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REAL TIME CONSTRUCTION PROGRESS MONITORING OF PREFABRICATED STRUCTURES USING BUILDING INFORMATION MODELING AND INTERNET OF THINGS

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Abstract— **Low productivity, ineffective management on building sites, a high risk of construction accidents, and a lack of information about project status are all issues confronting India's construction business. With the advancement of current techniques and technology, prefabricated construction is becoming increasingly popular in the construction industry. In the current COVID-19 scenario, there are a number of limitations to tracking the progress of the prefabrication building project due to a lack of real-time data collection and exchange. Today's construction firms are always on the lookout for cutting-edge technology that will allow them to meet their objectives at the lowest feasible cost while ensuring maximum worker and public safety. The Internet of Things (IoT) is the most recent technology to be implemented in the construction business. It is making it feasible for construction companies to focus more on the benefits of the internet in their projects in order to enhance procedures, minimise waste, and optimise the use of resources. Building Information Modeling (BIM) and IoT is used in this study to provide an innovative approach for monitoring prefabricated construction project progress. Ultrasonic sensors are used to determine the installation status of various project components, such as walls, columns, beams, etc. The status is then input by the site supervisor into an excel sheet generated by Dynamo, a visual programming language for Revit, and modifications made to the installation status of the component are reflected back into the Revit model, leading to fewer human errors. Prefabricated projects' monitoring will be revolutionised by this strategy, which will save time and ultimately lead to increased output.**

Keywords—**Building Information Modeling, Dynamo, Internet of Things, Prefabrication, Progress Monitoring.**

I. INTRODUCTION

In the field of Civil Engineering, no one can predict the future. Engineers are always looking for ways to streamline their processes and save time. Achieving faster and more accurate results while reducing time is critical. To get the intended result, there are a variety of methods that can be employed. Civil engineers' work has been attempted to be automated by a number of construction companies over the years. Switching to AutoCAD and BIM has made a huge difference for the businesses.

Project execution, which is broken down into several stages, demands a wide range of services and a huge number of personnel, making the construction business exceedingly complex by design[1].

Construction and infrastructure projects are typically difficult to communicate and coordinate due to their high level of complexity and lack of standardisation in the way they are carried out. Because construction projects are constantly changing, standard industrial monitoring solutions are not suited to them.

Construction project organisations are generally constituted as haphazard groupings that do not last beyond the term of the project, making data exchange and distribution more challenging[2].

While manufacturing and service businesses function on a more mobile basis, the construction industry operates in a stationary location with teams who work together for long periods of time and create working associations that allow for smooth information flow across levels of management. With the use of temporary crews, construction projects can be completed in a relatively short period of time. Communication and human interaction add to the difficulty of construction project management, making it even more challenging. Improper data collecting procedures in construction information management include manual and repetitive data collection as well as complicated reports [3].

Many construction projects are delayed, go over budget, and eventually fall short of their goals because of ineffective information management[4]. Construction site data can be used to track progress, budget, and overall quality, so a smooth exchange of data is essential for the proper operation of a construction management system [5].

To keep track of building projects, progress data is routinely employed to do so. Variations and delays that may have occurred are accounted for in this report. Progress monitoring is the most difficult task a project manager must undertake because of the numerous interdependencies among the various operations[6]. The timely collection of site progress data, its interpretation, and efficient communication are all critical components of a project's success and, as a result, are a major source of concern for construction enterprises[7]. A progress monitoring measurement system should be quantifiable, intelligible, acceptable for decision-making, rapid, consistent, cost-effective, and verifiable in order to be considered successful [8].

To obtain information on the progress of building projects, inspectors have typically used manual or visual inspections, which is inefficient and liable to error. Visual inspections are also infrequent and inconsistent, resulting in a great deal of documentation. The site's personnel lack the necessary experience and knowledge to keep accurate data on the site. According to a study, site supervisors don't seem to care about how a single delay in a vital activity affects the project as a whole[9]. It is a difficult problem for project managers and construction site personnel to deal with when it comes to obtaining accurate and timely information on the status of a construction project[10].

