Available online at https://asric.africa/engineering-sciences
ASRIC Journal on Engineering Sciences Vol.4(2)(2024) 65-86

Experimentation on The Integration of BIM and Laser Scanning Applications for Monitoring a Selected B+G+11 Apartment Building Construction Projects

Bethel Wubante Zewdu, Zekariyas Sintayehu Gebrekidan, Eyerusalem Kelemework Yigzaw, Bethel Melese Tamene, Kidus Dereje Milion

Debre Berhan University, Debre Birhan Ethiopia,
bethelwubante20@gmail.com Zekariyassintayehu@gmail.com, eyerusalemkelemework@dbu.edu.et, bethelmelese6@gmail.com, Kddking78@gmail.com

Received 11 April 2024; revised 03 June 2024; accepted 10 June 2024

Abstract

The need for precise and efficient monitoring techniques is becoming crucial as manual data collection and processing has become inadequate to handle the growing complexity of construction projects. This research explores the integration of Building Information Modeling (BIM) and laser scanning technologies for monitoring the construction of a selected B+G+11 apartment building. The study involved a detailed analysis of existing 2D architectural and structural designs, schedules, and progress reports, followed by the creation of 3D and 4D models using Revit and Synchro. Data collection was conducted using drones for external scans and mobile devices for internal surfaces. The scanned data was then processed into 3D models utilizing the Polycom app, Autodesk Recap, and Pix4D Mapper. The Undet-indexer Revit plug-in facilitated the comparison of planned versus scanned models for automated quality monitoring. The findings revealed the project was behind schedule, as detected using 4D BIM. Incomplete finishing works are detected through visualization of as-planned and the laser-scanned models. Quality checks using Undet-indexer showed deviations of up to 100*mm* between as-built and as-planned elements. The findings suggest that this integrated approach is promising and that even better results could be achieved with full resources.

Keywords: BIM, LiDAR Scanning, Automation, Progress, Quality, Monitoring

1. Introduction

Monitoring construction progress plays a vital role in successful Construction project management by ensuring that projects are completed on time and within budget. Excellent construction monitoring techniques are imperative to project success by spotting potential problems and take corrective actions to avoid costly delays and reworks. Moreover, it ensures the quality and compliance of the project.

As construction project complexity continuously increases, the need for precise and efficient progress monitoring is becoming increasingly critical. Gathering accurate and timely data is pivotal for effective progress tracking. The Traditional construction monitoring approaches primarily rely on manual inspections, data entry, and reporting, which include site visits, visual assessments, and documentation of progress using spreadsheets and paper-based methods (Ibrahimkhil, et al., 2023). These techniques are labor-intensive, time-consuming, and prone to errors, potentially causing delays and failing to provide the actual image of the construction project performance. Moreover, when relying on paper-based methods and spreadsheets, maintaining a comprehensive view of the project's status becomes difficult which can introduce inconsistencies and inaccuracies (Goedert & Meadati, 2008). These problems are acute in developing countries, particularly in Ethiopia, where a growing infrastructure sector and many public construction projects do not pay attention to monitoring and control practices (Birhanu, et al., 2020). Consequently, there is a critical need for more advanced, reliable, and efficient construction monitoring systems.

To overcome these challenges of the conventional construction monitoring process, the integration of innovative technologies such as BIM and LiDAR (Light Detection and Ranging) Scanning technologies is very promising. These technologies are revolutionizing the way construction projects are planned, executed, and monitored by integrating the design and the as-built information. BIM fosters seamless collaboration among architects, engineers, and contractors, offering a holistic approach across the project lifecycle by providing a digital representation of the physical and functional characteristics of the project design (Noaman, 2023; Nguyen, 2020). 4D BIM enables project stakeholders to visualize the construction sequence and schedule dynamically. By linking 3D models with time-related data, teams can simulate construction activities, which aids in understanding the spatial and temporal relationships of various tasks (Vassena, et al., 2023).

Meanwhile, Laser scanning is becoming mainstream for conducting construction surveys due to the accuracy of the data obtained and the speed of the process (Kavaliauskas, et al., 2022). The 3D laser scanning technology can achieve fast and high-precision measurement by creating a "point cloud" dataset of the target building and its components, based on which an accurate as-built 3D BIM model of the scanned items can be established (Wang, et al., 2023; Yelda, et al., 2019). Laser-scanned models provide detailed geometric information, allowing for accurate detection of deviations from design specifications, identification of structural defects, and assessment of material quality. (Martins & Evangelista, 2020).

Automated construction progress monitoring using as-planned building information modelling (BIM) and as-built point cloud data integration has substantial potential and could lead to the fast-tracking of construction work and identifying discrepancies (Kavaliauskas, et al., 2022). It enhances the efficiency of information management and results in improved reliability of the project model which facilitates the integration of the design and construction data (Goedert & Meadati, 2008). Multiple methods of automated construction monitoring techniques have been investigated by various researchers. These studies have demonstrated that remote-sensing technology can be used to obtain 3D data on the actual progress of a project and that the data collection can be performed efficiently.

For instance, In Kurdistan Iraq Laser scanning was applied for monitoring 580-unit apartments and were able to detect defects that had not been able to be detected by the traditional monitoring system (Polat & Ali, 2023). Similarly, In Margarita Dam Photogrammetry is employed to generate a 3D mesh model of as-built data which was then imported into the BIM model to facilitate a comparison between the design and the constructed work (Arbad, et al., 2023). Kavaliauskas, et al (2022) experimented to integrate BIM and laser scan models by the extracting data from the models, calculating the plane equation of the faces, and performing a point-to-plane distance estimation. By comparing the as-built model with the as planed BIM model, the researchers were able to analyze and automatically detect whether the construction of an object was completed or not (Kavaliauskas, et al., 2022). Ibrahimkhil et al (2023) have also tried a novel approach using BIM and laser scanning by the simultaneous localization and mapping technique to gather quick and accurate construction site progress information. As-built and as-planned BIM models were then compared using Python and Dynamo, to obtain progress percentages based on material quantities and were able to obtain an accuracy of 94.67% in estimation of the progress. Notably in Ethiopia, laser scanning has been applied to two projects dedicated to the documentation of heritage sites: monolithic church in Lalibela and Almakah temple of Yeha (Lindstaedt, et al., 2011; Rüther & Palumbo, 2012).

Although research on the integration of BIM and Laser Scanning Technology has increased in recent years, these studies are still at the initial level in terms of understanding and dissemination of the technology. Academic and practical studies of these new technologies are at a very low level, especially in developing countries. This paper aims to investigate the applicability of the integration of BIM and laser scanning application for monitoring selected building Construction projects. By developing as planned 4D BIM model and an as-built laser-scanned model, the actual progress and quality of the project are compared.

