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APPLICATION OF COMPUTER VISION FOR CONSTRUCTION PROGRESS MONITORING

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ABSTRACT

Progress monitoring of construction work is crucial to identify the discrepancies between the as-built product and as-planned design and take necessary action based on the results. Construction work is time consuming and labour intensive. However, the use of new technologies, such as computer vision (CV), in construction progress monitoring (CPM) can minimise human errors. Thus, the aim of this study was to explore the current applications of CV in the construction industry in general and in the different stages of CPM. A qualitative approach based on the Delphi technique comprising two interview rounds was used to collect the required data. The study findings revealed that CPM has seven stages: initial planning, data acquisition, information retrieval, verification, progress estimation and comparison, results visualisation and schedule updating. During these stages, CV can be used in various CPM activities, such as earthmoving operations, crane operations, formwork and rebar tracking, worker activity tracking, safety assurance, landscape identification, work item monitoring and integrating with other technologies. Familiarisation of the workforce with CV and research on the applications of CV in construction can help the construction industry to move with technology and be on par with other industries. This study would enable construction personnel to explore the possibility of applying CV in CPM. Further research on identifying the synergy between CV and CPM can be based on the study findings.

Keywords: *Construction Work Progress Monitoring; Computer Vision; Stages of Progress Monitoring*

1. INTRODUCTION

The construction industry has a low uptake of modern computer technologies, making the industry to stagnate technologically (Mahami, et al., 2019). Progress Monitoring of construction work is a laborious task, mostly conducted manually during the construction process, resulting in a large number of errors (Braun, et al., 2020). Construction progress monitoring (CPM) includes scheduling, cost and resource management, and change order management (Omar and Nehdi, 2016). Although it can be tedious, CPM can produce timely, comprehensive and most up-to-date data relating to designs, schedules, costs and progress performance and enable a fast and easy decision-making process (Alizadehsalehi and Yitmen, 2018). The use of new technologies can help overcome many challenges (Mahami, et al., 2019). New technologies, such as laser scanning (LS),

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radio frequency identification (RFID), ultra-wideband (UWB), global positioning systems (GPS) and wireless sensor networks have been used in CPM; these technologies, however, have their own drawbacks with regard to delivery time, cost-effectiveness, popularity (Omar and Nehdi, 2016), setting up and implementation, and accuracy in the case of large-scale projects (Park and Brilakis, 2012). Computer vision (CV) can be a cheaper option than any automated technology and could make construction monitoring easy (Zhong, et al., 2019).

When CV is used in CPM, a model would be created using as-planned information, which would be compared with real-time project data obtained using automation techniques (Fard and Peña-Mora, 2007). CV implementation has numerous enablers. It also has several challenges, such as lighting and environmental issues of the visual field (Spencer Jr, Hoskere and Narazaki, 2019), handling and gathering of big datasets with large capacities in the training of artificial intelligence (AI) (Fang, et al., 2020), and the proper selection of camera angles and monitoring of employee stress (Seo, et al., 2015). Many studies have been conducted on CV and CPM separately (Fang, et al., 2020; Park and Brilakis, 2012); the synergy between CV and CPM, however, has not been studied sufficiently, and no studies have been conducted to analyse the synergy between the two in the different stages of CPM. Thus, the aim of this study was to investigate how CV can be applied in the various stages of CPM.

2. LITERATURE REVIEW

2.1 CONSTRUCTION PROGRESS MONITORING

Progress monitoring of construction work, an ongoing task in construction, involves the periodic measurement of the actual project progress and its comparison with expected / as-built progress (Alizadehsalehi and Yitmen, 2018). If construction projects fall behind schedules and if discrepancies exist between as-built and designed baseline plans, many unfavourable events could occur during project implementation (Omar and Nehdi, 2016). Hence, the tracking and monitoring of construction work progress in real-time is a vital part of project management and is important in the achievement of project objectives. According to Ekanayake, et al. (2021), inefficient and inaccurate monitoring and tracking of construction work are two major factors responsible for time and cost inefficiencies in construction projects. CPM requires project schedule updating for which the actual data related to project progress at different project stages have to be obtained from the project sites to obtain processed data (Kazado, Kavgic and Ergen, 2019).