Because of the distance between the site and the office, the information is delivered later than expected. The project manager's ability to monitor schedule, cost, and key performance indicators (KPIs) is limited by the fact that operations are often measured in days, whereas the supervision teams submit progress updates on a weekly or monthly basis. It makes it more difficult for the project manager to deal with the inherent unpredictability that exists in building projects[11]. It is critical for project managers to have a dependable system that provides them with timely and detailed information so that they can make quick and efficient decisions while on the job [12].

The required data from the construction projects is not collected at a frequency that enables for the timely implementation of corrective actions. The fact that construction projects are regularly delayed and overbudget should not come as a surprise as a result. There has been a delay in identifying the challenges that are hindering progress, in particularly due to the absence of sufficient paperwork and records, which has been a contributing factor to this. A direct relationship exists between the amount of money spent on mitigation and the amount of time it takes to find a deviation from the schedule and put countermeasures in place on the ground. As a result, real-time information will enable the execution of appropriate countermeasures, which will reduce the amount of money wasted as a result of delays, reworks, claims, and disputes[13].

This rapid development and reliance on smart technologies is due to the proliferation of technical applications, internet technology, and the extraordinarily high rate of modernization in computer equipment that has occurred in recent years. Following the adoption of mobile computing, there has been a paradigm shift away from pervasive computing and toward smart technologies with smart sensors. Mobile computing makes it possible to stay connected from any location at any time. This interesting technology enables users to connect without the usage of cables from any location and at any time of their choice.

Pervasive computing, according to the definition, is "the physical world that is richly and invisibly interlaced with sensors, actuators, displays, and computational elements, integrated seamlessly in the basic items of our lives, and connected through a continuous network"[14]. When we talk about "pervasive computing," we're not just talking about computers, tablets, and smartphones; we're talking about all the things we use on a daily basis. Connection on any device comprises the concept of having chips put in anything from clothing to equipment and appliances, and even inside the human body.

When it comes to the "future construction site," it's debatable how far away it might be, especially considering that the construction industry hasn't always been at the forefront of technological adoption when compared to other industries[15]. The adoption of technology in the construction industry faces the same hurdles as any other firm, such as altering people's mentality to adopt technology, but the industry's unique functioning presents special challenges for fully integrating technology [16].

Although there are ongoing discussions over how far technology should be permitted to permeate human life, current technological breakthroughs indicate that individuals are heading in the direction of connecting gadgets to an infinite network of other equipment, hence allowing the IoT [17].

Construction-related technologies must take into account a variety of factors such as shifting project conditions, multi-level organisational structures, the shifting locations of construction staff, and widely dispersed construction activities. When talking about these issues, ubiquitous applications that are context-aware are significant. For example, giving the appropriate information to the right person at the right time and location is important [18&19].

II. LITERATURE REVIEW

Some of the studies that have been carried out by different researchers in adopting the IoT technology in the construction world is presented in this section.

The ability of wireless LAN, indoor GPS, and ultra wideband to pinpoint a user's location inside a building was tested by [20]. The suggested indoor GPS system makes use of Infrared (IR) light and lasers. The accuracy of each system was evaluated, as were the logistical issues, the technological criteria, and the prices. As a result of their research, the authors came to the conclusion that while making technological decisions, it is important to take into account not just the current legal environment, but also practical concerns such as availability and the accompanying implementation costs. The testing for this study was done in a lab setting under strict supervision.

In order to track construction workers using automated data collection technologies, a conceptual model was developed by [21] that they then utilised to evaluate a sample labour control model linked to a project model.

In recent years, the notion of labour monitoring has been expanded to include productivity tracking. A system suggested by [22] analyses workers' performance automatically, task by task. Using a combination of thoracic posture data and real-time location sensors, the system analyses worker behaviour by recording idle and travel time in a variety of locations, including the storage area, rest area, and work area.

By [23], a GPS-based system for tracking labour consumption was developed. To assess if a worker is working outside of a defined site zone, their technique examines location data. Hydraulic power projects have successfully incorporated the use of this method.

An image processing technique by [24] is used to analyse the parameters without the requirement for additional hardware, unlike earlier specialised measuring approaches. Despite the fact that the app is a commercial product, there is no information on the app's construction testing.