2. Methodology

2.1 Study Area

This study focused on one selected ongoing building project of the B+G+11 apartment building project which is located in Addis Ababa Ethiopia, occupying 403 m^2 of area in order to show the integration of BIM and laser scanning application for monitoring building Construction project.

2.2 Study Design

The stages of the study design can be distinguished into the following four points:

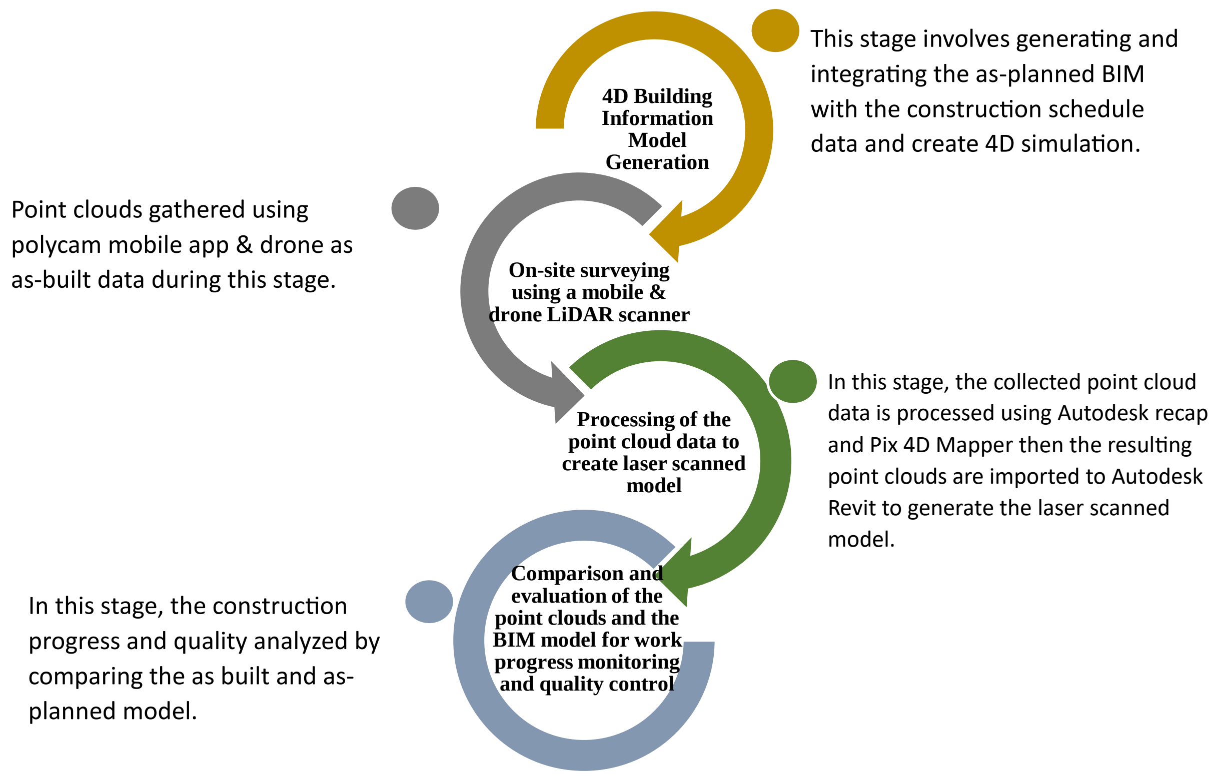

Figure 1: Study design diagram

2.3. Data Collection Method

The data collection process for this study is structured into two primary sections, which is collection of the exiting documents and scanning the existing construction building construction project.

2.3.1 Desk-Study of Conventional Design and Construction Documents

The researcher's initial approach involved extracting relevant information from the conventional design and construction documents, such as 2D drawings, the master schedule, and progress reports. A thorough analysis of these documents formed the basis for creating the 4D BIM, which is essential for accurate progress tracking and effective quality control.

2.3.2 As-Built Scanning

The researchers deployed laser-scanning technology to capture the current state of the construction site. This method allows for the creation of accurate 3D models that reflect the actual conditions of the building. The exterior part of the building was scanned using a drone scanner and the interior part of the building using a LiDAR mobile phone scanner. For scanning the mobile Lidar, two requirements are considered; the type of mobile phone should be above iPhone 12 pro and the method of scanning should be in LiDAR.

Flight path and Noise analysis	Equipment calibration	Monitoring equipment during data collection
• Flight and scanning path determination • Noise analysis done on each floor	• Before collecting the data, all of the equipment shall be calibrated to the manufacturer's specifications and serviced according to the manufacturer's recommendations.	• **Scanning speed**: 5-10m/s • **Data storage availability**: 500GB • **Overlap**: 25-50% • **Flight altitude** • *For exterior: 50-100m*

Figure 0: Drone Lidar scanning parameters

To ensure the Drone Lidar scanning quality the detailed checklist was prepared by considering Drone system requirements, Lidar sensor specifications, Scanning parameters, Flight planning and safety, Data processing and quality control, and Data deliverables. They were defined from previous literatures before the actual scanning took place. Figure 3 illustrates the scanning path defined prior to scanning and possible destructions and Noise identified as indicated in Fig 4.

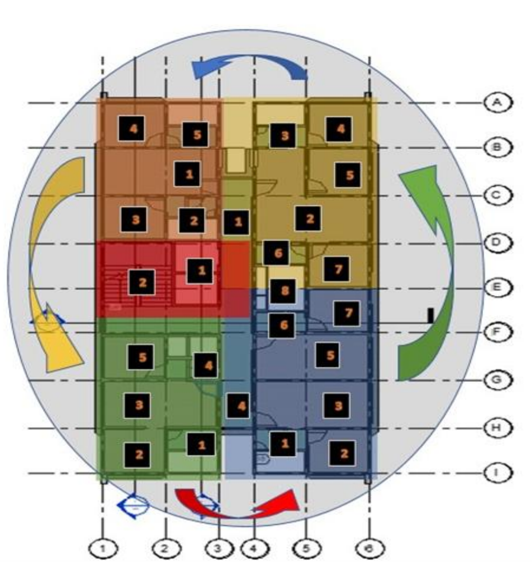

Figure 3: Scanning path

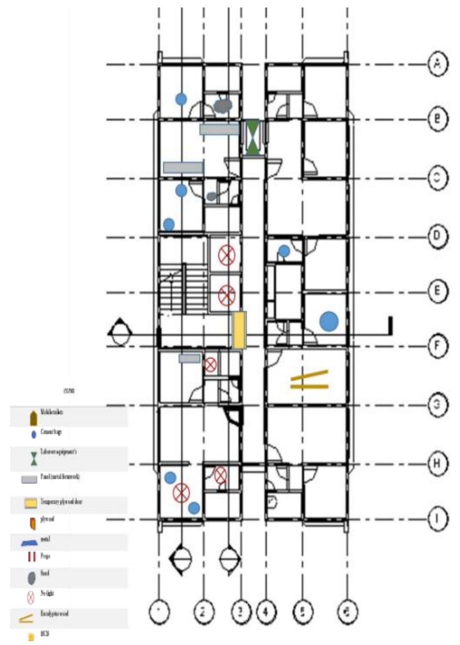

Figure 4: Noise analysis

2.3 Method Analysis

For the development of the BIM model using the conventional design documents Revit and Synchro software have been used. For capturing the current state of the B+G+11 apartment building mobile devices and drone have been used. Figure 5 illustrates the process, tools, and techniques used to analyze the study data.

