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Automated Construction Progress Monitoring – Industry Perspective

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Abstract
The project schedule is an important control mechanism, yet the construction schedule monitoring practices are largely manual and document-centric. This leads to poor tracking of project progress, resulting in delays, cost overruns, bitter stakeholder relationships, schedule changes, and legislative proceedings to settle construction claims. Advancements in technology (such as Building Information Models, Cloud Computing, Sensors, Computer Vision, IoT, etc.) have shown the potential to automate construction progress monitoring (ACPM) with real-time data tracking and reporting for effective decision making in managing construction projects. However, applications of these technologies are largely experimental and have yet not been adopted in the construction industry. The objectives of this paper are to summarise the potential of available technologies for automated CPM (ACPM), examine the current industry needs, and present the industry perspective on adopting ACPM. This paper presents the findings of a survey that assessed the awareness of the construction industry (CI) professionals regarding the available technologies and techniques which enable and facilitate ACPM. The research limitations and future work directions are also discussed.

Keywords
Construction Progress, Progress Monitoring, Automation, Awareness, Construction Industry.

1. Introduction

Construction projects are complex and dynamic, and the process is considered one of the most complex undertakings in any industry. The associated complexity of construction projects depends on multiple factors i.e., uncertainty, involvement of technology, inherent complexity, the rigidity of sequence, overlapping activities, and concurrency among many others (Wood and Ashton, 2010). Generally, project success is associated with the successful completion of the project within its planned cost and time by achieving an acceptable level of project specifications (Bannerman, 2008). To ensure success and stay aware of the status of the project at any given time, construction project management teams conduct continuous worksite inspections throughout the lifecycle of the project; usually termed ‘construction progress monitoring’ or ‘construction progress tracking’ (Mantel and Meredith, 2009). Traditional CPM techniques depend on manual and subjective interactions, which lack accuracy and consume more time and human resources. Such an approach has been recognized as one of the major problems that cause project delays and cost overruns (Omar and Nehdi, 2016). For the past few years, many attempts have been made to automate the CPM process and have shown the potential for effective construction project control (Kopsida *et al.*, 2015). The literature has explored a plethora of technology-enabled techniques to automate the CPM process i.e., Global Positioning System (GPS), Radio Frequency Identification (RFID), sensors, and Computer Vision (CV) based techniques (Navon and Sacks, 2007). Moreover, the CI is adopting a highly integrated project management environment throughout the lifecycle of the project in a vision for the future of the fully automated construction industry (Omar and Nehdi, 2016).

The process of CPM can be divided into four distinct categories or sub-processes i.e., data acquisition, information retrieval, progress estimation, and output visualization (Kopsida *et al.*, 2015; Sami Ur Rehman and Tariq Shafiq, 2021). Data acquisition refers to the means of collecting the as-built information from the construction worksite throughout the lifecycle of the project. The information retrieval process can also be termed as the organization of the as-built data, which refers to the retrieval of useful information regarding ongoing work processes. This information can be in the form of percent completion of individual activities, incremental milestones associated with larger activities or work packages, start or finish dates, weighed or equivalent units, subjective observations on pace or quality from the members of the project management office (Hegazy, 2013). The process of progress estimation corresponds to the comparison of as-built vs as-planned information. As-planned information is usually in the form of a baseline schedule and the as-built information is compared to it periodically to access the current state of the project and forecast the ending concerning time and cost. This process can also be termed the analysis of the as-built data or information (Omar and Nehdi, 2016). Many contracts require a periodic submission of project status reports to all the stakeholders, after performing various analyses the output visualization marks the final process of the overall CPM process. These reports can be in the form of S-curves, double S-curves, updated schedules, tracking Gantt charts, or other formats of written or visual reports (Hegazy, 2013).

In this paper, the authors aimed at summarizing tools and techniques presented in the literature to automate the CPM process, getting the perspective of the construction industry over the adoption of available tools and techniques, and identifying opportunities and challenges. Firstly, all available techniques were summarized and categorized based on their usefulness throughout the process of CPM Secondly, the responses of the concerned industry representatives over current practices being followed in the CI for progress data recording, reporting, and analysis. Furthermore, this study presented the views of CI professionals on the need for ACPM to be integrated into traditional practices or replaced with advanced techniques for effective decision-making. Lastly, this study presented the level of awareness of CI practitioners regarding the available technologies and techniques that enable ACPM, discussed the results, presented a concise conclusion, and laid down future research directions.