Prefabricated components were tracked in Hong Kong using RFID tags [25]. Components can be tracked from casting yard to construction site using this method before being incorporated into a new building. Furthermore, this approach is believed to eliminate installation problems and guarantee quality.

Real-time video footage captured by drones was used to assess building progress [26]. A few construction sites put the technology to the test to see how well it worked. There was no discussion of the technology's adoption or privacy concerns.

An image-processing-based method for keeping tabs on construction progress was developed by [27]. As-built and planned models were compared utilising photos taken on-site to build a 3D "as constructed" model that may be used for comparison. The as-built model is put on top of the as-planned model to show progress in the construction process. Using the D4AR modelling platform, progress is shown in green for elements that have been altered, and red for those that have not.

Non-automated visualisation options for construction progress monitoring were studied by [13]. It was done by comparing images of the "as-planned" and "as-built" versions of the same building.

A 3D BIM was used by [28] to compare and visualise as-built photographs of the building project to an as-planned 3D BIM. There were both planned and built buildings in this study, however the as-built photographs were manually collected.

For the purpose of eliminating construction site delays, [29] developed a system that is based on real-time sensor monitoring. Following a detailed examination of 30 different building industries, the researchers were able to identify the major cause of the delays. The sensors are examined on a regular basis, and if there is a problem, the site manager is notified instantly.

Reinforced Concrete (RC) constructions may be monitored and assessed by embedding sensors into the concrete and analysing the data to get the most up-to-date information about the structure's condition. A framework for this purpose was conceptualised by [30]. It was shown that sensors are preferable to standard techniques of durability assessment for RC structures because they allow continuous monitoring of the structure without disruptive sample and laboratory testing. Material scientists can use the sensor data to produce a concrete mix that is resistant to deterioration.

Kanan et al. [31] proposed a novel approach to prevent construction site accidents. An autonomous system that informs workers when they are in danger zones is developed with the help of a wearable device. Device activates and informs worker when it is in close approach to sensor that is situated in vehicle's back.

The idea of merging IoT and BIM was first proposed by [32]. Their concept was demonstrated through two case studies. In the first case study, they tracked the position of the workers and environmental parameters such as the brightness level at the workstations, the time spent in varied temperatures, and so on. To see the sensor data in real time in Autodesk Revit, the authors wrote a Dynamo script. In the end, they came to the conclusion that their concept had thepotential to be used in facility management and building processes.

As a real-time proximity warning device for construction sites, [33] utilised Radio Frequency technology for worker safety. They came to the conclusion that their technology is useful for detecting the presence of heavy construction equipment and that if anything is detected, the system warns the operators and workers about the potentially hazardous proximity issue.

The research community has recently concentrated on automated progress monitoring, and a number of studies have been conducted on progress monitoring by comparing as-built and as-planned data in order to improve efficiency. It is thegoal of this research is to investigate the capabilities of Dynamo and Revit, as well as the usage of ultrasonic sensors, to determine the status of individual components in a prefabricated construction. In this study, the purpose is to demonstrate how Dynamo can be utilized and how much potential it possesses. The ability to work with BIM models in Dynamo can be a very beneficial tool. It has already been said that building construction businesses are continually striving to develop innovative goods and ways of thinking. This article explains how the visual programming capabilities of Dynamo for Revit can open up new possibilities for effective construction progress tracking.

III. METHODOLOGY

In order to avoid project delays and overruns, timely data collection is critical, as we've seen in the discussion above. Using BIM with Dynamo, the project manager may monitorthe development of each placed prefabricated component on the computer screen without actually visiting the project site, eliminating the need for paperwork.

The proposed method comprises of several stages. The first stage is the 3-D modeling stage which will be accomplished by using AutoDesk REVIT. The second stage will be the component data extraction stage into an excel sheet using Dynamo. The third stage is the sensor device installation stage onto different prefabricated components at site. The fourth stage is the data transmission and storage stage using the Wi-Fi enabled microcontroller and Thing Speak web servers. In the fifth stage, the data is extracted by the supervisor from the Thing Speak website and it is updated in the excel sheet. The sixth stage will be updating the Revit model with the installation status of each component using the updated excel sheet and Dynamo script. The details of each stage are explained in this section. The proposed framework is shown in the Fig. 1

