International Journal on Recent and Innovation Trends in Computing and Communication
ISSN: 2321-8169 Volume: 10 Issue: 7
DOI: https://doi.org/10.17762/ijritcc.v10i7.5560
***Article Received**: 05 May 2022 **Revised**: 30 May 2022 **Accepted**: 20 June 2022 **Publication**: 31 July 2022*

Automated Construction Progress Monitoring of Prefabricated Concrete Structures using Building Information Modeling and Internet of Things

Ankit Katiyar
PhD Scholar: Department of Civil Engineering
Harcourt Butler Technical University
Kanpur, Uttar Pradesh, India
ankit.ktr13@gmail.com

Pradeep Kumar
Professor: Department of Civil Engineering
Harcourt Butler Technical University
Kanpur, Uttar Pradesh, India
pradeepkt64@gmail.com

Abstract— The construction industry in India is facing various issues pertaining to low productivity, inefficient management at construction sites, high construction safety risk and lack of information on the status of project. With the development of modern tools and technologies prefabricated construction is becoming more prevalent in the building industry. However, there are many limitations in the actual manufacturing process such as storage, quality checks, installation of the prefabricated components and its status which is due to the lack of real-time information collection and sharing. In order to speed up the construction process and better management and monitoring of the project, this research proposes the framework for integration of Internet of Things (IoT) and Building Information Modeling (BIM). The paper proposes a conceptual framework of an IoT enabled BIM platform to accomplish a real-time visualization in prefabricated concrete structures construction. This is done by using various sensors in the prefabricated components to demonstrate a highly efficient automated progress monitoring system of prefabricated construction.

Keywords- Building Information Modeling, Internet of Things, Prefabrication, Tilt Switch Sensors, Ultrasonic Sensors.

I. INTRODUCTION

According to the Project Management Body of Knowledge, a construction project's monitoring and controlling "consists of those processes required to track, review, and orchestrate the progress and performance of a project; identify any areas in which changes to the plan are required; and initiate the corresponding changes". The progress measurement process involves various inspections and comparing it with the plan to validate the progress that was predicted. The greatest challenge that a project manager has to encounter is progress monitoring as it is the main factor for completion of the project within the stipulated time and the allotted budget [1].

To ensure time and cost efficiency of the project, it is needed that precise information about the progress of the project should be available in a timely manner, but the major concerns that the construction companies are facing is collecting the site data efficiently, analysis of the data and communicate the interpreted data [2]. To mitigate disputes and claims, reworks and unpredicted costs from delays, it is important that inspections should be done on a regular basis so that managers can identify the problems at an early stage and prevent the delays in the tasks and take necessary preventive actions. Low quality control and insufficient management are the other factors that cause delay and hampers productivity [3].

The construction industry is still very far behind in adopting the new technologies and it does not have good monitoring systems [4]. In today's era, project control is very important, still the data for progress of construction projects is collected manually by visual inspections, filling forms on site, etc., which requires a lot of time, [5] and chances of mistakes in recording the data are high as the data that is collected depends upon the accuracy of measurements taken and on the experience of the inspector [6].

In recent times, monitoring of project progress has been automated by adopting Building Information Modeling (BIM).

International Journal on Recent and Innovation Trends in Computing and Communication
ISSN: 2321-8169 Volume: 10 Issue: 7
DOI: https://doi.org/10.17762/ijritcc.v10i7.5560
***Article Received**: 05 May 2022 **Revised**: 30 May 2022 **Accepted**: 20 June 2022 **Publication**: 31 July 2022*

BIM has shown potential for effective project control as it allows the usage of mobile devices in the inspection process instead of paper documents. Software packages such as Field 3D, Autodesk BIM 360 Field, LATISTA etc. are useful in regards to document management but the inspection process is still manual as the inspector has to visually inspect the building and update the BIM model manually.

In Facility Management, it is observed that a mobile based Augmented-Reality (AR) system is used rather than the paper based one for inspection of facilities as it is faster and simpler. Such AR system can also be used for progress monitoring but it will require installation of QR codes, barcodes etc. which is not feasible in the construction projects [7].

Other methods that are becoming prevalent in progress monitoring of construction projects are Global Positioning Systems (GPS), Laser Scanners, Barcodes, Audio and Video Technologies, Radio Frequency Identification (RFID) etc.,[4]. Skanska used an RFID system for pre cast components tracking. For outdoor construction, remote controlled cameras are being used for monitoring the construction projects remotely [8].