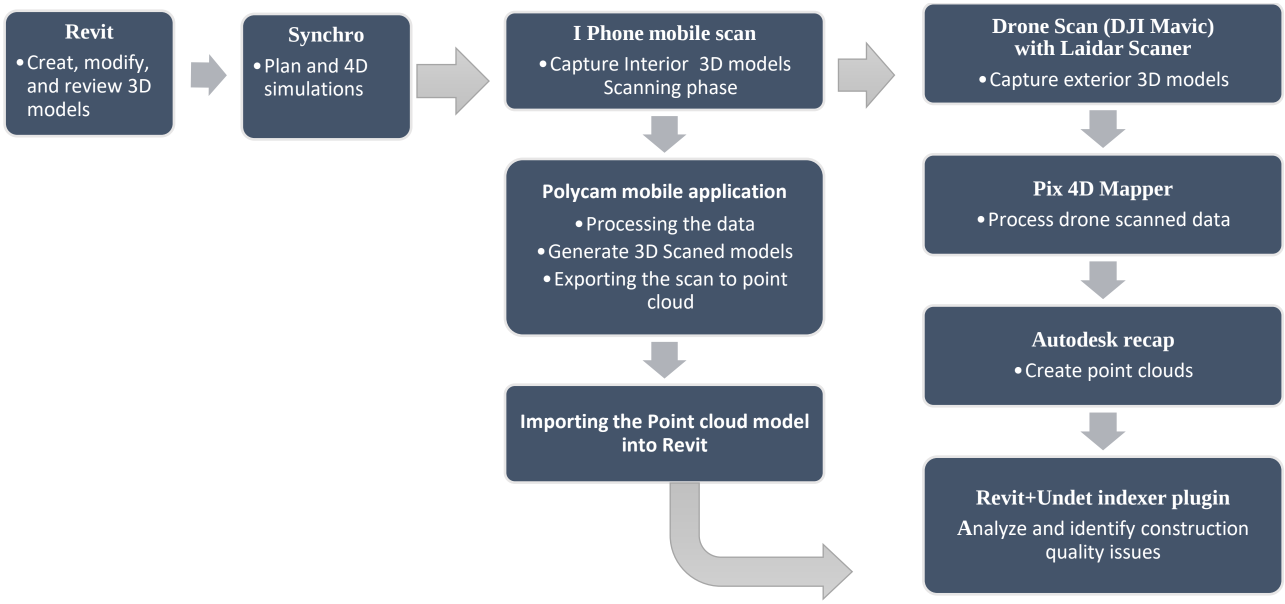

Figure 5: Methods and tools of data analysis

3. Results

The primary objective of this research is to evaluate the effectiveness of integrating BIM and laser scanning in monitoring construction projects. This involves assessing the accuracy of data capture, the efficiency of process workflows, and the overall impact on project management practices. This section aims to provide empirical evidence on the applicability and benefit of BIM and LiDAR Scanning by conducting a series of controlled experiments and real-world applications on a B+G+11 apartment building.

3.1 4D BIM Model Development

To develop the 4D BIM model sequences of activities are done. Figure 6 presents the detailed 3D and 4D model development process.

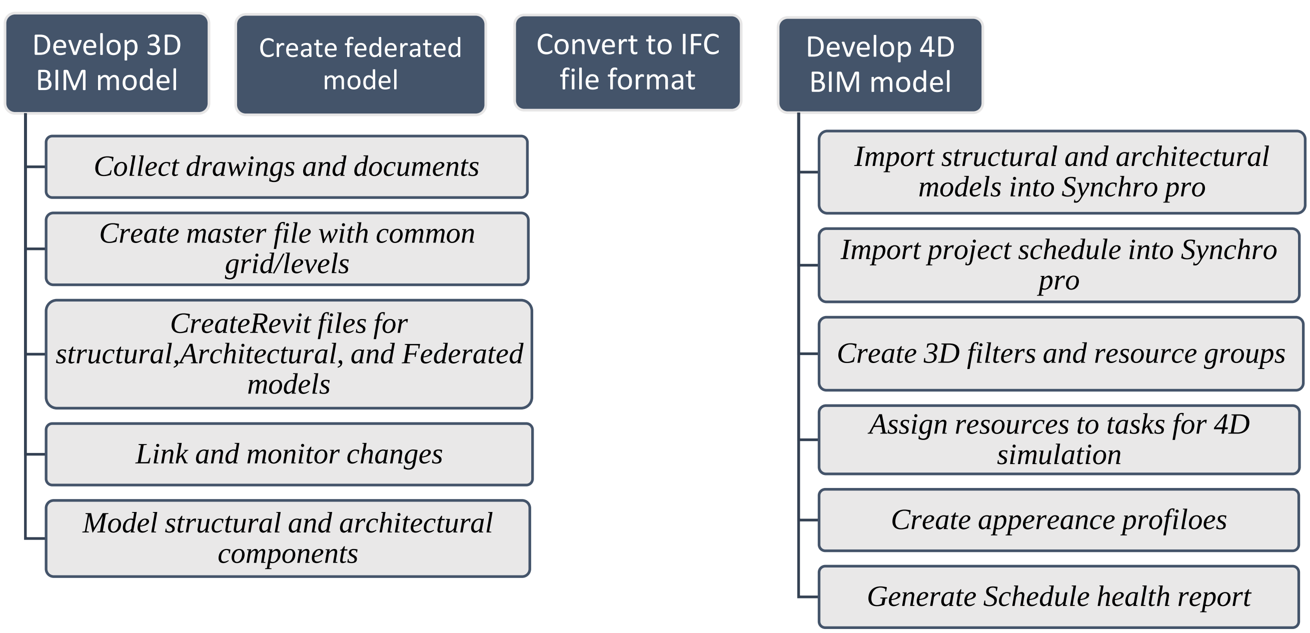

Figure 6: process to develop a 4D BIM Model

The first step was developing a 3D BIM Model from the 2D Architectural and Structural designs. During the development of the 3D model, several challenges were encountered. Initially, the structural drawing up to the second floor was incomplete, which delayed progress until the correct version was found and used to update the model. Additionally, there were two independently designed structural drawings, one from the raft level to the second floor and another from the second floor to the terrace level that lacked sufficient information and conflicted with each other, complicating the modeling process. Furthermore, the absence of an architectural model for the raft level to the second floor added difficulty, requiring reliance on specifications to determine material types and construction methods to proceed with the design.