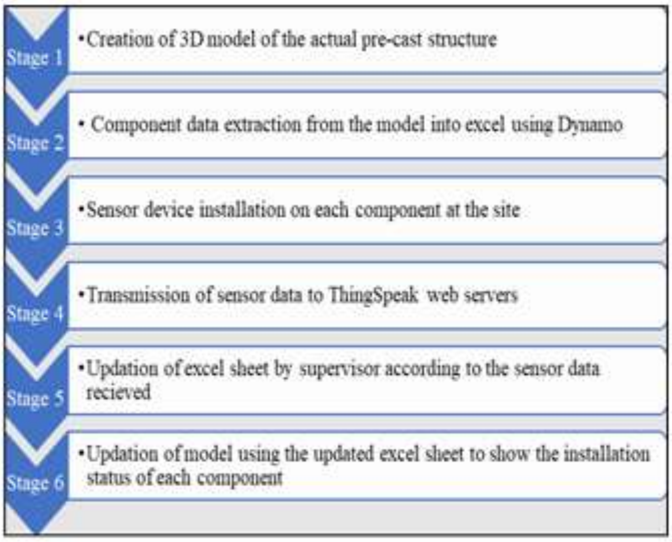

Fig. 1 Flowchart depicting the proposed framework

In the first stage a 3D model of the entire building will be created in Auto Desk REVIT. By default, each component inthe model has its "Mark" section set to "Invalid Height-Component Not Installed," therefore the installation status of each component will be specified in this section of the Autodesk Revit properties dialogue. This area of the properties menu will also display each component's name in the "Comments" section as seen in Fig. 2.

Secondly, a Dynamo script will generate an Excel spreadsheet that contains all the data from the model's various components. The programming language used by Dynamo is a hybrid of nodes and conventional scripting language. Any changes in Revit are automatically reflected in Dynamo, and vice versa, as the two softwares are linked. Using Dynamo, all of Revit's elements may be read and used. Each node serves a specific purpose and has a unique programming code. User-defined nodes can be anything from strings to numbers to input/output ports to other nodes. When a node is changed, so are its associated nodes. Each output can be connected to multiple inputs, and each input can be connected to several outputs, depending on the node's capabilities.