2. Literature Review

The success of any construction project heavily relies on timely and accurate information regarding the progress of all the activities involved in the construction project (Omar and Nehdi, 2016). All the phases of a construction project comprise many complex activities and their continuous monitoring and management have always been difficult tasks for the construction industry (Pučko *et al.*, 2018). The accuracy of CPM relies on the experience and capabilities of the field personnel who collects the required information based on manual visual observations and traditional practices (Golparvar-Fard *et al.*, 2009). However, manual visual practices and traditional CPM practices are inefficient, error-prone, and time-consuming (Navon and Sacks, 2007).

Information Technology (IT) has dominated every sector of life and brought revolutionary changes to information processing (Deb, 2014). To address the challenges faced by construction progress monitoring and management, researchers have studied IT-based tools and provided various useful methods to gather and process the required information (El-Omari and Moselhi, 2009; Tsai, 2009). Various types of multimedia such as photographs, audio, and video recordings have been used by many researchers to create information management models and enable information visualization for the critical path method using cameras and audio recording devices (Abeid and Arditi, 2002; Abudayyeh, 1997). The email has been a very effective mode to collect data, keep a follow-up, and store the necessary information regarding construction progress by initiating communication to request periodic updates and generating full schedule reports with a visual representation on a bar chart (Ahsan *et al.*, 2009; Hegazy and Abdel-Monem, 2012).

Geospatial tools help project management teams to visualize, track, control, monitor, and manage various aspects of construction projects (Cheng and Chen, 2002). Barcoding has been in use for years due to its low cost and accuracy; can be scanned using various wireless bar code readers or handheld devices; such as mobile devices; which allows the construction teams to keep track of materials, labor, and project progress especially in prefabricated construction (Lin *et al.*, 2014; Navon and Sacks, 2007). Radio Frequency Identification (RFID) has the capability of capturing and transmitting data over bigger ranges; hence many research studies identified its potential benefits in safety management, material management, and progress measurement at various types of construction projects (Jiménez *et al.*, 2013; Li *et al.*, 2012). Geographic Information System (GIS) allows the construction management teams to integrate project-specific spatial and non-spatial data to collect, analyze and manage a large amount of data. In recent years, research focus has shifted toward the use of imaging technologies to collect, analyze, store and manage important information for construction management purposes. Most research studies focused on generating the 3D models or Point Cloud Models (PCM) from digital visual datasets. Photogrammetry is an accurate method to create 3D models using digital photos of construction sites taken through various modes e.g., smartphones, digital cameras, surveillance cameras, or Unmanned Aerial Vehicles (UAV). This technique is being used in estimating the quantities of work done, geometric measurement of various building elements, and for various surveying-related purposes (Ahmed *et al.*, 2012; El-Omari and Moselhi, 2008). Videogrammetry is also a very robust tool to generate as-built models more accurately. Studies have shown its effectiveness in safety management, damage detection, and progress monitoring (Brilakis *et al.*, 2010; Zhu and Brilakis, 2010). Photogrammetry and Videogrammetry are affordable, portable, and take less processing time than 3D laser scanning; however, 3D laser scanning is among the most accurate. However, initial research has focused on data collection through various techniques. No research study has successfully automated or integrated the complete scope of the CPM. A summary of available techniques and their capabilities is presented in Table 1.

Table 44. Summary of available techniques and their capabilities.

Sr. No.	Category	Technology	Data Acquisition	Information Retrieval	Progress Monitoring	Output Visualization
1	Enhanced IT	Email	✓			
		Voice Notes	✓			
		Multimedia	✓			
		Construction Software (CDE)	✓	✓	✓	✓
2	Geospatial Tools	Barcoding	✓	✓		
		RFID	✓	✓		
		Ultra-wide Band	✓	✓		
		GIS and GPS	✓	✓	✓	
3	Imaging Technologies	Photogrammetry	✓	✓	✓	✓
		Videogrammetry	✓	✓	✓	✓
		Laser Scanning	✓	✓	✓	✓
		Range Images	✓	✓	✓	✓
4	Reality Technologies	Augmented Reality	✓	✓	✓	✓
		Virtual Reality	✓	✓	✓	✓
		Mixed Reality	✓	✓	✓	✓
5	Artificial Intelligence & Machine Learning	Computer Vision	✓	✓	✓	✓

3. Methodology

A quantitative research methodology was adopted to fulfill the objectives of this research study. A survey-based research strategy was adopted using a web-based questionnaire as a data collection tool, also adopted by (Sami Ur Rehman *et al.*, 2020).