To address these challenges, cross-checking and understanding the intentions behind the designs are studied and evaluated, by refereeing to specifications to determine material types and construction methods, enabling to proceed with the 3D model development.

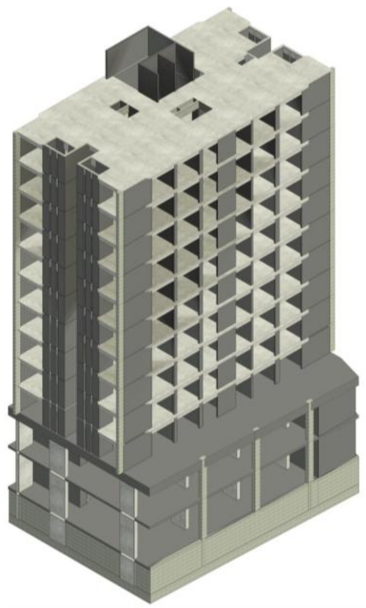

Figure 7: *3D Structural Model*

Figure 8: *3D Architectural Model*

After generating the 3D BIM model, the next step was to develop the 4D simulation using this model and the master schedules obtained from the project. Two master schedules were collected from the site, which were updated based on project progress and adjustments for work variations.

Before creating the 4D simulation, it was crucial to understand the key assumptions, links, and logic behind the master schedules to avoid misinterpreting the plans. Detailed investigations revealed several gaps, including conflicts between the first and second updated schedules and missing activities. For instance, the second master schedule starts at the 6th floor, while the first schedule ends at the 2nd floor.

To establish an accurate 4D model, input was further gathered from office and site engineers, who had a better understanding of the project plan than what was reflected in the master schedules. Historical monthly execution plans from progress reports were also reviewed. Despite these efforts, conflicts between the schedules and discrepancies in the data led to the use of the second master schedule for generating the 4D simulation starting at the 6^{th} floor.

After thoroughly understanding the project plan, the 4D model simulation commenced by importing the 3D models and the adjusted master schedule, followed by creating 3D filters to assign resources efficiently, as assigning resources individually would have been time-consuming and prone to errors. Defining the 3D filters was also critical to prevent mistakes, such as double-assigning 3D elements to specific tasks or failing to assign them altogether. Additionally, a colour palette was established for each element to verify and ensure the proper assignment of the 3D components. Finally, an appearance profile was created to illustrate a growth simulation that visually represents progress from bottom to top and left to right, with different colours assigned to various tasks for clarity.

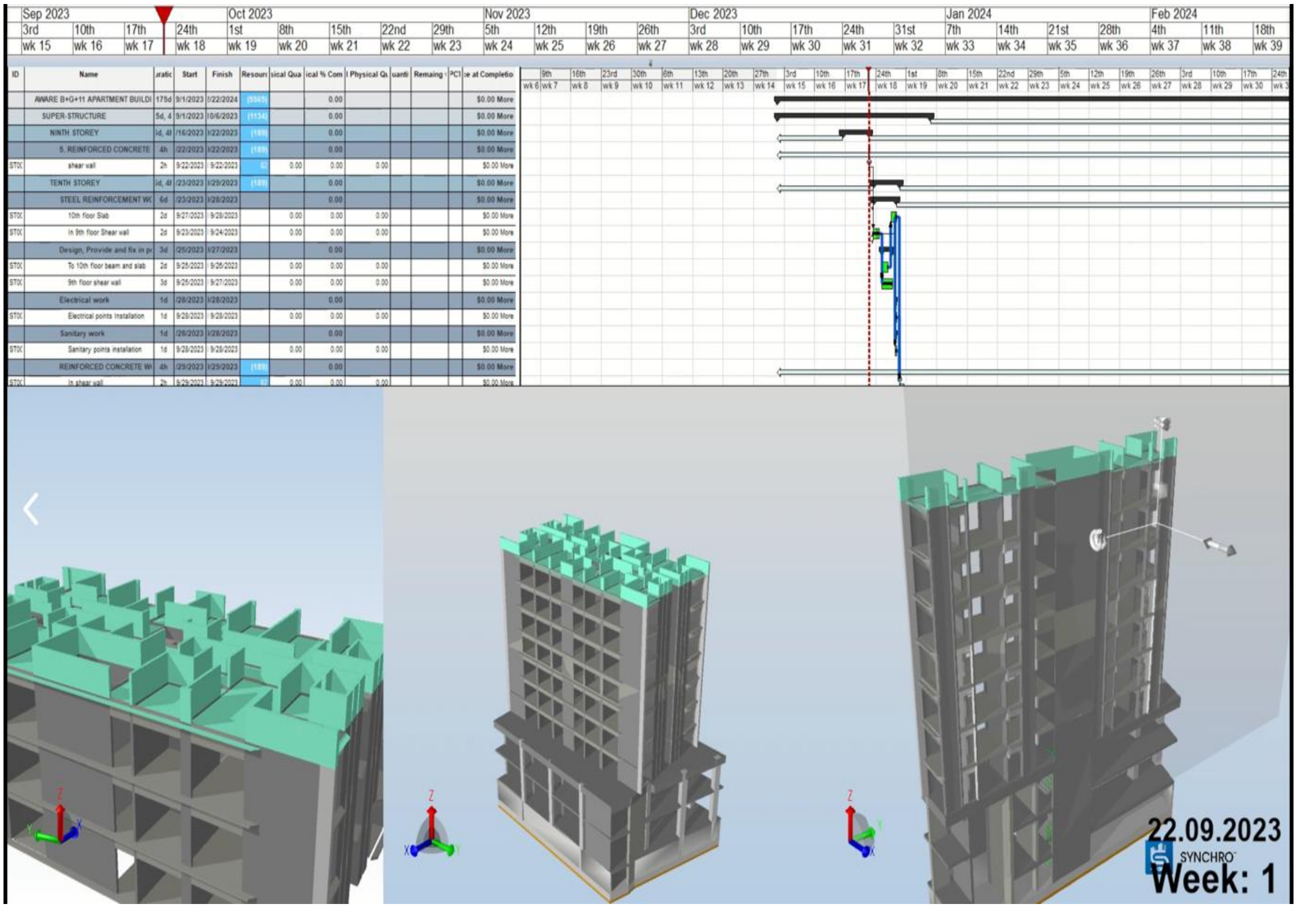

***Figure 9**: 4D simulation*

After 4D model was generated, a schedule health check was extracted from synchro to identify issues on the conventional schedule. These issues involve too tight schedule which make the time plan unrealistic, and tasks without defined predecessors or successors which led to unrecognized durations and potential delays. This affects the total project progress and makes it challenging to track using the plan while synchro automatically identifies and mitigates by limiting the unrealistic plan and also shows the parts where data are not integrated. Figure 10 shows the issues identified using the conventional scheduling method.