It can be assumed from the above literature that there is no practice that is being carried out for automated progress monitoring of the construction projects. Although there are methods and technologies that can aide in visualization of the project and can help in progress estimation, but none have been implemented yet. Such methods as developed and proposed by various authors are discussed in the literature in the next section and an innovative frame work is proposed which can become a benchmark in automated construction progress monitoring of prefabricated concrete structures.

To meet specific project goals, monitoring of project progress should be carried out periodically as it provides valuable information regarding the project. Such information is traditionally collected by recording the data manually on paper or by using handheld devices [9]. These methods require a lot of manpower and time and they may not be accurate, given the complexity of the project and the knowledge of the inspector.

In recent times, new and advanced technologies are emerging for recording as-built data from construction projects. The most popular amongst them are RFID, GPS, LiDAR and photogrammetry. However, the analysis and processing of data collected using GPS and RFID needs a considerable amount of human effort, [10] and these technologies also need regular maintenance and calibration thus making it a costly affair. Photogrammetry and LiDAR on the other hand proves to be a better alternative in automated progress monitoring in terms of saving cost and time [6].

A system consisting of a 3D BIM model combined with the schedule information to develop a 4D BIM model and combined with 3D laser scan point clouds for monitoring the progress automatically using the object recognition algorithm was developed by [11]. In this, each activity's progress rate is calculated by comparing the quantity of components likely to be completed in the stipulated time frame to the quantity of recognized components. Then the 4D BIM is updated with the information collected from the monitored progress. But the problem or drawback associated with this technique is that it necessitates the inspector to register the BIM and laser point clouds within the same co-ordinate systems. Also, the 3D model and the schedule have to be linked and updated manually which means that this method is not fully automated.

Golparvar-Fard et al., [6] developed a four-dimensional augmented reality model for construction progress monitoring. In this approach, the information was collected in the form of photographs by visiting the sites daily. To capture the whole building, various angles were used to take the photographs and Structure-from-Motion (SfM) technique was used to extract the geometric information from the photographs. The construction progress was calculated by comparing the schedule integrated in the 4D BIM and the as-built information obtained from the photographs.

Zhang and Arditi [12] developed a program based automated system that measures percentage of work completed by combining the developed 3D model and the collected point cloud data. They conducted the tests in the laboratory without taking the actual conditions at the construction site into consideration. Also, the specimens' geometry was very simple as opposed to the complexity of geometry in actual construction, but the major advantage of this technique was that this method of progress measurement and object identification was fully automated.

Another method for progress monitoring as given by [13] uses an iterative process. In this, the as-built status is regularly updated by comparing the BIM model and the scanned data. There is an assumption in this approach that the activities which are planned in the schedule should not deviate from their sequence.

Son et al., [10] developed a schedule updating system which automatically updates the schedules in Microsoft Project, thus making the life of project managers easier as they can make use of the updated schedule without any extra effort.

Omari and Moselhi [14] developed a project tracking system using photogrammetry, RFID and LiDAR. This approach calculated the volume of construction objects constructed and in turn calculates the percentage of the work completed.

Hammad and Motamedi [15] developed a framework for tracking and visualising the lifespan status of constructed facility components. This framework intends to build on earlier research into the use of RFID in facility building and maintenance while taking into account the organisational, procedural, technical, and cost-benefit concerns of establishing a system based on the framework. The tags stay with the building throughout its existence, and they are used for inspection and maintenance after it's built, as well as supply chain management. Colour coding and using the 3D model to aid tag management were among the concerns highlighted at the visualisation session. This research's main contribution is a description of the essential tasks for tracking facility components at various stages of their life cycle. The visualisation options for an HVAC system during the building and maintenance phases were demonstrated using a case study.

A method for photogrammetrically constructing point clouds for construction progress monitoring, as well as a mechanism for comparing as-planned and as-built results focusing only on geometry was developed by [16]. A real-life situation is used to examine this. The utilisation of additional information provided by the BIM as well as related process data to improve these results is also explored. To establish the present state, images from a calibrated camera are used to create a dense point cloud. The scale is determined by control points, which demands manual involvement during orientation. The component verification evaluation measure correctly recognises manufactured parts, but it misses a larger percentage of them because of occlusion, noisy points, or insufficient input data. As a result, this geometrical analysis must contain additional information and visibility constraints.