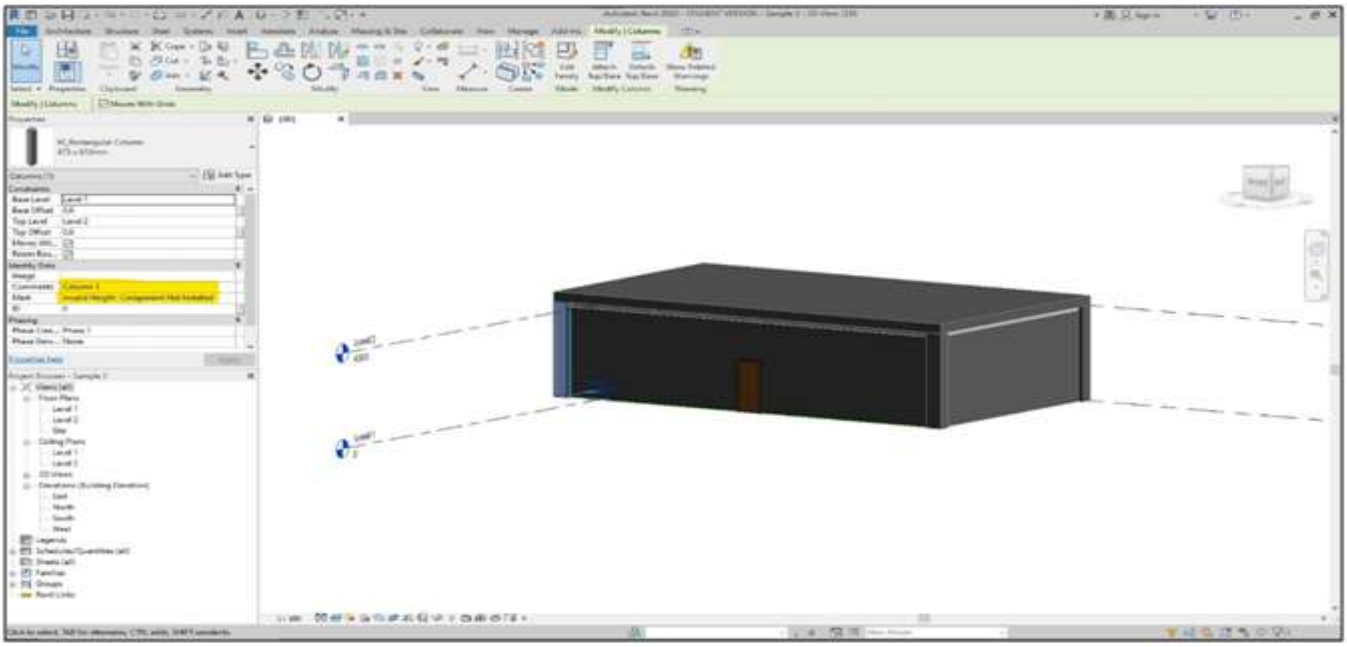

Fig. 2 3D model in REVIT along with Component name and Installation Status

In the third stage, a device with an ultrasonic sensor and a microcontroller as illustrated in Fig. 3 is mounted to each component at a fixed location. To keep the device running, a battery will be used. Sound waves are used to determine the distance between an object and the Ultrasonic sensor. It consists of a transmitter and a receiver as its two primary components. As soon as a barrier is encountered, the receiver section gets an echo and converts this acquired sound wave into electrical energy, which aids in calculating the distance between the sensor and the obstruction. Arduino IDE will be used to write the code for the ultrasonic sensor.

Fig. 3 Device containing Ultrasonic Sensor

For prefabricated construction, each component's height from ground level will be predetermined. The ultrasonic sensor will detect the distance between the device and the ground surface, and the Wi-Fi-enabled microcontroller will transmit the data to the Thing Speak website in stage 4. Visualization of the internet of things can be done using Thing Speak, which is an open-source platform.

As illustrated in Fig. 4, an excel sheet will be generated and saved in Google Drive, and the file will be shared with the site supervisor in the fifth stage. Ultrasonic sensor devices will be attached to each component, and the data collected by these devices will be saved on the Thing Speak web server. The supervisor can see the distance data recorded from each device and assume that each component has been installed if they match up with their predetermined height. The installation status of each component can be changed based on this assumption from “Invalid Height- Component Not Installed” to “Valid Height- Component Installed” in the google sheet as seen in Fig. 5