According to the findings, in Fig 10 the lead, lag, floats and invalid dates percentages exceeding the limit indicate that the project is behind schedule. In addition, the relationship types that are finished to start decreasing in percentage shows that the schedule is very tight and has a risk of not adhering to the planned schedule.

Synchro Schedule Health Check

Project: D:\4D 1 (4).sp

	Test	Description	Goal	Result
1	Missing Logic	Tasks without predecessors or successors	< 5%	35.24%
2	Leads	Relationships with negative lag	0%	14.92%
3	Lags	Relationships with positive lag	< 5%	20.97%
4	Relationship Types	Relationships other than FS type	< 10%	47.98%
5	Hard Constraints	Incomplete tasks with hard constraints	< 5%	0.00%
6	High Float	Incomplete tasks with at least 44 days float	< 5%	86.79%
7	Negative Float	Incomplete tasks with negative downstream float	0%	0.00%
8	High Duration	Incomplete tasks with at least 44 days duration	< 5%	4.72%
9	Invalid Dates	Tasks with forecasted dates before the Data Date and/or actual dates past the Data Date	< 1	20
10	Missing Resources	Incomplete tasks without scheduling resource assignments	N/A	100.00%
11	Missed Tasks	Tasks with actual finish dates later than baseline plan finish dates	< 5%	0.00%
12	Critical Path Test	Checks critical path integrity	N/A	N/A
13	Critical Path Length Index	Ratio of critical path length + total float to the critical path length	>= 0.95	1.00
14	Baseline Execution Index	Ratio of the number of tasks completed to the number that should have been completed against the baseline	>= 0.95	1.00

Figure 10: Synchro schedule health check

The missing logic affects the total project duration of the project as it doesn't exactly show the sequence and dependency of tasks. The lead, lag, floats and invalid dates percentages exceeding the limit indicate that the project is behind the schedule. In addition, the relationship types that are finished to start decreasing in percentage shows that the schedule is very tight and has a risk of not adhering to the planned schedule.

3.2 Developing Laser Scanned Model of the Project

The scanning process commenced at a stage where the building's structural framework was largely complete, with interior plastering finished up to the fourth floor. In developing laser scanned model two methods were used, Drone with installed LiDAR scanner for scanning the external surfaces and iPhone mobile scanning the internal structures.

3.2.1 Drone Scanning and Processing

As-built data from the construction site were collected with DJI Mavic LiDAR scanner drone by adjusting some parameters to ensure the best quality data output. Before the scanning started, google map was used to extract the exact location of the site by using the live coordinates, then parameters in table 1 were adjusted.

Table 1: DJI Mavic Lidar Scanner Drone Adjustment Parameters

Parameter	Value
Flight attitude	$30m + 38m = 68m$
Side overlap	80%
Front overlap	70%
Point cloud density	1347point/$m3$
Ground sample distance (GSD)	0.82cm/pixel

Figure 11 and Figure12 show setting up the drone parameters as stated in Table 1. Two separate scans were taken where duration of the scan took 4 minutes each flight.

Figure 11: Adjustments of drone parameters

Figure 12: Setting of flight path

The scanned data come into two separate folders for each of the two missions containing 9 types of file extensions (IMU, RTK, RTL, RTS, CLC, CLI, CMI, LDR, and JPG). Both processing software Autodesk Recap Pro and Pix4D Mapper were tested to generate the 3D scanned models from the raw data.

During the 1st mission, a total of 25 images were captured with 2,703,112 points and an average density of 456.46 points/m. However, when converting the scan into 3D models, some areas were identified to be missed. As the picture in Fig 13 indicates the generated model was not satisfactory, hence the second trial was conducted using a Pix 4D mapper.

Figure 13*: 1st Mission data processed using Autodesk Recap*

Figure 14: *1st Mission data processed using Pix 4D Mapper*

The second mission contains 47 scanned images with 4,690,457 points with an average density of 432.18 points per m^3. The processed 3D scanned Model is better than the first mission as indicated Fig 15.

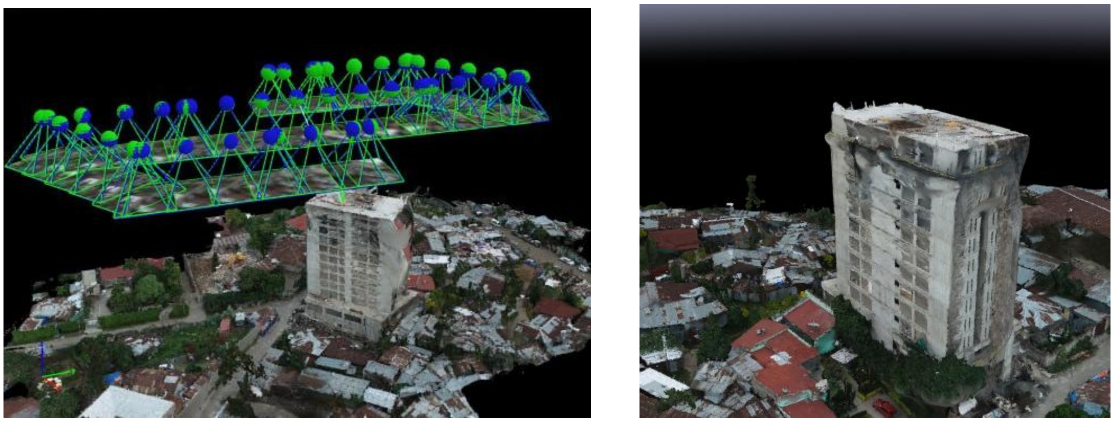

Figure 15: 3D Scanned model processed from the 2nd mission data using Pix 4D Mapper

More enhanced quality scanned model is generated by combining the two-mission data using 72 images from 6,325,559 points with an average density of 505.43 points per m^3.