The questionnaire was designed to collect the responses of the CI practitioners regarding the existing practices for CPM and their awareness of the available techniques for ACPM. The survey questionnaire was divided into three (03) sections. The question types were multiple-choice questions with an allowance for selecting a single answer choice or checklist type one or more choices depending on the objective of the question. The first section of the questionnaire aimed at collecting the demographic information of CI practitioners including years of experience, type of organization, current position, department, and size of their organization. The second section aimed at exploring existing practices and problems associated with them. The third and final section listed all available techniques that enable all four sub-processes i.e., data acquisition, information retrieval, progress estimation, and output visualization; and ask for their awareness of these techniques in enabling sub-processes of the ACPM.

The questionnaire was developed using a cloud-based survey tool i.e., SurveyMonkey. The link to the survey questionnaire was circulated among personal industry connections and CI practitioners identified and shortlisted through the online professional platform LinkedIn. A total of 100 responses were received to date and were being considered for the analysis to report the findings through this research study.

4. Findings

4.1 Demographic Analysis

Most of the respondents belonged to the client organization representing 36% of the total respondents. The respondents belonged to general contractors and consultants comprising 25% and 20% respectively. A significant number i.e., 10%

of respondents belonged to academia as well. The rest of the respondents were associated with architect organizations, designers, sub-contractors, and personal businesses. For the current position of the respondents, 20% of the respondents were project engineers followed by project managers and planning engineers with a contribution of 14% and 10% respectively. The rest of the respondents held a wide array of job titles including but not limited to assistant project managers, construction managers, resident engineers, site engineers, CEOs, managing directors, executive engineers, etc. Furthermore, 49% of the respondents held the experience between 4 to 6 years followed by 26% and 13% of the respondents belonged to the 7 to 10 years and 0 to 3 years bracket respectively. Also, 7% of the respondents held more than 20 years of construction-related experience. For their current department within the organization, 24% belonged to the general management of construction projects followed by construction execution, planning and estimation, and consultancy with 21%, 17%, and 14% respectively. Lastly, 56% of the respondents belonged to large-scale organizations with more than 250 employees.

Overview of Existing Practices

This section explored the input of the CI practitioners on existing CPM practices in the industry. The inquiry started from the type of instrument or data collection tool being used in the industry i.e., verbal, paper-based forms/templates, photos/videos, emails, etc. Furthermore, their opinion was explored by asking whether they think that current practices are timely and comprehensive progress-related information. Later, they were asked to identify the problem associated with traditional CPM practices and provide their opinion if any. Lastly, they were asked whether they think that there is a need to automate the existing CPM process or not using a simple Yes/No type of question.

The prevailing progress-related data collection instrument or tool was reported as paper-based forms/templates. Over 86% of the respondents selected this option confirming the use of paper-based templates during the execution of the project to collect progress-related information from the construction site. A significant number of respondents also selected the use of photos and videos as a progress recording, reporting, and analysis tool and as evidence of the construction progress. Moreover, 36% and 33% of respondents also identified the use of emails and verbal communication as a tool for CPM respectively. Apart from these options, individual respondents also highlighted several other tools for CPM i.e., the progress measurement system (PMS), Whatsapp, ERP solutions like Procore and Plangrid, and letters. Figure 1 summarizes the responses associated with this question.

Fig. 51. Summary of responses associated with the type of CPM tool currently being used in the CI.

In response to the inquiry over the effectiveness of existing practices for providing timely and comprehensive progress-related information, over 64% of respondents chose Yes, and the rest selected No as an answer. This represented that in one way or the other traditional CPM practices seemed to be working for the CI in fulfilling their contractual requirements regarding project tracking and updating the client or consultant.

