International Journal of Civil and Structural Engineering Research ISSN 2348-7607 (Online)
Vol. 9, Issue 1, pp: (10-20), Month: April 2021 - September 2021, Available at: www.researchpublish.com

DYNAMIC LABOR TRACKING SYSTEM IN CONSTRUCTION PROJECT USING BIM TECHNOLOGY

Ahmed M. Abdel-Alim[1], Salah Omar M. Said[2]

[1]Associate Professor of Construction Management, [2]Teaching Assistants of Construction Management,

[1]Email: Dr.Ahmedabdelalim@m-eng.helwan.edu.eg, [2]Email: Omran_salah@m-eng.helwan.edu.eg

Faculty of Engineering at Mataria, Helwan University, Cairo, Egypt

Abstract: **The worker's time theft is lurking in the depths of the construction industry as an enemy. Adding more supervisors to construction sites may appear to be the obvious solution. They are left out of the more pressing matters because of non-essential and time-consuming tasks like ensuring every worker is where their timecard indicates they should be. Tracking solutions streamline back-office processes and can provide real-time site monitoring. The tracking technology of indoor construction activities can bring immediate awareness and corrective action for the project. Accordingly, this study selected hybrid Bluetooth low energy (BLE) with Building Information Modelling (BIM) technology as a tracking engine. Also, the study aims to add a layer to the 3D BIM model by visualizing the worker's productivity. The process begins with an indoor tracking system powered by (BIM) technology, BLE, and ends with a friendly Client Early Warning System (CEWS) dashboard. The CEWS can show the percentage of completion of activity in the BIM model. Furthermore, the construction industry has been negatively impacted in various ways because of the COVID19 pandemic. The workers have had to adjust to social distancing requirements, adhere to the most recent sanitation and personal protective equipment policies, and adapt to technology to perform tasks remotely, if at all possible. In the event of a pandemic, the findings of this study will assist organizations in establishing safe working environments in which to complete their projects through an alert system in a friendly dashboard.**

Keywords: **BIM; Bluetooth Low Energy (BLE); Client Early Warning System (CEWS); Building Information Modelling (BIM); Resources Tracking.**

1. INTRODUCTION

Indoor tracking continues to be a challenging task for researchers and construction companies around the world. A large number of articles and modules were written in order to track building activities through the use of a web-based or portal. Furthermore, fewer concentrated on data visualization for indoor activities [1]. This research aims to build a hybrid dynamic tracking method that incorporates both Building Information Model (BIM) and Bluetooth Low Energy (BLE) beacon signals to monitor the activity. Integrating with a document management platform using (HoloBuilder) also addresses the challenge of tracking actual indoor productivity.

Nonetheless, the information loop is the bottleneck in the construction process, and capturing data on time will aid in decision-making and provide the client with an early warning. Labor productivity is one of the performance indicators used to evaluate a construction project. It defined construction productivity as the amount of work performed per hour. 360-degree photos can be used to identify the actual output manually. This study's document management platform is HoloBuilder. Fig.1 illustrates the study's primary approach.

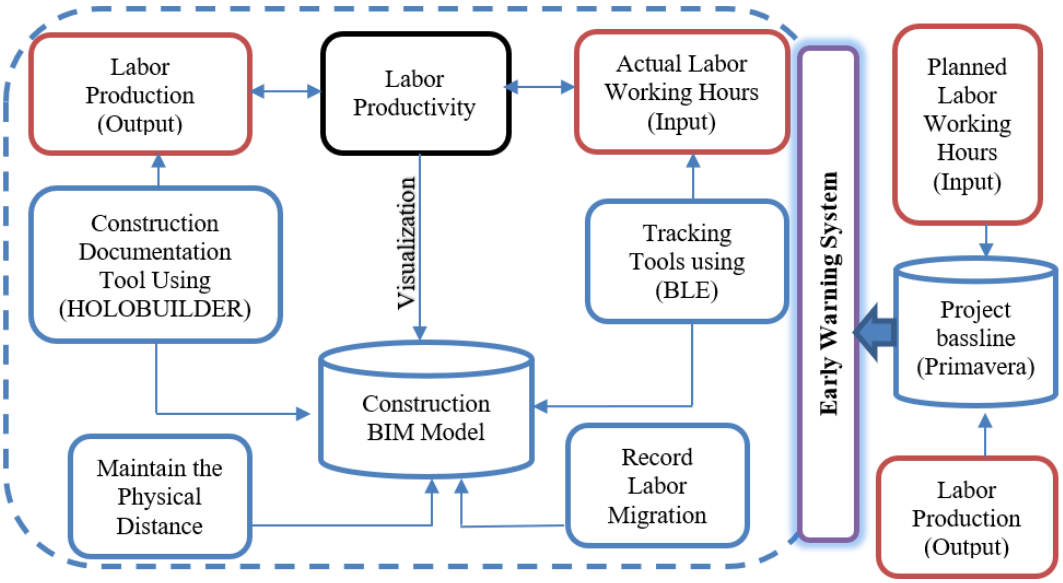

Fig.1 The study key approach.

HoloBuilder's main benefit is its BIM integration. Planned data and accompanying scheduled activity resources are saved in Primavera (P6). It will be used to deal with various programming languages. Computer programmers use the Integrated Development Environment (IDE) to design software. For a long time, converting and running a program required many software tools to convert and operate (including a text editor, a compiler, a linker, and operating system commands). Recently, all software programs and duties were merged into one program called the (IDE) [2]. This study's purpose is to improve project decision-making capabilities by closing the tracking information loop. The Client Early Warning System (CEWS) collects planned data from project baselines and BIM models and accurate project data from Bluetooth Low Energy (BLE) devices. Using BIM technology, measure actual labor working hours and daily progress to show labor productivity and migration.