The study which focuses on the issue of information bottlenecks in the information-loop during the construction phase of a structure was done by [17]. Many authors have noted the difficulties in obtaining timely data to support the decisions needed to improve project performance. The TRIMO construction company, with whom the authors collaborated to develop a standardised system for outstanding construction project management, approved their decision to concentrate on activity monitoring. Based on the industry's needs and IT capabilities, they chose a combination of mobile computing, computer vision and material identification. They've upgraded the functional components and integrated them into an activity monitoring system that runs automatically. Although the system assists project and site managers in detecting project failures related to construction activity execution early on, there is still room for improvement.

Using satellite remote sensing technology, an automated approach for assessing progress on large-scale linear projects was proposed by [18]. The authors developed a prototype model using multi-temporal satellite pictures to demonstrate the practicality of the established framework in a minor portion of an elevated railway project. The inclusion of location-based progress reporting improves the framework and allows for more effective visualisation. A web-based interface with a top-view progress graphic and line-of-balance charts, also known as objective and progress charts, was built to display progress reports. Using line of balance charts and a map-view visual, the system proves to be a useful tool for notifying project top management about overall project progress.

II. PROPOSED FRAMEWORK FOR PROGRESS TRACKING

As per the above literature it is quite evident that RFID, GPS, Remote Sensing and LiDAR have been used in the work done on automated progress tracking. This research presents a system for progress monitoring that makes use of the Internet of Things and BIM. Ultrasonic sensors and tilt switch sensors, in conjunction with the usage of Building Information modeling are used to determine the status of the precast components and thereby tracking the project's progress. The proposed framework is depicted in Fig. 1.

A 3-D BIM model of the project will be created in Autodesk Revit, and data from all components present in the model will be extracted using Dynamo script into an excel sheet. Dynamo is an open source visual programming language for Revit. The installation status of each component will be entered into the comment section of the properties dialog of Autodesk Revit for each component which will be "Not Installed" by default for each component. The data extracted into the excel sheet will also contain a column for the installation status of the component.

At the construction site, a device containing an ultrasonic sensor along with the tilt switch sensor linked to a microcontroller will be installed on each component. Ultrasonic sensor will be used to measure the height from the ground surface and the tilt switch sensor will be used to check the orientation of the component. The programming for the sensors will be done using Arduino IDE. As the framework is focused on prefabricated buildings, the height of each component to be installed will be predetermined. The ultrasonic sensor will collect the height data and the tilt switch sensor will show if the component is vertical or not. All these data will be transferred to ThingSpeak website, which is an open-source platform for Internet of things visualization with the help of Wi-fi enabled microcontroller.

The height and the orientation data from the ultrasonic and tilt switch sensors respectively will be extracted from the ThingSpeak servers using the code written in javascript. The code will be written in such a manner that it takes the average of last 20 readings recorded by ultrasonic sensor and it records last 20 readings of the tilt switch sensor. If the average of the 20 readings recorded by the ultrasonic sensor falls within the range of 5% of the predetermined height and all the 20 readings of the tilt switch sensor shows that the component is vertical then the installation status of that component will be changed from "Not Installed" to "Installed" in the excel sheet. The dynamo script will then be executed once more, and the component's installation status will be automatically updated in the model.

International Journal on Recent and Innovation Trends in Computing and Communication
ISSN: 2321-8169 Volume: 10 Issue: 7
DOI: https://doi.org/10.17762/ijritcc.v10i7.5560
***Article Received**: 05 May 2022 **Revised**: 30 May 2022 **Accepted**: 20 June 2022 **Publication**: 31 July 2022*

In addition, the color of the component will change according to its installation status i.e., the component color in the model will be grey if that component is not installed and it will change to green as soon as the component gets installed.

As a result, progress of the project can be easily and flawlessly tracked simply by opening the BIM model and making a few easy clicks without having to visit the project site.