2.2 PROGRESS MONITORING STAGES

According to literature, CPM can be divided into several stages as given in Table 1.

Table 1: Progress monitoring stages

Stages	A	B	C	D	E	F	G	H	I	J	K	L
Initial planning/Scheduling			✓	✓		✓			✓			
Data acquisition	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Information retrieval	✓	✓		✓	✓	✓	✓	✓	✓	✓		
Verification					✓						✓	
Progress estimation and comparison	✓	✓	✓	✓				✓	✓	✓	✓	✓

Stages	A	B	C	D	E	F	G	H	I	J	K	L
Results visualisation /reporting	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓
Schedule updating						✓						

Sources: A - Pushkar, Senthilvel, and Varghese (2018), B - Omar and Nehdi (2016), C - Meredith and Mantel (2009), D - Daniel, Kavgic, and Ergen (2019), E - Braun, et al. (2015), F - Kim, Son, and Kim (2013), G - Fard, Mora, and Savarese (2015), H - Alizadehsalehi and Yitmen (2018), I - Fard and Peña-Mora (2007), J - Han and Fard (2017), K - Braun, et al. (2020), L - Wang, et al. (2021)

According to Table 1, CPM has seven basic stages. Planning in CPM includes breaking down project work into various activities and indicating their expected dates of completion to enable the identification of the project stage to which a project activity would belong (Daniel, Kavgic and Ergen, 2019). According to Braun, et al. (2020), data acquisition and information retrieval can be expedited using traditional methods, which require a high level of human intervention and automation. The authors explained that the data and information collected have to be verified manually to ensure accurate verification. Presently, engineers and project managers monitor the working status of a construction labourer by looking at images (Braun, et al., 2015). Progress estimation is the comparison of planned schedules with as-built schedules or models to determine project progress (Pushkar, Senthilvel, and Varghese, 2018). In the stage following project estimation, data visualisation and reporting is performed to make the decision-making process smooth (Han and Fard, 2017). After processing the information using the actual start date, actual finish date, and measurement date, the project schedule will be updated to enable the reallocation of resources (Kim, Son and Kim, 2013).

2.3 COMPUTER VISION AND CONSTRUCTION PROGRESS MONITORING

2.3.1 Integration of Computer Vision with Construction Progress Monitoring

CPM is necessary to determine the differences between the as-built product and as-planned product so that corrective actions could be taken to minimise the differences (Ekanayake, et al., 2021). Project visualisation has an important role to play in construction projects (Wang, et al., 2021). Inefficient and inaccurate CPM contributes to the time and cost overruns of a construction project. Fard and Mora (2007) stated that the inherent complications and dynamic nature of construction projects, which involve outdoor activities, make it difficult to keep up with as-planned progress during project implementation despite the use of improved construction equipment and management strategies. Vision-based tracking, which can track multiple entities present within a camera view, can be used to overcome the aforementioned challenges (Park and Brilakis, 2012). CV, which is cheap and easy to execute, can monitor project progress accurately. Extracting comprehensive information from the images via computer vision-based systems can help automate diverse construction-related activities, such as the progress monitoring, safety management, quality control and productivity tracking of construction projects (Paneru and Jeelani, 2021). Remotely controlled unmanned aerial vehicles (UAV) and unmanned ground vehicles (UGV) can be used in large construction sites to ensure safety at the sites and collect data efficiently (Elena, Vito and Pecce, 2019). CV-based technologies have accelerated the automation of CPM, helping to overcome the challenges faced when using traditional and manual methods, which are labour intensive and error-prone (Ekanayake, et al., 2021).