2. MOTIVATION TOWARD THE RESEARCH:

There are numerous issues that the construction industry must deal with daily, and it is in this context, scientific research is essential in providing practical solutions. This study has many motivating challenges, but the main pillars are early stakeholder involvement, worker performance tracking, and Building Information Modelling (BIM), as indicated in Fig.2.

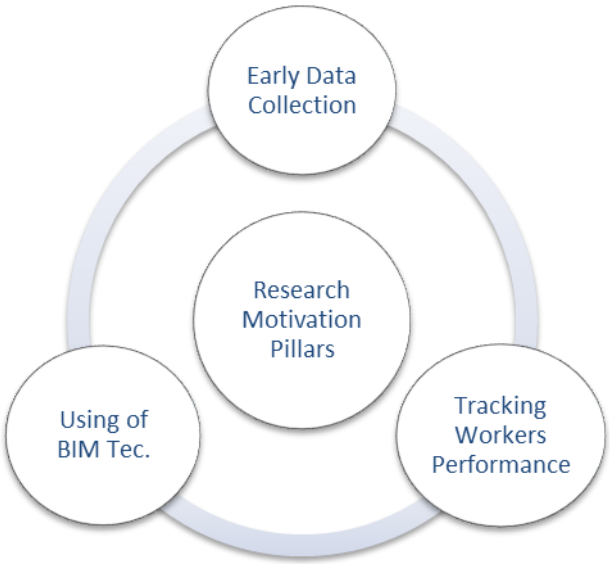

Fig.2. Study motivation pillars.

2.1 Early Data Collection Bottleneck

Traditional data collection methods are complex, costly, and time-intensive, especially in the construction industry. The only solution for decision-makers is to increase staff to collect all data directly efficiently. Data input, verification, and modification by humans can be risky. The data may be linked to an error in reproducing the data, using outdated data, or favoritism. Due to information loops, getting data on time is a bottleneck in construction projects. In this instance, automated data collecting is a powerful solution for decision-makers. Corrective action deals with a problem that's already occurred, while preventive action is about stopping a problem from happening. Both actions need to be intensely dependent on data. The inclusion of an integrated intelligent construction dashboard that collects all project data will help to improve the efficiency of project activities. The efforts made by researchers in this area are effective in the right direction, attracting attention to the subject's relevance and encouraging it to be considered a research subject.

2.2 Tracking Workers Performance

The project manager has difficulty tracking the migration of contractor workers from one activity to another within the same project. Many contractors operating in proximity may lead to problems. Once the project manager accepts the contractor schedule, it is difficult to determine where everyone works, on which floor, and what item. It would be exciting to have a technology that could detect each contractor's performance and impact on each other. Moreover, construction accidents can occur anywhere, causing severe injuries to workers and extensive property damage. Worker tracking is sometimes a lifesaver for workers, despite some people's displeasure. Initially, providing construction sites with supervisors may appear to be the evident approach. Due to their qualifications and expertise, supervisors are usually paid more than workers. They are left out of the more critical issues because of non-essential and time-consuming activities like ensuring every worker is where their timecard indicates. It also limits its capacity to manage numerous tasks concurrently. Technology can help track labor or site operations.

The coronavirus, also known as COVID-19, is caused by coronavirus 2 (also known as SARS-COV-2), associated with a significant acute respiratory disease [3]. As a result of the COVID19 pandemic, the WHO has imposed various health conditions, including maintaining social distance between workers, making using tracking in emergency and health situations must be maintained. The only way to trace the information flow from site to the office quickly appears to be automated tracking.

2.3 Building Information Modelling Technology Use

In the construction industry, BIM is a relatively new mandatory technology, and it has been found that most tracking procedures do not rely on BIM technology as a single source of truth. The construction BIM model is rich with actual construction data and information by the engineers. It is motivating to link construction BIM models with the tracking technology in the research.

3. LITERATURE REVIEW

Adding dynamic data to BIM models, such as existing conditions, sensor measurements, control signals, etc., can help owners analyze building operations and maintenance, which can help them make decisions [4]. Thus, the study seeks to improve and support resource management in buildings and civil constructions using BIM. Tracking and reporting systems have attracted researchers. Analyzing picture or video data usually counts the number of moving persons but tracking individual humans' activities is complex.

Because mobility is the primary aspect, background subtraction cannot detect static objects like trucks or excavators. Moreover, background subtraction is only relevant in the attached camera and requires updating to reflect changes in the background. Researchers have used many tracking systems, which mainly use RFID to meet identification requirements. Before going to select the tracking method and tool, a detailed comparison with the most famous tracking systems has been made for systems such as Inertial Navigation Systems (I.N.S.), Ultra-Wide Band (U.W.B.), Smartphone application, Laser scanning, WLAN-based, Japan's indoor messaging system, Pedestrian Dead Reckoning (P.D.R.), and RFID. More than a few have been used and test other technologies, including a WiFi-based positioning system for tunnel construction, which was intended to switch from the Global Positioning System (G.P.S.) when resources were operated indoors [5]. Others used Bluetooth (B.L.), while few used Bluetooth Low Energy (BLE). Indoor tracking solutions like ZigBee-based localization were tested [6].

U.W.B. is a tracking method for precise location tracking. Unlike RFID, it sends data over a wide bandwidth, reducing signal interference and making it easier to pass through walls. However, several investigations have shown that the accuracy of UWB-based localization technology is strongly dependent on a clear line-of-sight from readers to monitored subjects. The biggest downside of U.W.B. is the high hardware cost, which is roughly $140 per square meter [7].