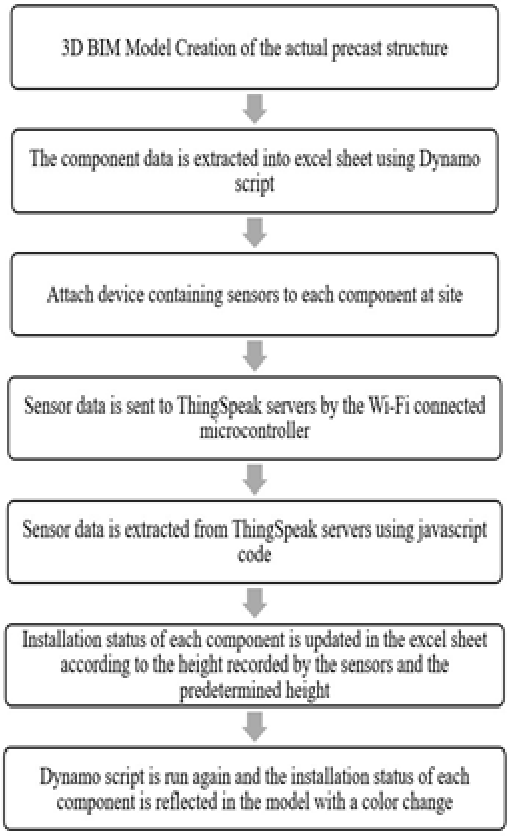

Figure 1. Flowchart of framework for Automated Progress Tracking

III. CONCLUSIONS AND FUTURE WORK

This study showcases numerous strategies and procedures that have been established or proposed by various researchers in order to assess project progress. IoT and BIM have been explored in many studies, and their results show that there are no studies that directly uses IoT and BIM for monitoring the progress of precast concrete constructions. This research is aimed at automated progress monitoring of Prefabricated Concrete Structures using BIM and IoT. The proposed method uses a simple assembly of tilt switch and ultrasonic sensor for monitoring the installation status of the component and updates the status automatically in the Revit model thus eliminating the need of manual updating and the errors associated with it. Also, the progress of a project can be visualized directly on a computer screen without physically visiting the construction site. Based on the suggested conceptual model, it is believed that the proposed model can be used successfully to track prefabricated construction. Also, as the whole process is automated, the need for manual entry of the project progress will be eliminated, which in turn will result into less human errors in progress reporting and the project manager can track the progress of various projects without actually visiting the project site, just by opening the Revit model and making few clicks.

Future research will be done to use the suggested framework in a prefabricated construction project in the real world and validate it with the generated BIM model, the sensors that were installed, and the readings collected by the sensors. It is anticipated that one of the obstacles that will be faced will be a correct positioning of the sensor on the component and any obstructions which would hinder it in measuring the height from the ground surface.

REFERENCES

[1] K. C. Iyer and K. N. Jha, “Factors affecting cost performance: Evidence from Indian construction projects,” *International Journal of Project Management*, vol. 23, no. 4, pp. 283–295, May 2005, doi: 10.1016/j.ijproman.2004.10.003.

[2] Vanitha, D. D. . (2022). Comparative Analysis of Power switches MOFET and IGBT Used in Power Applications. International Journal on Recent Technologies in Mechanical and Electrical Engineering, 9(5), 01–09. https://doi.org/10.17762/ijrmee.v9i5.368

[3] K. S. Saidi, A. M. Lytle, and W. C. Stone, “Report of the NIST Workshop on Data Exchange Standards at the Construction Job Site,” in *20th ISARC, Eindhoven, Holland*, Sep. 2003, pp. 617–622. doi: 10.22260/ISARC2003/0095.

[4] R. Maalek and F. Sadeghpour, “Reliability assessment of ultra-wide band for indoor tracking of static resources on construction sites,” *Proceedings, Annual Conference - Canadian Society for Civil Engineering*, vol. 1, pp. 675–684, Jan. 2012.

[5] R. Navon and R. Sacks, “Assessing research issues in Automated Project Performance Control (APPC),” *Automation in Construction*, vol. 16, no. 4, pp. 474–484, Jul. 2007, doi: 10.1016/j.autcon.2006.08.001.

[6] E. K. Zavadskas, T. Vilutienė, Z. Turskis, and J. Šaparauskas, “Multi-criteria analysis of Projects’ performance in construction,” *Archives of Civil and Mechanical Engineering*, vol. 14, no. 1, pp. 114–121, Jan. 2014, doi: 10.1016/j.acme.2013.07.006.