Although traditional CPM practices were enough to fulfill the requirements of the construction contracts, the respondents also identified several problems associated with traditional CPM practices. Over 66% of the respondents identified that traditional practice involved manual activities throughout the process. Furthermore, over 54% of the respondents labeled the current practice as a time-consuming activity and over 52% identified that the outcome of the traditional practice lacked accuracy and was not useful for effective decision-making. Moreover, the respondents highlighted several other problems as well i.e., the erroneous nature of the progress data, labor-intensiveness of the overall process, difficulty in analyzing and understanding the information, and the progress data being least meaningful. Figure 2 summarizes the responses associated with this question.

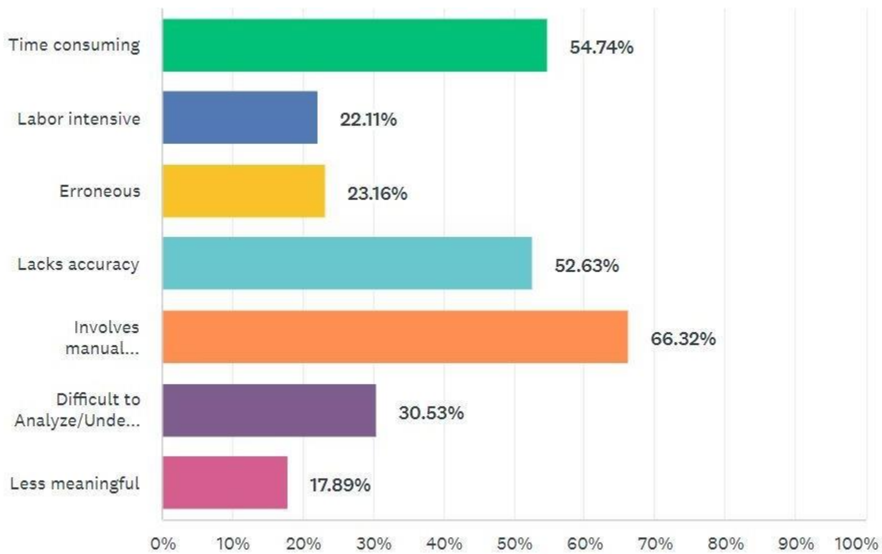

Fig. 2. Summary of responses associated with the problems with traditional CPM practices.

After giving their opinion on the problems associated with the traditional CPM practices, the CI practitioners were asked whether there is a need of automating the CPM process or not, and in response to this question, almost all of the respondents i.e, over 96% selected Yes as an answer. Figure 3 highlights the need for automating the CPM practices.

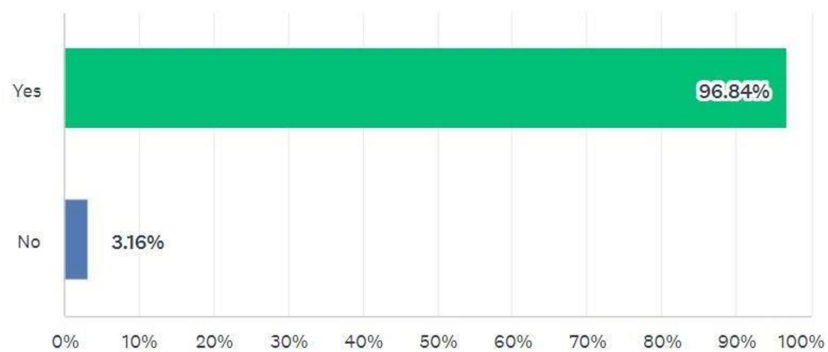

Fig. 3. Summary of responses associated with the need for automating the CPM practices.

4.3 Awareness Regarding Available Technologies and their Capabilities

This section summarized the responses received for section 3 of the survey questionnaire which aimed at assessing the awareness of CI practitioners regarding the available techniques that enable ACPM and their capabilities in enabling sub-processes of the ACPM process. The respondents were asked questions to gauge their awareness regarding the available techniques as identified by the literature across all sub-processes of the ACPM. An example of the questions in this section is as follows: "*Do you agree that the Computer Vision technique can perform 1) data acquisition (collection of as-built data) 2) information retrieval (extracting useful as-built information) 3) progress* *estimation (comparing as-built vs as-planned), 4) output visualization (generation of useful reports), 5) Not aware at all*." Figure 4 summarizes the responses regarding the awareness of available techniques

In response to the opinions about enhanced IT tools which comprise Construction Software, 43% of the respondents agreed that it can perform data acquisition from the work site via the inputs from site engineers or supervisors. Moreover, 41% agreed to its ability for retrieving useful information from the acquired data, 56% agreed that it can efficiently perform the comparison between as-built and as-planned, and 43% agreed that it can help in the visualization of progress information. Only 17% of the overall respondents showed their unawareness of this tool.