RFID is barcoding on a tag or label that is recorded by a device that stores data. An antenna receives and transmits a signal, has a local power source (such as a battery), and manages hundreds of meters from the RFID reader. Unlike standard barcodes, RFID tags can be embedded in the monitored object and do not need to be visible to the RFID reader. The tags vary in size, data storage capacity, power supply, memory type, data transfer speeds, frequency, reading range, and cost [8]. RFID is a useful tracking technique in dense areas but lacks accuracy [9]. Ergen and Akinci employed RFID in 2007 to track and fix the labor hat tags.

Wi-Fi is significant modern technology advancement. Wi-Fi can be used in the construction site because it connects devices to the internet wirelessly. Short and long-distance Wi-Fi is easy to utilize. The main disadvantage of employing it in labor tracking is that all workers must connect to receive their address, causing problems controlling random labor entry compatibility time. It also is not very power efficient for a portable gadget.

Bluetooth Low Energy (BLE), formerly known as (Bluetooth Smart), is a wireless local area network technology developed by the Bluetooth Special Interest Group for novel healthcare, fitness, security, and home entertainment Bluetooth SIG, 2021applications. The critical difference between BLE and RFID is that BLE uses less energy and has a more extended read range. BLE eliminates the need for USB converters, cables, cellular and Wi-Fi connections. Bluetooth is one of the most cost-effective and universal IoT technologies. Initial setup for tracking tools takes a long time [10]. Other tracking technologies indicate tool inaccuracy or high energy usage. It appears that BLE technology can solve the tracking issues in present indoor positioning sensors. Various research efforts focused on integrated systems using tracking technology. Therefore Y. Fang et al. used a cart with four big antennae for tracking RFID with BIM [1]. A combination of support vector fingerprinting and Kalman filtering has been investigated by [11] to improve tracking methods. To increase the quality of indoor navigation. Taneja et al. created processes to generate navigation models from Industry Foundation Classes (IFC) and employed an (IMU) and Wi-Fi sensor for relative and absolute tracking [12].

The hybrid BLE with BIM technology was chosen as a tracking engine based on the study and expert survey. Despite this, the BLE system has been locally adapted due to tracking system concerns. The study used an IDE to deal with multiple programming languages.

4. LABOR PRODUCTIVITY

Labor productivity is another performance metric for a construction project. In a labor-intensive business-like construction, the worker is the primary productive resource. Thus, building productivity is heavily reliant on human work. Also, the concentration of labor required to execute specific tasks necessitates labor productivity [13]. It defined productivity as production per labor hour in construction. Productivity is commonly expressed as an output/input ratio. In equation form, it is as follows:

Productivity = output ÷ Input ……..…….…... Eq.1

= Total output ÷ Total work hour

Different measures of productivity serve different purposes. It was defined different aspects of measures as follows [14]:

a) Economic Model: Total Factor Productivity (T.F.P.)

(T.F.P.) = Total Output / Labor + Material + Equipment + Energy + Capital. ……..…...Eq.2

b) Project Specific Model:

Productivity = Output / Labor + Material + Equipment ……..……. Eq.3

c) Activity Oriented Model

Labor Productivity = Output / Labor cost or Work hour ……. Eq.4

Cost of labore is a major part in construction costs. Labor capacity and productivity measure overall project performance and practical usage of personnel, equipment, and money. Understanding the productivity rate goes beyond determining the project's profitability. The labor characteristics, project work environment, and non-productive activities all influence productivity.

5. BLE TOOL'S ADAPTATION & CONFIGURATION

5.1 Data Mapping

Revit plugin (Add-in) for labor visualization in the BIM model has been adapted. The add-in was created in the C# programming language and based on the Dot Net Framework 4.5.2. The add-in also was created to be compatible with any version of Autodesk Revit, which is a significant benefit. Many kinds of data will be dealt with by the CEWS from various sources, using various programs. The decision support system (D.S.S.) excel sheet was presented as the primary CEWS dashboard backbone. This D.S.S. will serve as an inventory for the project and a tracking system for the data collected. Each parameter in the D.S.S. sheet, including its units, data source, and integration connection approach, is represented in Fig.3. The BIM model Primavera, as well as the BLE devices, are the key sources of information. This data will be integrated with the D.S.S. through an API, an excel equation, or filling in blanks in the D.S.S. as needed.