2.4 IMPORTANCE OF COMPUTER VISION FOR CONSTRUCTION PROGRESS MONITORING

During the past decade, a growing trend of using CV and its applications in the fields of architecture, engineering and construction and facility management could be observed (Xu, et al., 2020). CPM is important because the as-built progress of a construction project has to be constantly monitored and compared /analysed with the planned progress of the project to minimise the discrepancies between the two (Fard and Peña-Mora, 2007). The manual inspection and monitoring of construction progress have many challenges related to cost, time and quality (Braun, et al., 2020). However, the traditional and manual CPM, which requires human interactions, still dominates the construction industry (Braun, et al., 2015). Thus, many studies have been done on the use of advanced technologies, such as LS, GPS, RFID, augmented reality (AR) and UWB, in the construction industry (Omar and Nehdi, 2016). Nonetheless, CV is considered cheaper and more flexible than other automated technologies (Zhong, et al., 2019). In recent years, there has been a dramatic increase in the number of digital photos taken in construction environments, making the development of the required systems feasible, cost-effective and fast (Hamledari, McCabe and Davari, 2017). Because the construction industry is labour intensive, by using CV, companies can reduce their labour requirements and use UAV/UGV to access risky areas while ensuring the safety of the people (Elena, Vito, and Pecce, 2019). Thus, the use of CV in CPM deserves investigation.

3. RESEARCH METHODOLOGY

A purely qualitative approach was used in the study based on its objectives; however, it has limitations because of its subjectiveness and dependency on linguistic variables, leading to inaccurate outcomes (Islam and Nepal, 2016). The Delphi method is a systematic and interactive research technique involving two or more rounds of structured surveys or interviews, which can be used to obtain the views of an independent expert panel (Aghimien, Aigbavboa and Oke, 2020). The literature is not specific about the number of rounds that would be required to achieve a consensus using the technique. Nevertheless, in most construction management-related studies, a consensus can be reached after the second or third Delphi round (Ameyaw, et al., 2016). Thus, a two-round Delphi technique was used in the study to achieve the study objectives. Because the study required personal perspectives and experience-based answers, a qualitative approach was adopted in the Delphi survey (Hammarberg, Kirkman and de Lacey, 2016). Manual content analysis was used to analyse the qualitative findings of the survey.

3.1 RESPONDENT PROFILES

The purposive sampling technique was used in the study to facilitate the intentional selection of those who are best suited to take part in the survey (Etikan, Musa, and Alkassim, 2016). The Delphi technique can be effectively used with a heterogeneous panel consisting of experts coming from different fields (Skulmoski, Hartman and Krahn, 2007). Furthermore, a heterogeneous sample would help obtain a generalised overview of the subject. The selected heterogeneous sample consisted of participants from countries such as Sri Lanka, Australia, the United Kingdom, New Zealand, the United Arab Emirates, Singapore, Malaysia and Oman. Fifteen participants took part in the first round of the survey, while eleven participants took part in the second round. For a Delphi survey, a robust result is possible with a panel of 10–20 experts in the first round (Nashir, Mustapha and Yusoff, 2015). In Table 2, the profiles of the survey respondents are presented.

Table 2: Respondent profiles

Code	Round		Designation	Experience (years)	Industry
	R1	R2			
I1	✓	✓	PhD candidate	5.5	Construction
I2	✓		Contract manager	12	Construction
I3	✓	✓	Senior computer vision developer	10.5	IT
I4	✓	✓	PhD candidate	3	Construction
I5	✓	✓	PhD candidate	5.5	Construction
I6	✓	✓	PhD candidate	7	Construction
I7	✓		Quantity surveyor	8	Construction
I8	✓		Quantity surveyor	4	Construction
I9	✓	✓	Quantity surveyor	3.5	Construction
I10	✓	✓	Quantity surveyor	11	Construction
I11	✓	✓	Senior project manager	28	Construction
I12	✓		Senior cost manager	6	Construction
I13	✓	✓	PhD candidate	4	Construction
I14	✓	✓	Senior project manager	20	Construction
I15	✓	✓	Project manager	15	Construction

4. RESEARCH FINDINGS

4.1 DELPHI ROUND 1

4.1.1 Identification of the Stages of Construction Progress Monitoring (Round 1 Phase 1 Findings)

Seven stages of progress monitoring of projects were identified from the literature. In Phase 1 of Delphi Round 1, the interviewees were requested to validate these stages for CPM and suggest any new stages that need to be included in CPM. Table 3 lists the progress monitoring stages of construction projects agreed upon by the interviewees.