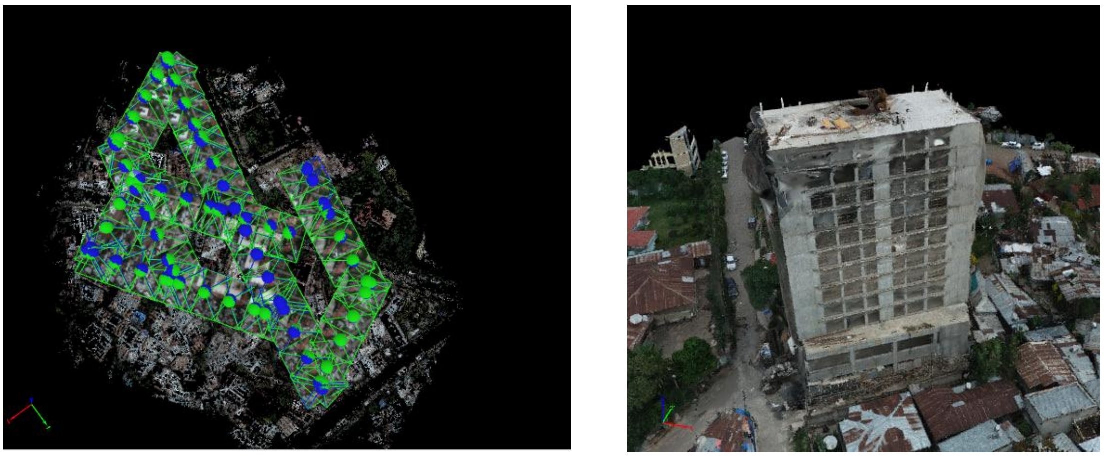

Figure 16: 3D Scanned model processed from both 1st and the 2nd mission data using Pix 4D Mapper

3.2.2. Mobile Scanning

Today's smartphones and tablets have high-resolution cameras and sensors. Some even contain LiDAR (Light Detection and Ranging) scanners that are needed for capturing detailed 3D data. These mobile devices and the accuracy of laser scanning technology create accurate models of real-time project progress. The interior of the building is scanned using a mobile phone as scanning using a drone inside the building has the risk of collusion. Moreover, based on the noise analysis performed before the scanning three floors (1st, 4th and 11th) are selected for scanning. The common challenges encountered during mobile scanning and the mitigation strategies employed are summarized in the table below.

Table 2: Challenges encountered while mobile laser scanning and mitigation strategies used

No	Challenges Encountered	Mitigation Strategies used
1	Natural light distorting the scans	✓ Take multiple scans using different angles and techniques ✓ Covered building openings ✓ Use selfie tick to scan the outsides surfaces of the openings to detect the edges of the openings
2	Height above 2*m* and unreachable objects such as celling and stairs produced poor scan quality and unable to detect edges	✓ Used selfie sticks for improved data capture especially on unreachable edges and ceilings ✓ Refer Fig 18 on how precisely stair case edges are captured after adopting the mitigation

3	Construction site noise impacting data clarity	✓ Conducted noise analysis, ✓ Eliminated controllable noise sources, and ✓ accounted for remaining noise impact ✓ Minor noises recognized and accepted as part of the scan ✓ Remove scans distorted by notices beyond the acceptable level example 11th floor plan was discarded from the analysis refer Fig 17
4	Interruption due to Device battery life limitations	✓ Employed power banks for uninterrupted scanning operation
5	Insufficient overlap between scans and Device's processing capacity as the scan volume increases	✓ Ensure sufficient overlap between scans ✓ Figure 20 demonstrated the distorted model floor plan generated on the 4th floor model

While the scanning process produced satisfactory results for the 1st floor, the data collected from the eleventh floor fell short to produce noise free and complete model as shown in Fig17.

Figure 17: *3D Scanned model of 11th floor with viable noises*

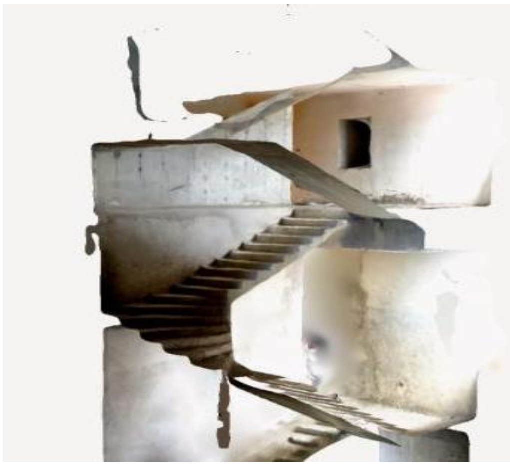

Figure 18: *Mobile scanned staircase*

The distorted and misaligned LiDAR scan output observed on 4th and 11th floors of a building with multiple partitions is likely a result of a combination of factors. Insufficient overlap between scans, a crucial element for accurate alignment, can lead to gaps and mismatches in the data. This can't be achieved because the iPhone's LiDAR sensor, while useful for basic scans, has limitations in range and accuracy, particularly in complex environments. This can contribute to noisy data and inaccuracies in the final model. Movement during scanning, whether it's the iPhone within the environment, can also introduce errors and distortions. Reflections and excess light from surfaces like openings and walls can disrupt the LiDAR signal, resulting in missing data and inaccuracies.

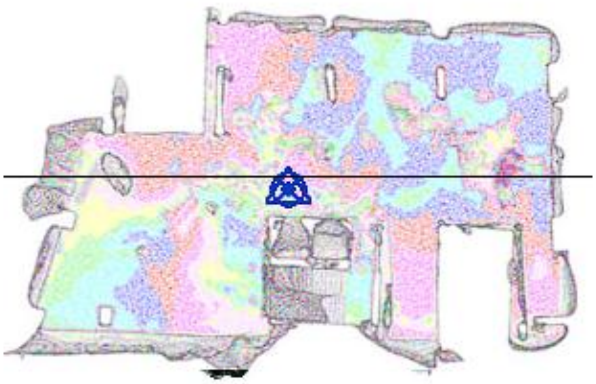

Figure 19: *1st Floor Lidar scan data*

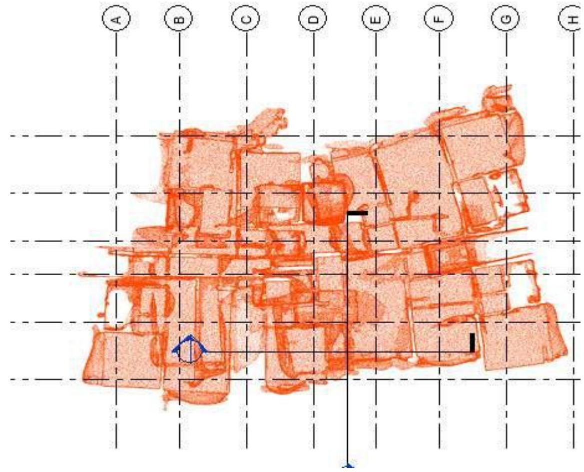

Figure 20: *4th Floor Lidar scanned data using mobile*

To improve the scan quality, it's essential to ensure sufficient overlap between scans, use a tripod for stability, scan in a well-lit environment with minimal reflections, and remove obstacles. By addressing these factors, a more accurate and realistic 3D model of the building can be created

These experiences both demonstrate the potential of mobile scanning technology and highlight its current limitations. Addressing challenges related to natural light, Height/ reachability limitation, construction site noise, and device battery life, and can make future scanning operations more effective and reliable. As technology evolves, incorporating these insights will improve the accuracy and utility of mobile scanning in construction projects, paving the way for more efficient and accurate progress tracking

3.3 Evaluating Construction Project Progress

3.3.1. Evaluation of the Conventional Project Monitoring Technique

Traditional project monitoring methods for building construction often fall short of providing accurate and reliable insights into project progress. This section investigates into the shortcomings of conventional techniques by analyzing the progress reports of the selected case study project.

