of BIM technology into the design process provides an opportunity to enhance the efficiency and accuracy of design productivity measurement. By using BIM, design information is digitalised and centralised, providing a comprehensive and accurate representation of the design process. This digital representation enables the automatic collection and analysis of design data, reducing manual effort and minimizing the risk of errors.

Indeed, the utilisation of BIM software has provided construction professionals with access to valuable information about the design process through computer-generated data. For example, design log files stored in Autodesk Revit Journal files (Revit 2017) have been found to contain information about modelling activities, including the modeller's interactions with the software, during design sessions (Yarmohammadi et al., 2016). Further studies have aimed to extract implicit process information from design log data by implementing a tailored sequential pattern mining approach (Yarmohammadi et al., 2017). In a more recent study, Yarmohammadi and Castro-Lacouture (2018) proposed a novel approach for automated design productivity measurement, using an API-enabled approach to collect real-time data directly from BIM software. This approach has the potential to not only streamline the data collection process but also provide more efficient productivity measurement during schematic and design development phases. Similarly, Zhang et al. (2018) proposed a pattern retrieval algorithm to identify the most frequently used sequential patterns in a project by design professionals using BIM log data in the Autodesk Revit Journal files. With this information, baseline productivity can be measured (by averaging the time taken to complete a task), and individual designer performance can be evaluated.

Figure 5 presents the knowledge gaps and future directions identified in this study.

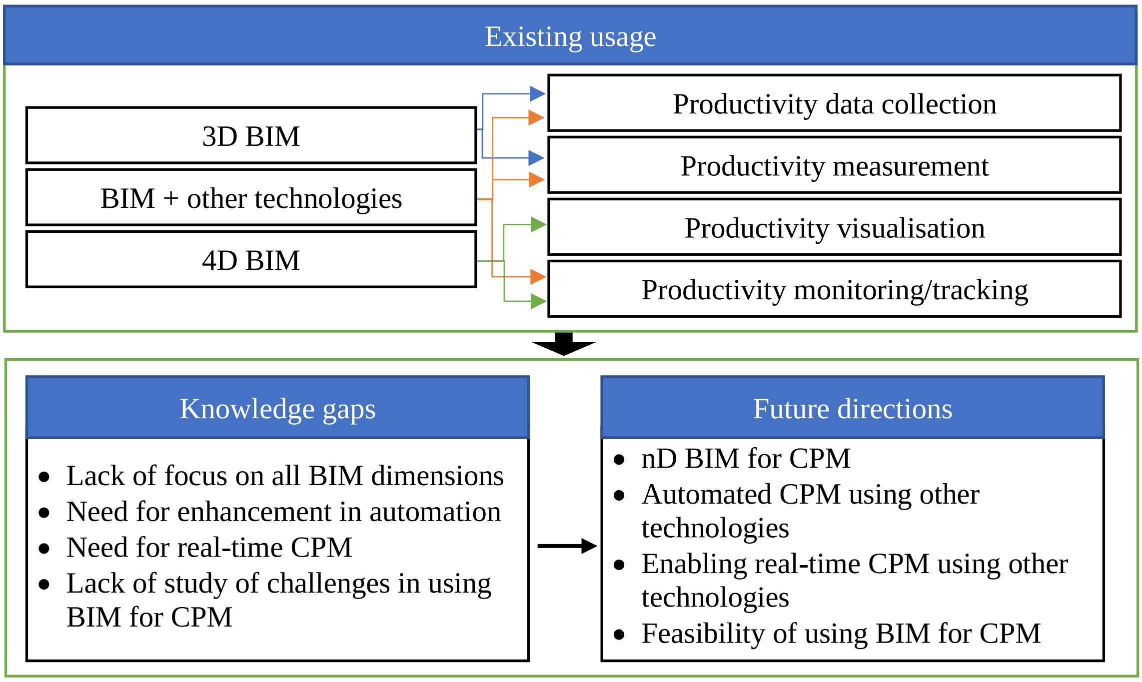

Figure 5: Framework of knowledge gaps and future research direction

4. CONCLUSIONS

Productivity is considered a critical performance indicator of the construction industry since it allows for the overall success of construction projects in terms of time, cost and quality. Therefore, having effective and efficient CPM is vital to improve productivity and to realise the progressive improvement of the construction industry. Traditional CPM was text-based and manual which has various limitations including a huge time and effort for the data collection and analysis. BIM has been identified as one of the technologies that is useful to automate the CPM, since it enables efficiency and effectiveness in the CPM process. BIM has been utilised not only for the CPM at the construction stage but also at the design stage, which is comparatively more complex than CPM. Studies on utilising BIM for CPM focus on identifying the labour data including working hours and worker locations. Furthermore, automated quantity take-off and efficient productivity tracking and monitoring were identified as benefits of utilising BIM in CPM. Therefore, as of now, BIM has been utilised for data collection, analysis, measurement and even visualisation of construction productivity.

While previous researchers have made huge and significant efforts in the use of BIM for CPM, the systematic literature review has identified various knowledge gaps as presented in Figure 5. First, while there are various BIM dimensions, studies on using BIM for CPM are merely focused on 3D and 4D BIM. Therefore, future, studies can focus on the potential and limitations of utilising nD BIM for CPM including 5D, 6D, 7D. and other dimensions of BIM. Especially, 5D BIM, which has the cost information and enables automated quantity take-off, shall be investigated in detail in the CPM context. Second, even though, BIM enables automated productivity measures, it still falls under semi-automation, due to the requirement of manual input. Therefore, there is a need to enhance automation in CPM. This can be achieved by integrating some other advanced technologies such as digital twin (DT) and the Internet of Things (IoT). Third, real-time CPM is still a challenge in the context of BM for CPM. Therefore, enabling real-time CPM shall be investigated by integrating advanced technologies such as DT and IoT. Finally, while BIM has been identified with various benefits in terms of utilising it for CPM it still has some limitations and challenges. Especially, cost overrun with BIM in terms of cost of training, cost of software, lack of financial resources, huge capital investment, and uncertain return of BIM investment are major concerns in adopting BIM. Therefore, there is a knowledge gap in terms of identifying the feasibility of using BIM for CPM. Future research can focus on investigating the above knowledge gaps in utilising BIM for CPM.

5. ACKNOWLEDGEMENTS

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