Table 3: Progress monitoring stages

No.	Stage	I1	I2	I3	I4	I5	I6	I7	I8	I9	I10	I11	I12	I13	I14	I15
1	Initial planning/ Scheduling	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
2	Data acquisition	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
3	Information retrieval	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
4	Verification	✓	✓	✓	X	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

No.	Stage	I1	I2	I3	I4	I5	I6	I7	I8	I9	I10	I11	I12	I13	I14	I15
5	Progress estimation and comparison	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
6	Results visualisation /reporting	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
7	Schedule updating	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

According to Table 3, all the respondents except I4 have validated all the stages of CPM identified from the literature. I4 was of the view that verification could be a part of progress estimation and comparison and said, "Four stages, namely *initial planning*, *data acquisition and processing*, *comparing and results visualising* and *schedule updating* will be sufficient to demonstrate the entire process". I6 added, "After the 6th stage, a new stage will be required to look back at the previous plan." However, the interviewees I7, I8, I9, I11 and I3 did not agree on having this additional stage because the work envisaged during this stage could be included under *progress estimation and comparison*. With the agreement of most of the interviewees, all seven stages of progress monitoring mentioned in the literature were considered as applicable to construction projects.

According to I3, the initial plans for the project/section are prepared, and the milestones are determined during the planning stage for the easy and gradual management of the project. I5 stated that data acquisition could be the most time-consuming process in the PM workflow as it takes as much time as the whole construction process so that the information retrieval can be done in parallel with the construction progress. I6 also agreed that data acquisition is time consuming and laborious and that, therefore, in most projects, automated techniques are used in the planning stage more than in other stages. I4 added that the information retrieved from the data has to be verified manually or by using software to ensure the accuracy of the CPM workflow and to improve the reliability of the comparison made between the as-built and as-planned schedules. I1 added that the results visualisation stage is necessary to ease decision making and that it helps schedule updating after comparing the as-planned models with as build models. The seven stages identified were then considered for validation.

4.1.2 Use of Computer Vision in Construction Progress Monitoring (Findings of Delphi Round 1 Phase 2)

Thirteen uses of CV in construction-related activities, such as earthmoving operations, crane operations, formwork and rebar tracking, worker activity tracking and safety assurance, were identified from the extant literature. The interviewees were requested to determine whether these uses could be validated for CPM. Nine new uses of CV in CPM also were identified through the interviews. Most of the interviewees validated for CPM, a majority of the CV uses stated in the literature. The uses such as tracking of worker travelling and their activities, nailing using a hammer and bending, identified using the literature review were rejected by the interviewees I1, I3, I4, I5, I6, I8, I10 and I11, stating that those activities did not require monitoring because they were not related to the progress of site work. I1 and I4 disagreed with most of the items identified from the literature, stating that if a task was not directly related to the completion or partial completion of a work item, its progress did not require monitoring. I4 opined that the monitoring of machinery and labour activities do not come under CPM, although they would be required to evaluate worker efficiency and productivity. I9, I12 and I13 opined that labour productivity and safety measures could be considered during CPM because the data retrieved from those activities can help project managers and other supervisors to track construction work progress. I1, I4, I6, I8 and I11 were of the view that safety did not have to be considered during CPM. I11 stated that safety is not related to CPM but to health, safety and environmental monitoring. However, the other interviewees agreed that safety assurance could be considered during CPM because it exerts a considerable influence on the project timeline.

Nine new uses of CV also were identified at the interviews. I3 added two of the new uses, namely taking crude measurements from the sites and performing aesthetic works with the help of AR, which can help CPM. I3 said, "Most of the technologies recently developed cannot be used independently and have to be integrated with other technologies; CV also can be integrated with other technologies, such as AR and virtual reality (VR), in the planning processes of CPM". I7 agreeing with I3, stated that the integration of CV with building information modelling (BIM) will be effective with BIM also being an emerging technology in construction. I4 also introduced a few new uses of CV in CPM, namely the construction of columns, walls, prefabricated items, installation of HVAC and plumbing systems, and material counting. He was also of the view that if an item/work monitored is required to complete an item in the bill of quantities or an element that is essential to the project, it could be included in CPM.