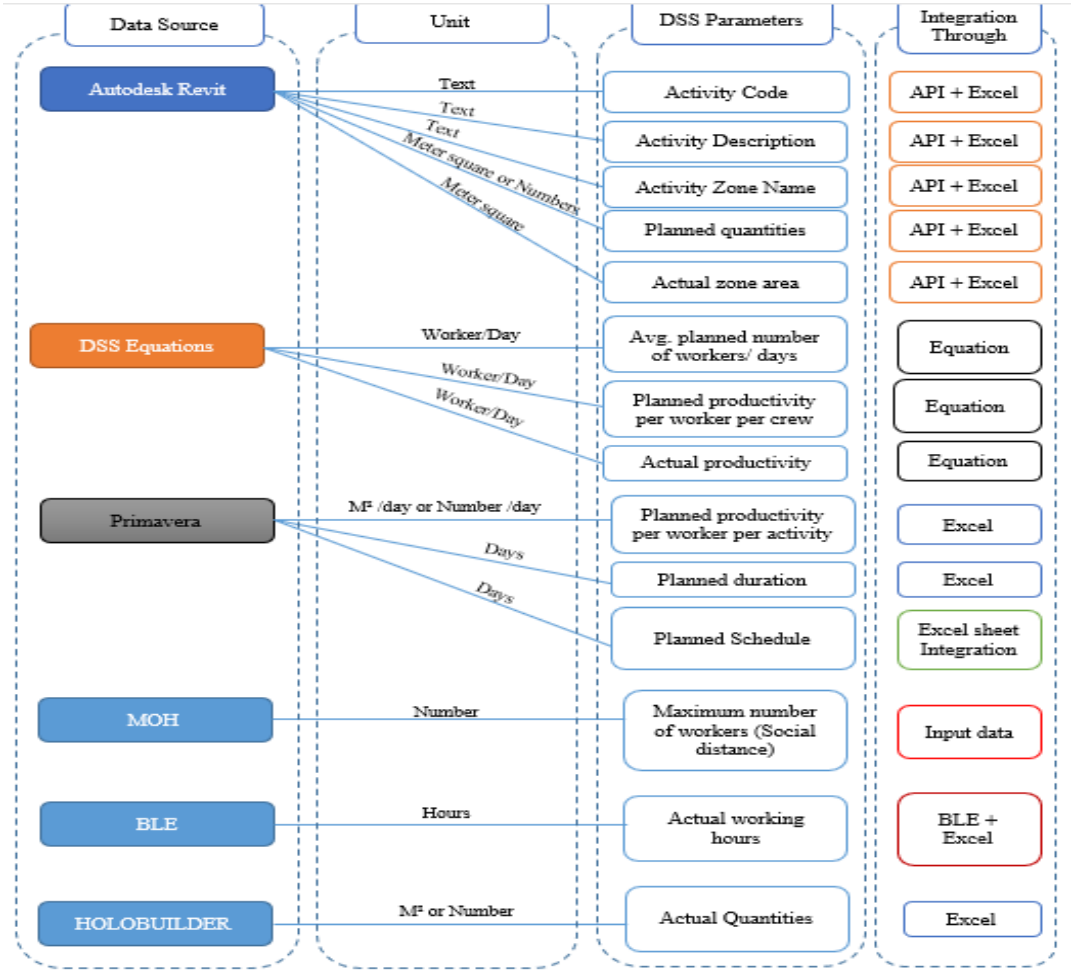

Fig. 3 Data mapping and interoperability between different software applications

5.2 Tool's adaptation and configuration

The innovation in BLE technology and the scanning approach enables the industry to provide infinite connections without pairing. When J Park et al. conducted a lab examination into the maximum number of BLE device communication, they discovered that the primary device could quickly detect more than 30 BLE sensors (BLE version 4.0) [18].

BLE radio waves tools are not available in the Middle East; the approach offered is an adaptation. With a weight of approximately 15.45 grams and dimensions of approximately 10 x 10 cm, the Bluetooth device dimensions (40.0mm x 20.0mm x 10.0mm). Each Bluetooth Low Energy Tag requires a small lithium battery that emits radio waves for more than a year. The BLE tags are essential for attaching to the safety jackets of those involved in the connected labor. As a result of the interaction with the D.S.S., an automated comparison with the planned data is performed, and real-time labor

visualizations on BIM are displayed. The labor symbol is displayed on the BIM model about the planned data. The visualization enables the user to efficiently and simply evaluate the current labor status, allowing early corrective action.

6. THE PROPOSED METHODOLOGY

Many studies have studied the benefits of BIM in the construction industry over the last decade. The industry needed effective tracking technologies for people, materials, and equipment to have a clearer picture of what was going on. It can also help with construction management decision-making [19]. Many efforts have been made to visualize construction and operation. Some professional users add time or cost value to 3D models, known as the 4 or 5-Dimensional models (4D or 5D) [20].

An additional layer to the 3D BIM environment is added by evaluating the 3D model's work productivity. As demonstrated in Fig.4, it drove a framework for indoor tracking using BLE tools and BIM platforms. BIM integration into BLE improves construction position estimates [21]. Fig.4 displays the main framework with a CEWS dashboard. An easy-to-read productivity dashboard and an assessment based on planned productivity rates. Contractors' labor can be hard to track. For instance, the main contractor sometimes is responsible for managing electrical fixtures and ceiling items simultaneously. The project manager or client cannot determine the actual daily production rate for the same contractor. The contractor provides a certain number of resources each day but does not identify them. The CEWS allows the client or project manager to track daily labor migration and productivity from one zone or floor to another.