Fig. 4. Summary of responses associated with the awareness of available techniques.

The category of imaging technologies comprises photogrammetry, videogrammetry, range images, and laser scanning. Overall 42% of the respondents were aware of the capabilities of the photogrammetry technique to perform data acquisition, 34% to perform information retrieval, 30% to estimate progress by comparing as-built and as-planned and 43% to visualize the output effectively. Only 15% were unaware of this technique and its capabilities. Similarly, in the case of videogrammetry, 47%, 35%, 30% and 46% of the respondents were aware of its capability to perform data acquisition, information retrieval, progress estimation, and output visualization respectively. Moreover, 29% of the respondents were aware of the capability of range images to collect as-built data from the construction environment, 27% were aware of its capability to retrieve information, 22% of its capability to perform progress estimation and only 13% agreed to its capability to produce useful results for effective decision making during the execution phase of the project. However, 39% were unaware of the capabilities of range images to enable the ACPM process. Lastly, 37% of the respondents were aware of the capability of laser scanning to enable as-built data acquisition, 40%, 32%, and 22% of the respondents were aware of its capability for information retrieval, progress estimation, output visualization respectively. A significant number i.e., 29% of the respondents were unaware of the capabilities of laser scanning for progress monitoring.

In the category of reality technologies, 26%, 26% and 20% of the respondents were aware of the data acquisition capabilities of Augmented Reality (AR), Virtual Reality (VR), and Mixed Reality (MR) respectively. Similarly, 32%, 29%, and 21% were aware of the information retrieval capabilities of AR, VR, and MR. Moreover, regarding AR, VR, and MR, 33%, 31%, and 23% of the respondents were aware of their capabilities to enable progress estimation, and 38%, 39%, and 26% of their capabilities for output visualization respectively. However, a significant number of respondents were unaware of these technologies and their contributions to enabling the ACPM process.

CV lies under the category of Artificial Intelligence and Machine Learning. Overall 33% of the respondents were aware of its capabilities to effectively collect data from the construction environment regarding construction progress and only 30% agreed to their awareness regarding the capabilities of CV to retrieve progress-related information from acquired data in the form of point cloud models. Moreover, 32% and 31% of the respondents were aware of CV's capabilities to efficiently compare as-built and as-planned to estimate the progress of the construction project and extract useful reports to visualize the outcome of progress estimation to enable project management teams to use the information and take important decisions to keep the project on track and deliver the desired project deliverables within the planned time and cost targets. However, a significant number i.e., 35% were unaware of its capabilities to perform ACPM.

4. Conclusions

This research study aimed at summarizing the techniques which enable ACPM and their capabilities in enabling sub-processes of the ACPM process i.e., data acquisition, information retrieval, progress estimation, and output visualization. Moreover, it aimed at exploring the existing CPM practices being followed in the CI and associated problems. Lastly, assessing the awareness of CI practitioners regarding the techniques available to enable the ACPM process. A comprehensive review of the available literature revealed several techniques across five major categories i.e., Enhanced IT, Geospatial tools, Imaging technologies, Reality technologies, and Artificial Intelligence & Machine Learning. A web-based closed-ended questionnaire survey revealed that prevailing CPM practices in the CI were labor-intensive, erroneous, time-consuming, and involves manual activities. The feedback of the CI practitioners suggested that the industry requires the ACPM practices either to be integrated within existing practices or replace the traditional CPM practices. The results showed that the majority of the CI practitioners were not aware of the ACPM techniques identified through the literature review and also they were not aware of the capabilities of these techniques in enabling the overall ACPM process. This study highlighted the need for educating the CI practitioners regarding all the technological advancements in the field of construction innovation and involving them in the process of the research to be able to effectively design methods and techniques according to the requirements of the CI. The end-users of all ACPM technologies and techniques are CI practitioners only their awareness will lead to experimentation with such technologies and eventually their adoption by the CI.

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