4.2 DELPHI ROUND 2

4.2.1 Use of Computer Vision in the Various Stages 0f Construction Progress Monitoring

During Phase 2 of Delphi Round I, the uses of CV in general construction applications that were identified from the literature were validated for CPM. During Delphi Round 2, the CV uses in CPM were categorised according to the stages in which they were applied. Table 4 lists under each progress monitoring stage of construction, the CV uses that were validated for CPM by more than 75% of the respondents.

Table 4: Uses of CV in different stages of construction progress monitoring

	Use \ Stage	Initial Planning/ Scheduling	Data Acquisition	Information Retrieval	Verification	Progress Estimation and comparison	Results Visualisation	Schedule Updating
Earthmoving operations	Excavator: Moving, scooping, rotating, dropping or stopping		✓		✓		✓	
	Dump truck: Moving / static							
	Loading time analysis of dump truck movements		✓					
	Tracking of onsite workers engaged in excavation work		✓		✓		✓	

Use	Stage	Initial Planning/ Scheduling	Data Acquisition	Information Retrieval	Verification	Progress Estimation and comparison	Results Visualisation	Schedule Updating
Crane operations	Loading concrete, moving to and returning from the work zone, unloading concrete and detaching the concrete bucket		✓		✓		✓	
	Moving the hook							
Formwork and rebar tracking	Detection of effective/ineffective work performed by the workmen				✓			
	Measuring, moving, preparing and resting					✓	✓	✓
	Fixing, placing, taking and transporting formwork							
	Connecting, fixing, placing, transporting and welding rebars							
Worker activity tracking	Laying bricks, transporting, cutting plates, drilling, tying rebars, nailing, plastering, shovelling, bolting, welding and sawing				✓			
	Tracking picking up, holding, walking, putting down, measuring and cutting, breaking of gypsum boards and idling		✓		✓			
	Normal climbing, backward-facing climbing, climbing while carrying an object and reaching to a side on the ladder		✓		✓			
Safety assurance	Identifying risky heights and edges at the sites		✓		✓		✓	
	Identifying workers wearing safety vests and other safety gear		✓		✓		✓	
	Ensuring environmental safety by detecting cracks in concrete and steel		✓		✓		✓	
Landscape identification	Identifying hills and valleys in a region		✓		✓			
General	Making crude measurements							
	Counting material, such as rebars							

Use		Initial Planning/ Scheduling	Data Acquisition	Information Retrieval	Verification	Progress Estimation and comparison	Results Visualisation	Schedule Updating
Work item monitoring	Monitoring construction of columns and walls		✓	✓	✓	✓	✓	✓
	Monitoring installation of services, HVAC and plumbing		✓	✓	✓	✓	✓	✓
	Monitoring prefabricated construction work	✓	✓	✓	✓	✓	✓	✓
	Monitoring, plastering, framing, insulating fit outs and refurbishment work	✓	✓	✓	✓	✓	✓	✓
Integration with other technologies	Conducting aesthetic work using AR systems						✓	
	Using as a tool to feed BIM systems in real time		✓		✓			
	Integrating with digital twin technology		✓		✓		✓	

CV is used mostly in data acquisition, verification and visualisation stages of CPM. In Table 4, the uses of CV endorsed by more than 70% (>= 5) of the respondents as being applicable to CPM are highlighted in green. The new uses of CV identified during Delphi Round 1 are highlighted in grey. According to I9, in a construction site, material counting can be done easily either manually or by using cheap technologies, such as RFID, and rough measurements can be made without using an advanced system. Thus, two uses of CV identified during Delphi Round 1, namely making crude measurements, and counting material, such as rebars had to be removed during the second round because a majority of the respondents did not endorse them.

According to I4, CV *can* be used in all stages of CPM in activities coming under the category of *work item monitoring*. I5 stated that CV-based CPM should be incorporated into a project during its initial stages, especially when CV has to be integrated with other technologies. I13 added that the use of *CV* during data acquisition, verification and results visualisation stages of CPM for activities such as crane operations, safety assurance and landscape identification could overcome many challenges and obstacles faced during construction. I10 opined that CV could be used in data acquisition, verification, and results visualisation stages of CPM than in any other stages of CPM.

The interviewees from the industry believed that all tasks associated with CPM, including worker and productivity-related activities, are performed in the sites; however, the interviewees representing the academia believed that the tasks involve the comparison of as-planned and as-built schedules.