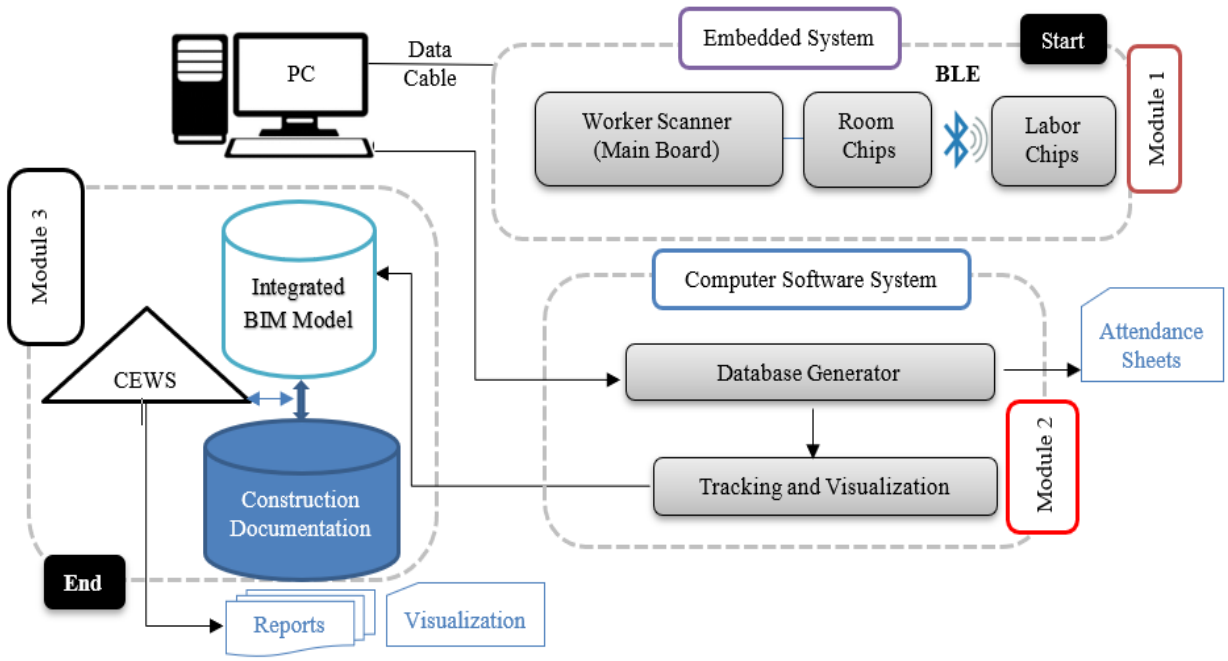

Fig.4 The research main framework and modules.

The BLE embedded system indoor tracking approach starts with (Module one). A computer software system linked to the BIM model was developed to quickly visualize and record indoor positioning data. So the CEWS is ready to extract and evaluate data from all actual site positions. There are three main sections in the proposed study. The worker scanner is shown in the first embedded device module. A database generator and a BIM visualization tool are in the second module, Computer Software System. Module 3 includes CWES, BIM models, and the Document Management System. Each module builds on the previous concepts and equations.

7. IMPLEMENTATION AND VALIDATION OF THE PROPOSED TECHNIQUE

7.1 Research Limitations

BIM, BLE, and a document management system. The field test was carried out at Helwan University, College of Engineering Mataria, Civil Engineering Department, Main Meeting Room, 3rd Floor, and two adjacent rooms on the 3rd floor of the engineering Mataria (Egypt, Cairo). It was discovered that the BLE tracking tool is most efficient in open

spaces with no impediments and in regions that are no larger than 100.0 square meters. At the beginning of site activity, it takes some time to configure each BLE tag and feed it with data relevant to the worker's name and related activity before it can be used, therefore allowing extra time during this period.

7.2 Decision Support System (D.S.S.)

Fig5, which illustrates the various inputs to the decision support system (D.S.S.). A user should specify the maximum number of workers per square meter per intranational health regulations in the country that apply to the D.S.S if they wish to maintain social distance between workers in the construction site.

Input Data						
Today	1-Feb-20					
Max Number of Workers per m^2 As per World Health Organization	0.25	/m^2				
Project Stackholders	Contractor					
	Sub-Contractor					
	Consultant					
	PMCM					
	Client					
Planned Resources	8	Hr/Day				
Working days per month	26	Day	Worker discription		Avg Rate /Unit/Day	Avg Rate per worker /Unit/Day
Planned productivity for Ceilling Activity	2.4	M^2/Day/ Worker	Panel Ceilings Fixer +1.5 Helpers	2.5	6 m^2/day	2.4 m^2/day
Planned productivity for Aluminum Windows Activity	0.75	No.'s /Day/ Worker	Aluminum Windows 2 Fixer +2 helpers	4	3 No.'s / day	.75 No.'s / day

Fig.5 Input data sheet to be used in conjunction with the D.S.S.

7.3 Client Early Warning System Dashboard (CEWS)

The user will also input the date and shall identifying the project stakeholders. From the project schedule, everything else will be pulled immediately without any more processing. Fig.6 depicts the data inventory for the D.S.S., representing the engine for the CEWS dashboard (for only one week). The primary goal of this excel sheet is to consolidate all of the project information into one convenient location.

EW-BIM-DSS			Avg planned Workers /day	M^2/ Day /Worker	M^2/d or Nos For Crew	Duration (Day)	Actual Zone Area M2	Max Number of Worker Per Zone - per Day- MOH COVID	Quantities - planned LOD 300 and Actual LOD 400 (M2 or No)	Actual and planned Daily Attendance Sheet For One Month (per Ho						Cumulative Resources (Hrs)	Quantities of Completed Work (M2 - Nos)	Cumulative Productivity (Unit/Day/ Worker)
Zone	Activity Code	Description								Sat 1-Jan	Sun 2-Jan	Mon 3-Jan	Tue 4-Jan	Wed 5-Jan	Thu 6-Jan			
Z1	ARC-CE-P-Z1	Planned - Arch - Ceilling Activity Z1	4	2.4	9.6	9.0	90	22.5	86.4	32	32	32	32	32	32	192	57.6	2.40
	ARC-CE-A-Z1	Actual - Arch - Ceilling Activity Z1	Actual			15.0			90	0	16	32	32	32	32	144	41.5	2.31
	ARC-AW-P-Z1	Planned -Arch- Aluminum Windows Activity Z1	3	0.75	2.25	2.0			4	0	24	24	0	0	0	48	4.0	0.67
	ARC-AW-A-Z1	Actual -Arch- Aluminum Windows Activity Z1	Actual			3.0			4	0	16	16	16	0	0	48	4.0	0.67
Z2	ARC-CE-P-Z2	Planned - Arch - Ceilling Activity Z2	4	2.4	9.6	5.0	45	11.25	43	0	0	0	0	0	0	0	0.0	0.00
	ARC-CE-A-Z2	Actual - Arch - Ceilling Activity Z2	Actual			7.0			45	0	0	0	0	0	0	0	0.0	0.00
	ARC-AW-P-Z2	Planned -Arch- Aluminum Windows Activity Z2	3	0.75	2.25	1.0			2	0	0	0	24	0	0	24	2.0	0.67
	ARC-AW-A-Z2	Actual -Arch- Aluminum Windows Activity Z2	Actual			1.0			2	0	0	0	23	0	0	23	2.0	0.70
Z3	ARC-CE-P-Z3	Planned - Arch - Ceilling Activity Z3	4	2.4	9.6	3.0	29	7.25	29	0	0	0	0	0	0	0	0.0	0.00
	ARC-CE-A-Z3	Actual - Arch - Ceilling Activity Z3	Actual			4.0			29	0	0	0	0	0	0	0	0.0	0.00
	ARC-AW-P-Z3	Planned -Arch- Aluminum Windows Activity Z3	3	0.75	2.25	1.0			2	0	0	0	0	24	0	24	2.0	0.67
	ARC-AW-A-Z3	Actual -Arch- Aluminum Windows Activity Z3	Actual			1.0			2	0	0	0	0	0	25	25	2.0	0.64