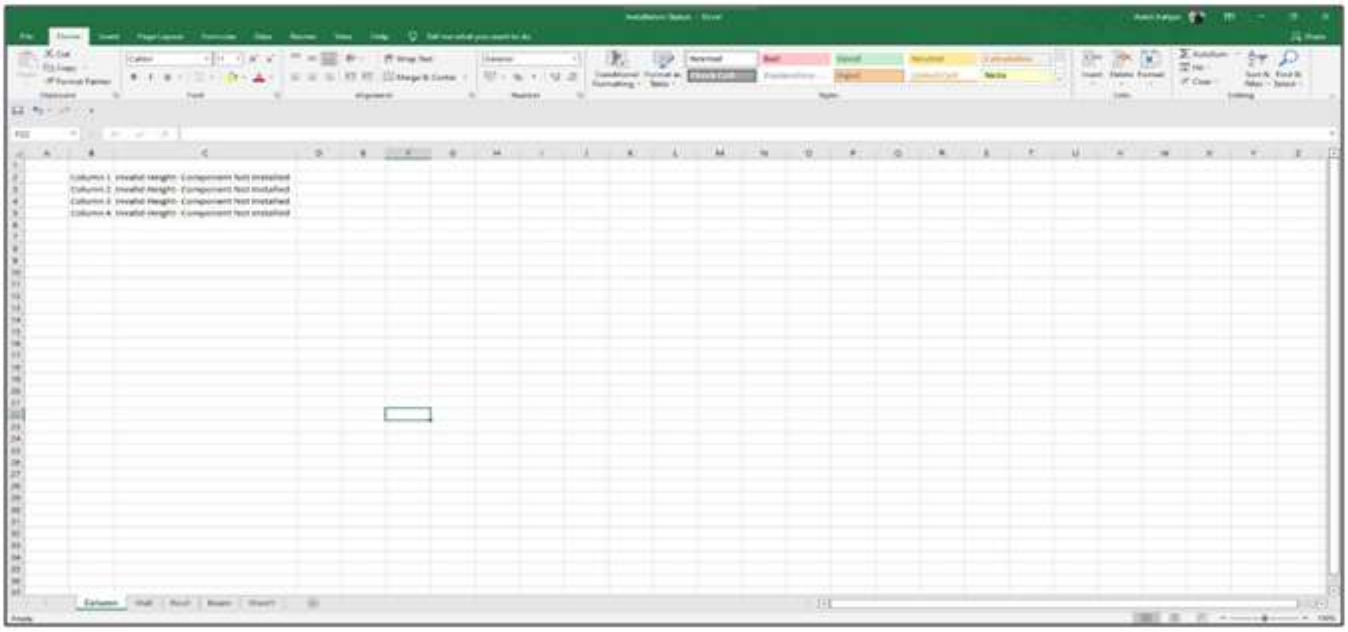

Fig. 4 Generated excel sheet containing all the components in the model along with their installation status

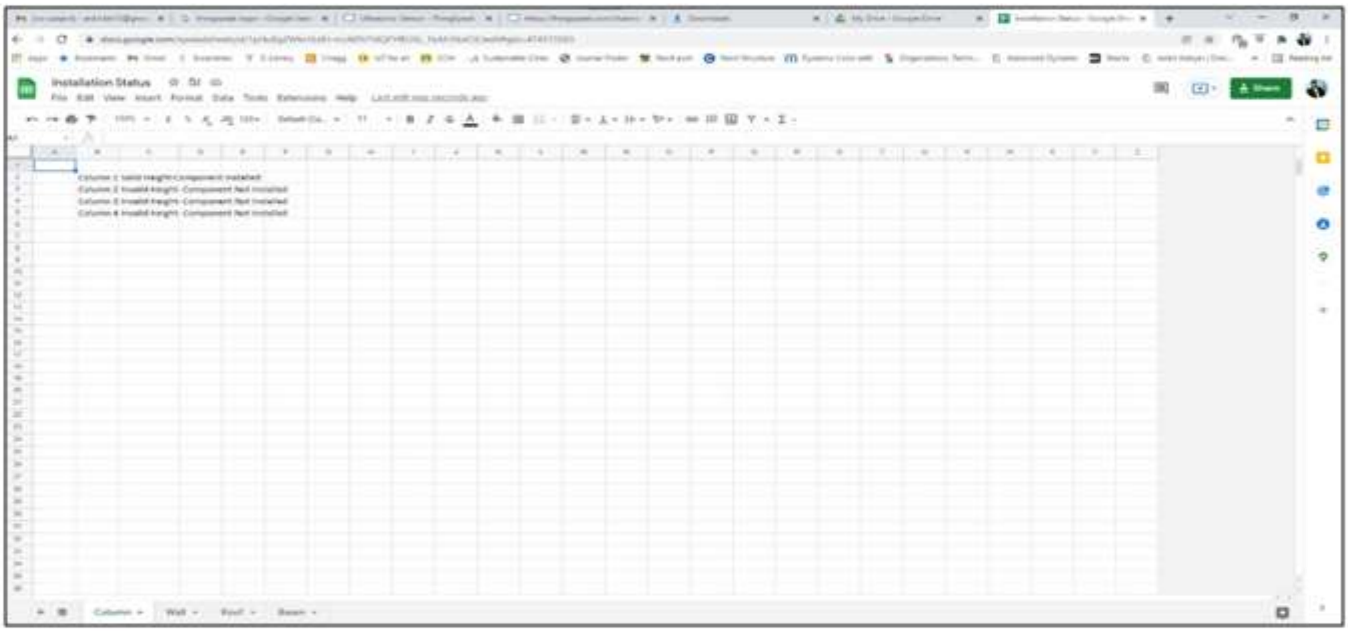

Fig. 5 Changes made by the supervisor in the google sheet according to the installation status of each component

In stage 6, a dynamo script will be run to read the data from the excel sheet that the supervisor has modified, and then, as shown in Fig. 6, the installation status of the components will be changed in the 'mark' section of the properties dialogue of the specific component in the Revit model, thus enabling the project manager to see the real-time progress of the project on the computer screen.