4.3 DISCUSSION

Few past researchers, such as Ioannis Brilakis, Ahmadian Fard, Pena Mora and Johnny Wong, identified the uses of CV in construction projects to optimise and increase the efficiency of construction work monitoring and tracking. Because CPM is costly, time-consuming and error-prone, automation can be more efficient and productive than CPM (Yang, et al., 2015). Construction projects use a significant number of resources such as labour, equipment and materials, and the proper management of these resources would have a positive impact on onsite productivity, which requires constant monitoring (Bügler, et al., 2016). I4, endorsing the literature, stated that the use of CV in CPM can save many resources, including costs and time. Workers actively engaged in work, idling or resting, also could be monitored as a part of CPM (Luo, et al., 2018). However, I1 stated that items relating to workers and recording of their idling times do not come under CPM and that they are related to labour force productivity. I9 did not agree with I1 and endorsed what is reported in the literature by stating that although the monitoring of workers and recording their idling times cannot be considered a part of CPM, they are required to conduct CPM effectively. Thus, the monitoring of workers and recording their idling times are also crucial for CPM. Cost for the workers can also be reduced from 25% - 35% from the construction project costs, which makes it cost-efficient and CV can be applied to promote the reduction of idling of the workers (Luo, et al., 2018). Generally, construction sites can be highly risky because they are dynamic and difficult to access. The use of CV in CPM can also promote safety at construction sites. Because safety monitoring in a construction site is important, it can be automated by using CV and identifying the safety hazards through worker behaviour analysis (Fang, et al., 2020). Although I1 disagreed that monitoring of safety in a construction site is important, most of the other interviewees agreed that monitoring of safety could be useful for CPM. The interviewees introduced a few more uses of CV under *monitoring work items* and *integration with other categories*. Monitoring of individual work items, such as structural framework, walls, prefabricated modules and HVAC installation are directly associated with CPM. Most of the interviewees accepted that these uses of CV could be used in CPM as well.

5. CONCLUSIONS AND RECOMMENDATIONS

The aim of the study was achieved cumulatively via the literature review and two-round Delphi survey. Twenty uses of CV for CPM were identified and categorised into major activities such as earthmoving operations, worker activity tracking, safety assurance, work item monitoring and integration with other technologies. CV can be applied to track the activities of plants and machinery, such as cranes, excavators and dump trucks, to determine their efficiencies and impact on construction progress. Tracking of workers also can be done using CV, and the data obtained can be used in CPM. Worker productivity can be tracked by analysing the idling times of the workers and the number of effective man-hours required for a task. This data can help CPM by providing an overview of the worker standards and providing a reliable plan. CV significantly assists in monitoring the progress of work items, such as structural, brick/block and mechanical, electrical, and plumbing works. Another use of CV in CPM is its use as an automated tool by integrating it with BIM and AR technologies. Because the synergy between CPM and CV has been hardly discussed in the literature, facilitating research in the area can be helpful for the further development of CPM. Promoting methods to implement CV by integrating it with BIM will allow BIM to be further automated and reduce the extent of human intervention required and make CV popular among project management teams. CV can be integrated with virtual reality in various ways, such as VR/AR and mixed reality. Implementation of these technologies in construction will help solve many issues encountered in projects because it will enable the early identification of problems using simulations.

The aim of this study was to identify the applicability of CV in CPM. Thus, the study findings can be used as a reference when conducting further studies on determining the synergy between CV and CPM. The findings will encourage and promote construction automation. Because of the limited applicability of CV in the construction industry, the expert sample selected for the study had to be selected only from a few countries. Thus, the study findings cannot be generalised in the global context.

Moreover, there are several shortcomings in the effectiveness of using CV vision in the construction sector since the construction industry is infamous for being one of the least digitalised sectors. Furthermore, the unavailability of required technology and unavailability of human resources with sound knowledge in computational areas in construction would also become a barrier in implementing CV for construction PM. Although the application of CV for PM is possible in theory but there are several computational issues in practice that still need to be resolved. Thus, this study can be used as a benchmark for further studies on identifying the practicality of adopting CV for PM and how to overcome challenges and barriers in doing so.

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