Fig.6 A section of the comprehensive Decision Support System (D.S.S.) Excel spreadsheet.

It is critical to link the D.S.S. with the BIM model to retrieve all necessary project data. The BIM model has rich information; nevertheless, Fig.3 previously illustrated which data needed to be extracted from the BIM model and linked with the D.S.S.

This study develops a data gathering approach for actual labor productivity statistics by combining the BIM model with accompanying information into a graphical user interface CEWS. The CEWS was supplemented by many charts, which made it easier to understand the outcome. Fig.7 offered some light on the current condition of only one zone (zone one)

(Ceiling and window) for the specified activities. The graphic illustrates a 6-day delay in-ceiling activity compared to the anticipated start and finish dates. The outcomes of this study are explored in the previous and next figures.

On the other hand, there is no lag in the activity of the window, which is positive progress. There is a variance in the ceiling quantities by 3.6 square meters. Additionally, the cumulative working hours for the first week indicate that the laborers working on the ceiling activity are working 48 hours less than what was planned, which requires the project manager's attention because this will impact the project duration if this activity is critical. If there is a problem, the project manager can recall the CEWS detailed attendance sheet to precisely define the issue.

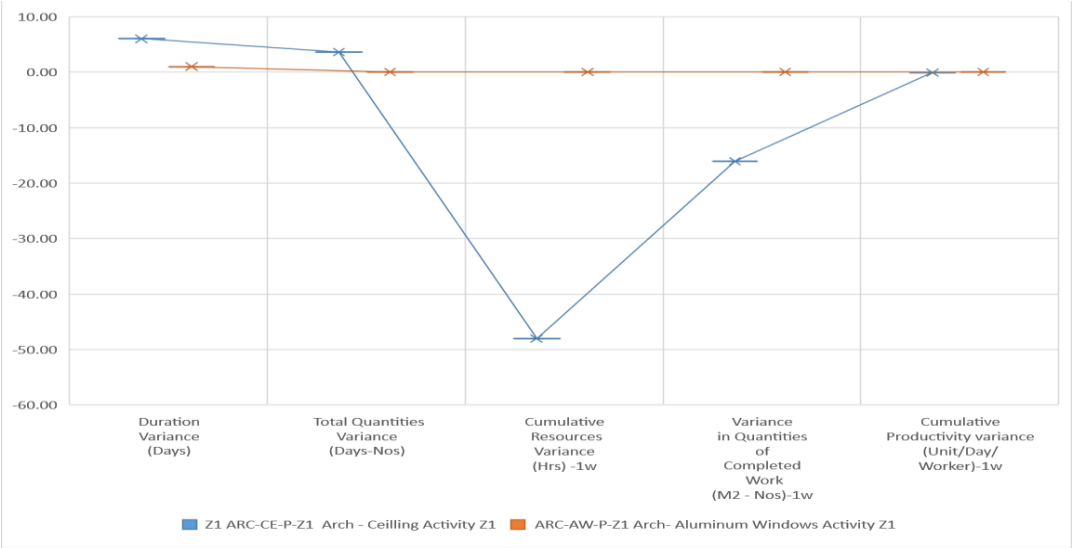

Fig.7 Status of zone one for Ceiling and window activity for the first week.

The chart depicts the difference between actual amounts and those estimated by the contractor. The variance in the productivity value is the most significant value to consider. According to the figures, there is a harmful variance in-ceiling activity of 0.09m2/day/labor for this week, which will impact the duration of the activity.

Fig.8 offered additional light on the current condition of zone two (Ceiling and window). The graphic illustrates that the cumulative working hours for the 2nd week indicate that the laborers working on the ceiling activity are working 96 hours less than planned; the contractor failed to provide labor this week for ceiling activity. This also requires the attention of the project manager because this for sure will impact the project duration. According to the figures, there is a negative variance in-ceiling activity by 2.15m2/day/labor for the second week.