The primary problem is the lack of effective integration between progress reports and updated project timelines. This disconnects leads to confusing documentation that fails to accurately represent the project's real-time status. Consequently, the project is significantly behind schedule, with a 113.21% overrun in the planned timeline and only 50.8% of the work completed, compared to the scheduled 57.62%. This indicates poor project management and tracking, contributing to delays and inefficiencies.

In addition to that, there were two separate reports for the actual work done, one the physical status percentage and the other to date executed percentage which is a progress report expressed with quantity and amount. This indicates either there was a data collection error or an overestimated quantity. This also highlighted lack of integrated data management in the conventional method which doesn’t give the real image of the project status that resulting in inaccurate progress reports and ineffective project tracking.

Moreover, the result indicated that there is a significant discrepancy which emphasizes a systemic problem where reported progress frequently exceeds actual accomplishment. For example, earthworks were claimed to be 106% complete, which is statistically impossible and misleads non-technical stakeholders about the project's true status. These errors often stem from inaccurate quantity estimations, as the entire project plan relies on these estimations as a baseline. The figure illustrates the difference between the estimated contract amount and the reported actual work following the completion of structural works.

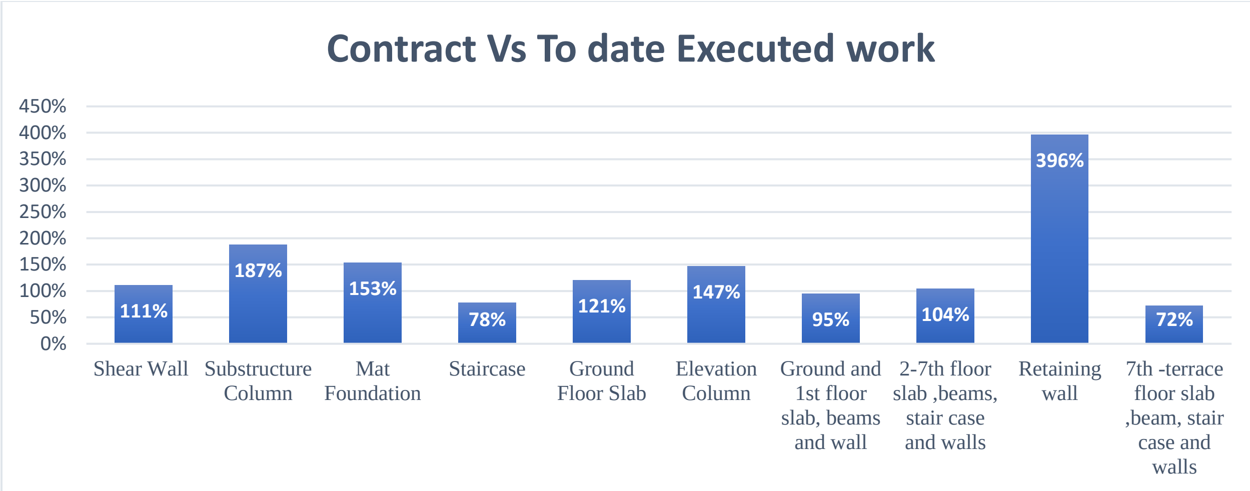

Figure 21: *Quantity comparison between contract vs executed*

The results in Fig 20 reveals notable discrepancies between contract quantities and the quantities actually executed for various structural elements. For instance, elements such as substructure columns, mat foundations, retaining walls, and ground floor slabs have executed quantities that surpass the contract amounts. This discrepancy suggests possible underestimation in the contract or data collection error of the reported executed work. The results suggest that the monitoring techniques employed may not accurately measure actual progress. After structural works are completed, the completion percentage should ideally be 100%. However, a value exceeding 100% indicates potential errors in either the baseline quantity estimates or the measurement of actual work quantity. To understand the source of the error furthermore analysis was done by comparing quantities generated from the structural 3D BIM with the executed model.

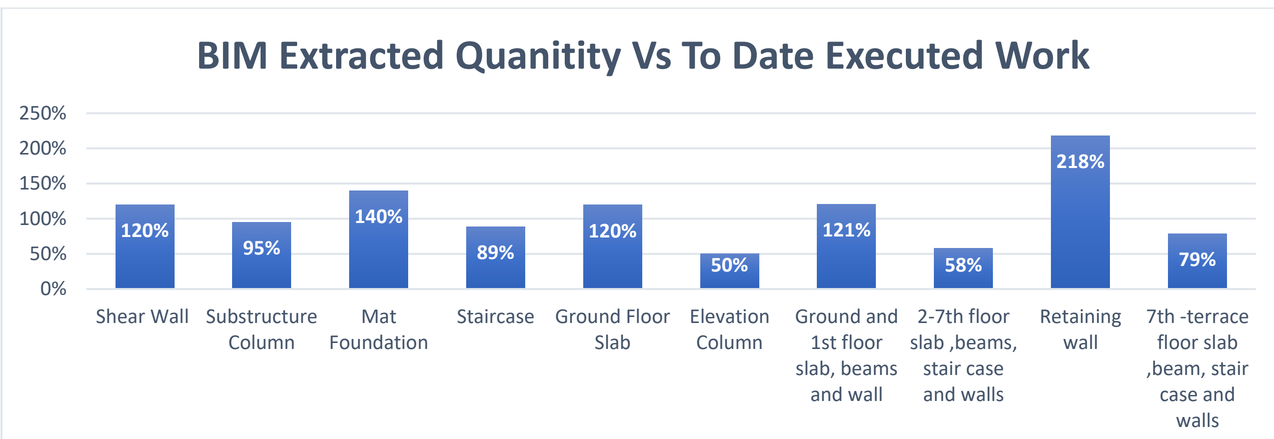

Figure 22: *Quantity comparison between contract vs executed vs 3D BIM model for substructure*

Furthermore, when analyzing the 3D BIM model's derived quantities against the to-date executed quantities for elements such as shear walls in the substructure, mat foundations, ground floor slabs, and beams and walls in the ground and first floors, as well as retaining walls, the executed quantities exceeded those predicted by the BIM model. Even though the variation between the estimated quantity and the executed work has reduced it still does not reflect the actual physical status. Where most of the status is above 100% and some completed works such as the elevation column less than 100% execution, which indicates problems in the reported work executed. This discrepancy indicates potential issues in data collection and quantification, as well as the likelihood of rework, further highlighting the importance of accurate initial estimates and ongoing project monitoring.