[7] M. Golparvar-Fard, F. Peña-Mora, and S. Savarese, “Monitoring of Construction Performance Using Daily Progress Photograph Logs and 4D As-Planned Models,” in *International Workshop on Computing in Civil Engineering (2009)*, Jun. 2009, pp. 53–63. doi: 10.1061/41052(346)6.

[8] M. Gheisari, G. Williams, B. N. Walker, and J. Irizarry, “Locating Building Components in a Facility Using Augmented Reality vs. Paper-Based Methods: A User-Centered Experimental Comparison,” in *Computing in Civil and Building Engineering (2014)*, Jun. 2014, pp. 850–857. doi: 10.1061/9780784413616.106.

International Journal on Recent and Innovation Trends in Computing and Communication
ISSN: 2321-8169 Volume: 10 Issue: 7
DOI: https://doi.org/10.17762/ijritcc.v10i7.5560
***Article Received**: 05 May 2022 **Revised**: 30 May 2022 **Accepted**: 20 June 2022 **Publication**: 31 July 2022*

[9] T. Sawyer, "Modeling Supply Chains," *ENR*, vol. 260, no. 14. McGraw-Hill, Incorporated, pp. 24–27, 2008.

[10] S. Cox, J. Perdomo, and W. Thabet, "Conference Proceedings-distributing knowledge in building International Council for Research and Innovation in Building and Construction CIB w78 conference 2002 Aarhus School of Architecture, 12-14 Construction Field Data Inspection Using Pocket PC Technology," 2002. [Online]. Available: http://itc.scix.net/

[11] H. Son, C. Kim, and Y. Kwon Cho, "Automated Schedule Updates Using As-Built Data and a 4D Building Information Model," *Journal of Management in Engineering*, vol. 33, no. 4, p. 04017012, Jul. 2017, doi: 10.1061/(asce)me.1943-5479.0000528.

[12] Y. Turkan, F. Bosche, C. T. Haas, and R. Haas, "Automated progress tracking using 4D schedule and 3D sensing technologies," *Automation in Construction*, vol. 22, pp. 414–421, Mar. 2012, doi: 10.1016/j.autcon.2011.10.003.

[13] C. Zhang and D. Arditi, "Automated progress control using laser scanning technology," *Automation in Construction*, vol. 36, pp. 108–116, 2013, doi: 10.1016/j.autcon.2013.08.012.

[14] C. Kim, C. Kim, and H. Son, "Automated construction progress measurement using a 4D building information model and 3D data," *Automation in Construction*, vol. 31, pp. 75–82, 2013, doi: 10.1016/j.autcon.2012.11.041.

[15] S. El-Omari and O. Moselhi, "Data acquisition from construction sites for tracking purposes," *Engineering, Construction and Architectural Management*, vol. 16, no. 5, pp. 490–503, Sep. 2009, doi: 10.1108/09699980910988384.

[16] A. Hammad and A. Motamedi, "Framework for lifecycle status tracking and visualization of constructed facility components," in *7th International Conference on Construction Applications of Virtual Reality*, Jan. 2007, pp. 22–23.

[17] A. Braun, S. Tuttas, A. Borrmann, and U. Stilla, "A concept for automated construction progress monitoring using BIM-based geometric constraints and photogrammetric point clouds," *Journal of Information Technology in Construction*, vol. 20, pp. 68–79, Jan. 2015.

[18] D. Rebolj, N. Č. Babič, A. Magdič, P. Podbreznik, and M. Pšunder, "Automated construction activity monitoring system," *Advanced Engineering Informatics*, vol. 22, no. 4, pp. 493–503, Oct. 2008, doi: 10.1016/j.aei.2008.06.002.

[19] A. Behnam, D. C. Wickramasinghe, M. A. A. Ghaffar, T. T. Vu, Y. H. Tang, and H. B. M. Isa, "Automated progress monitoring system for linear infrastructure projects using satellite remote sensing," *Automation in Construction*, vol. 68, pp. 114–127, Aug. 2016, doi: 10.1016/j.autcon.2016.05.002.

[20] E. T. Nekerow, D. Yakob, and D. Teshome, "Data mining based medical intelligent system for chronic kidney disease diagnosis and treatment in the Oromo language", Int J Intell Syst Appl Eng, vol. 10, no. 2, pp. 232–241, May 2022.