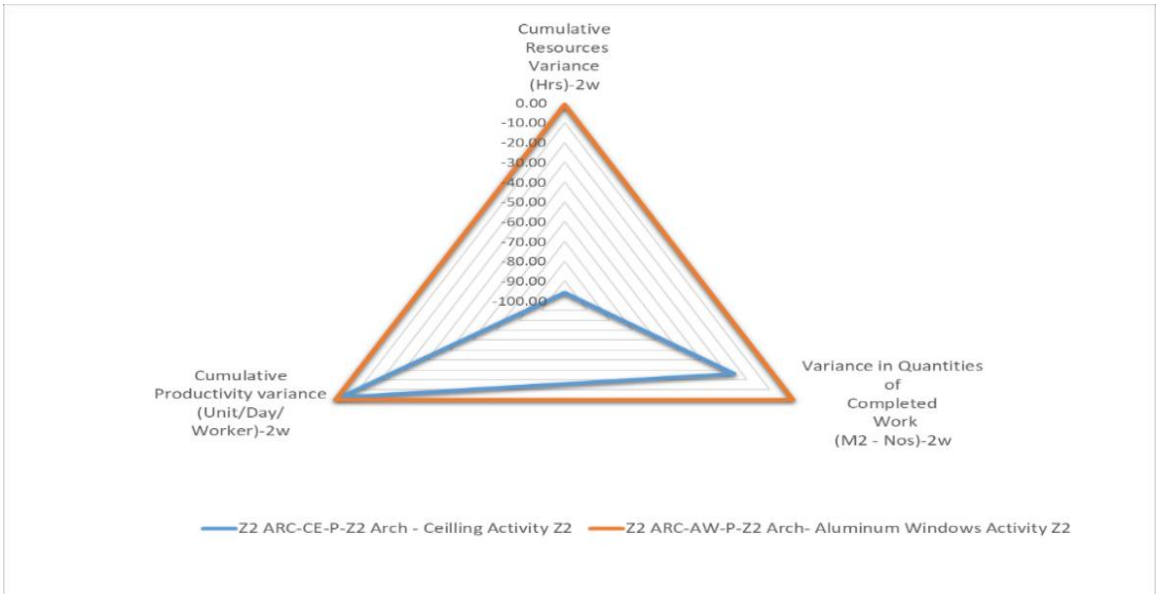

Fig.8 Status of zone two for Ceiling and window activity for the second week.

Fig.9 depicts the CEWS dashboard in its entirety, with the original CEWS excel sheet and BIM model wholly integrated. It is separated into three zones as per the case study, with different possibilities to indicate the percentage of completion for each activity and the availability of workers compared to the planned data in each zone and the O.W.H. social distance commitment, respectively.

Fig.9 Client Early Warning System Main Dashboard.

The dashboard is linked to the BIM model through hyperlinks, and it enables the visualization of worker or activity statuses to be displayed. BIM will alter how projects are designed, constructed, and operated and how project stakeholders are engaged. It represents a trend away from gut instinct and toward more data-driven decision-making. As a result of accessing the CEWS hyperlink, the ceiling and Aluminium Windows activity percentages are shown in Figs.10.

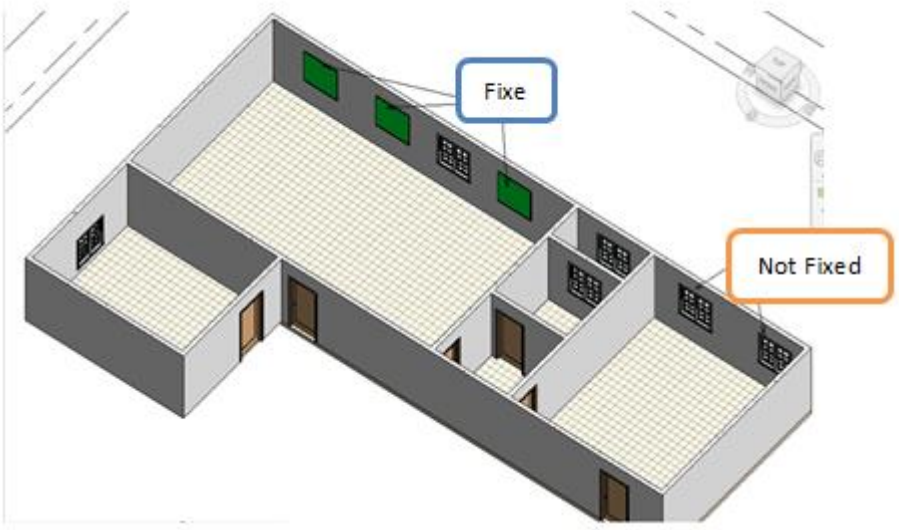

Fig.10 Percentage of Complete for the Windows Activity.

8. CONCLUSIONS AND RECOMMENDATIONS

Traditionally, progress is tracked visually, with daily or weekly reports issued. The inspectors' job is to ensure the task is completed according to the contract's requirements. They use checklists to inspect and log issues, which are then discussed at weekly meetings. Because this system depends heavily on inspectors' judgment, observational abilities, and experience, reports are likely incomplete or incorrect. To address this issue, numerous emerging technologies for automated control programs have been examined. Using Bluetooth Low Energy and Building Information Modeling (BIM) technology, this study described how to automatically assess worker productivity and work completion. Only this method combines BIM, BLE, and a document management system.

Tracking technology has attracted researcher's attention for several years, especially after COVID19. Many researchers have emphasized the benefits of using BIM technology in the construction industry. This study aims to establish an integrated tracking system for analyzing workers' workplace behavior using the BIM environment. Through the CEWS dashboard, the client bridges the gap between productivity information bottlenecks and the information loop. Gathering data on time supports this decision related to the contractor's performance. However, the system helps the client and site

managers detect project failures regarding the worker's migration or not comply with health and safety regulations to maintain social distance.

There is no doubt that tracking technology exposed in this paper and others can offer new solutions in construction. Some of the future research lines are as follows:

- Data Synchronization. All tracking data is aggregated into a single business computer or project server. Therefore, it was recommended to collect the tracking data in a cloud base and be integrated with Autodesk BIM360. Based on that, the client can access the activities condition at any place and at any time.

- Safety. Another determining factor to be improved in construction is safety. Bureau of Labor Statistics stated that the construction industry incurred more fatal injuries than any industry, and workers' injuries and illnesses cost billions each year (N.S.C., 2006). The tracking tools can be used as an alert system for safety managers [22].

- Emergency. The tracking system can be used for tracking workers in emergency cases such as fire or building devastation. The system can guide the lifeguards to inform them of the latest position for workers.