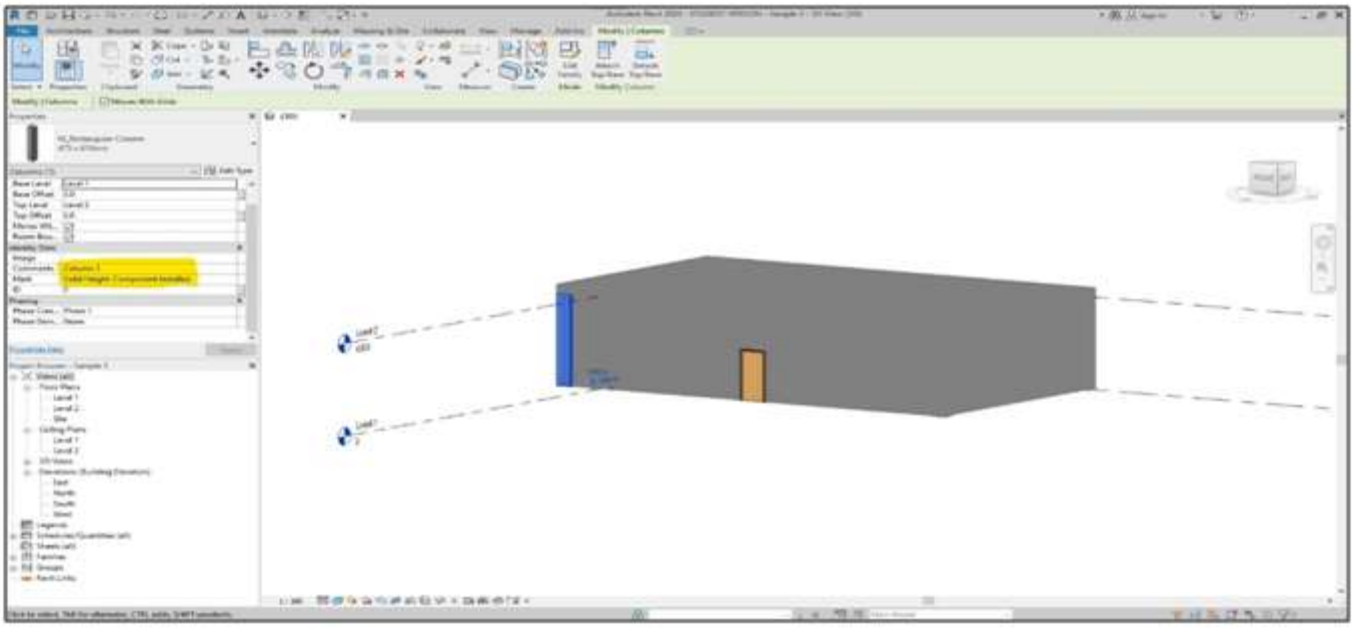

Fig. 6 Changes made by the supervisor reflected back in the model after the execution of the dynamo script

IV. CONCLUSIONS

Real-time monitoring can be accomplished through the use of a number of different information technologies; however, the bulk of these technologies are used to monitor workers or evaluate buildings using picture matching and comparisons between a planned and actual model. A system exists to track the prefabricated components, but it is only capable of tracking only the movement of prefabricated components from the casting yard to their final destination on-site at the construction site. Real-time installation status of prefabricated components has not been studied so far to the best of the author's knowledge gathered from reading the literature.

This study's usage of ultrasonic sensors opens up a previously unexplored avenue for tracking the progress of precast concrete structures. It will be possible to determine the status of various components based on the data from the sensors. The project manager will be able to keep track of progress without having to rely on the site supervisor's report, and this will save time by eliminating the need for site visits.

Based on the assumptions and findings of the proposed concept, it is expected that future prefabricated construction projects will be successfully tracked. As a result, there will be less human errors in the reporting of progress, and the project manager will be able to observe the progress in real time because all of the data is stored in Google Drive. With the help of Revit, the project manager will also be able to keep track of various projects without having to personally visit each one.

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