REFERENCES

[1] Fang, Y., Cho, Y., Zhang, S., and Perez, E. "A Case Study of BIM and Cloud-enabled Real-time RFID Indoor Localization for Construction Management Applications." ASCE Journal of Construction Engineering and Management, 10.1061 /(ASCE) CO.1943-7862.0001125,05016003. Dec 2016.

[2] Marcel Bruch, Eric Bodden, Martin Monperrus, and Mira Mezini. IDE 2.0: Collective Intelligence in Software Development. H.A.L. Id: Hal-01575346. https://hal.archives-ouvertes.fr/hal-01575346. Aug 2017.

[3] O. (O) and Coronavirus, 2020. W.H.O. (WHO), coronavirus disease (COVID-19) (2020) https://www.who.int/health-topics/coronavirus, Accessed 13th Feb 2021

[4] Kapp, P. H. (2009). "So, Can You Revit" Historic Preservation Design Education and Digital Media, Offprint from Preservation Education & Research, Volume 2, 2009.

[5] X. Shen, W. Chen, M. Lu, Wireless sensor networks for resources tracking at building construction sites, Tsinghua Science & Technology 13 (2008) 78–83.

[6] X.M.W. Yong, Zheng Li, Lei Wang, Y.T. Zhang, Experimental analysis on radio transmission and localization of a ZigBee-based wireless healthcare monitoring platform, in Proceedings of the 5th International Conference on Information Technology and Application in Biomedicine, in conjunction with the 2nd International Symposium and Summer School on Biomedical and Health Engineering, Shenzhen, China, 2008, pp. 488–490.

[7] N. Li, B. Becerik-Gerber, Performance-based evaluation of RFID-based indoor location sensing solutions for the built environment, Adv. Eng. Inform. 25 (2011) 535–546, http://dx.doi.org/10.1016/j.aei.2011.02.004

[8] Ali Motamedi and Amin Hammad. RFID-Assisted Lifecycle Management of Building Components Using BIM Data. Concordia Institute for Information Systems Engineering. 26th International Symposium on Automation and Robotics in Construction (ISARC 2009).

[9] J. Chai, C. Wu, C. Zhao, H.-L. Chi, X. Wang, B.W.-K. Ling, K.L. Teo, Reference tag supported RFID tracking using robust support vector regression and Kalman filter, Adv. Eng. Inform. 32 (2017) 1–10, http://dx.doi.org/10.1016/j.aei.2016.11.002

[10] B. Dawes, K.-W. Chin, A comparison of deterministic and probabilistic methods for indoor localization, J. Syst. Softw. 84 (2011) 442–451, http://dx.doi.org/10.1016/j.jss.2010.11.888.

[11] Y. Zhuang, J. Yang, Y. Li, L. Qi, N. El-Sheimy, Smartphone-based indoor localization with Bluetooth low energy beacons, Sensors (Switzerland) 16 (2016) 1–20, http://dx.doi.org/10.3390/s16050596.

[12] S. Taneja, B. Akinci, J.H. Garrett, L. Soibelman, Algorithms for automated generation of navigation models from building information models to support indoor map-matching, Autom. Constr. 61 (2016) 24–41, http://dx.doi.org/10.1016/j.autcon.2015.09.010.

[13] Wen Yi & Albert P.C. Chan "Critical review of labor productivity research in construction journals" Journal of Management in Engineering, Vol.30, No.2, 1 Mar, 2014©ASCE, ISSN0742-597X pp. 214-225.

[14] H. Randolph Thomas & Carmen I. Napolitan "Quantitative effects of construction changes on labor productivity" Journal of Construction Engineering & management vol.121, No.3, September,1995©ASCE, ISSN0733-9364 pp.0290-0296.

[15] R. Navon, R. Sacks, Assessing research issues in Automated Project Performance Control (APPC), Automation in Construction 16 (2007) 474–484.

[16] S. Kiziltas, B. Akinci, E. Ergen, P. Tang, Technological assessment and process implications of field data capture technologies for construction and facility/ infrastructure management, Electronic Journal of Information Technology in Construction. 13 (2008) 134–154. http://www.itcon.org/data/works/att/2008_10.content.07637.pdf.

[17] John Caulfield, A new report tracks industry preferences for building documentation tools. More firms are adding scanning and photography to their services: 20 Sept 2018, access date 22 Aug 2021.

[18] Jee Woong Park, Jingdao Chen, Yong K. Cho Self-corrective knowledge-based hybrid tracking system using BIM and multimodal sensors / Advanced Engineering Informatics 32 (2017) 126–138. http://dx.doi.org/10.1016/ j.aei.2017.02.001

[19] A. Vasenev, T. Hartmann, A.G. Dorée, A distributed data collection, and management framework for tracking construction operations, Adv. Eng. Inform. 28 (2014) 127–137, http://dx.doi.org/10.1016/j.aei.2014.01.003.

[20] Junbok Leea, Young-Jin Park, Chang-Hoon Choib, Choong-Hee Hana a Dept. of Architectural Eng., Kyung Hee Univ., 1732 Deogyeong-daero, Giheung-gu, Yongin 446 701, Republic of Korea. Graduate School, Kyung Hee Univ., 1732 Deogyeong-daero, Giheung-gu, Yongin 446-701, Republic of Korea. Automation in Construction 84 (2017) 121–132.

[21] Jee Woong Park, Jingdao Chen, Yong K. Cho Self-corrective knowledge-based hybrid tracking system using BIM and multimodal sensors / Advanced Engineering Informatics 32 (2017) 126–138. http://dx.doi.org/10.1016/ j.aei.2017.02.001

[22] 90-Yuchun Tang, Nini Xiaa, Ying Lua, Liz Vargab, Qiming Lia, Guangchong Chena, and Juan Luo. BIM-based safety design for emergency evacuation of metro stations. Automation in Construction. Volume 123, March 2021, 103511.