Without the proper figures to represent the actual progress of the project monitoring and controlling decisions are ineffective. The contrast between reported and actual work progress stresses the limitations of traditional data collection and reporting methods. These shortcomings hinder effective decision-making and compromise project quality. Additionally, the analysis revealed that many contract quantities were underestimated, leading to significant cost overruns and wastage as the executed quantities far exceeded the original estimates.

3.3.2 Progress tracking using the 4D Model and the Laser Scanned Model

Using 4D model and laser scanned model for assessing the project progress, identify any deviation and improving project visualization. Creating 4D in 3D model offers stakeholders visualization of the designed building progress and facilitates better planning and scheduling. The laser scanned model is provides precise real-time progress of as-built building and enabling accurate comparison of between planned and actual construction progress.

Progress Tracking using the Developed 4D Model involves using the progress report and the laser-scanned data to compare the actual work with the planned one.

***Figure 23:** Progress tracking process*

In order to visually understand what the project should reach at the time of the evaluation look a head plan of April 2024 are generated from the 4D Model. Using the April 2024 progress report the collected the project status are feed into the 4D model and the current state of actual progress of the project are generated. As illustrated in Fig 23 stakeholders of the project can understand and track the progress of the project easily even without any technical details. Furthermore, the scan models are utilized to compare the as planned vs as built model visually. According to the as planed model in Fig 23, painting works, installation of windows terrace roofing works should have been completed. However, the 3D scan model in Fig 16 indicated these activities have not yet been started.

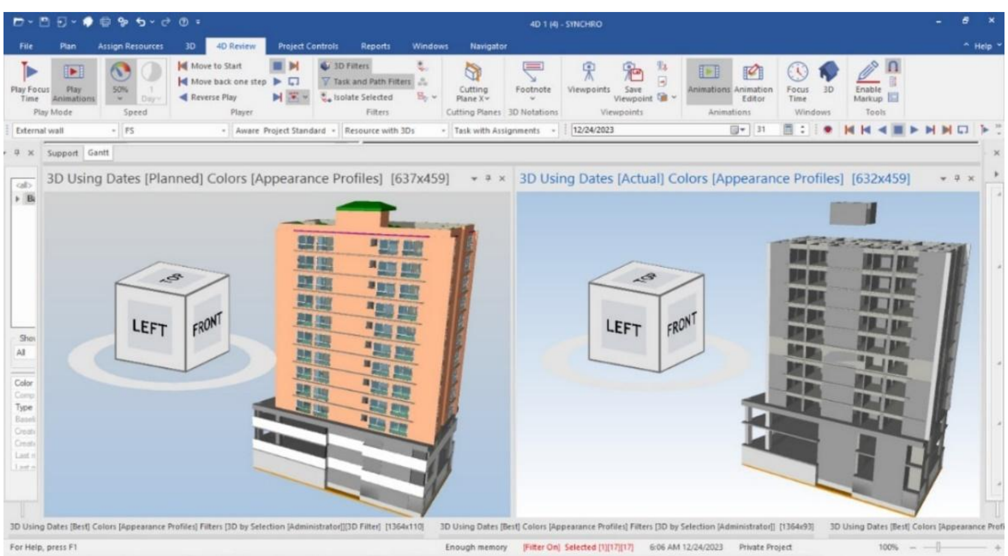

***Figure 24:** Comparison of As Planed 4D Model, and Actual Progress of 4D Model*

For the internal work progress checking the 3D planned model was of the first floor was computed though visual check of the scanned model. By comparing as planned model incomplete works are easily identified.

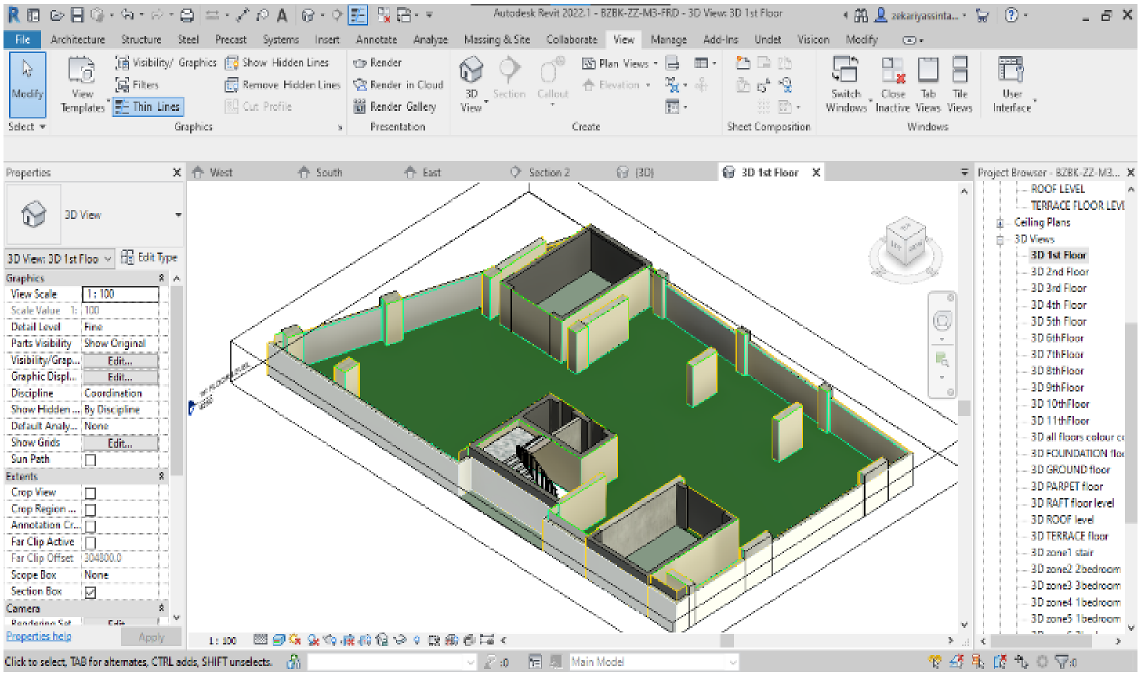

Figure 25: Comparison of 1st floor planed 3D model and actual progress of scanned model

3.4 Evaluating Construction Project Quality Using 3D Model and The Laser Scanned Model

In this stage of analysis, the primary objective is to highlight the importance of using additional standalone software, to automate the detection of construction quality problem issues. We have utilized the Undet Indexer, in enhancing the scan to BIM process.

3.4.1 Surface Analysis Tool

One of the key features of the Undet Indexer is the Surface Analysis Tool. This tool is used to compare 3D models to point clouds, ensuring that the designed model accurately reflects the scanned data. In the current circumstance, this software's results are used oppositely because the tool is typically employed to control the quality of the designed model with reference to scanned data. However, in this case, the comparison is made between the scanned model and the designed model. As a result, the interpretation of the output is reversed; negative results indicate that the surface of the scanned element is outward further from the designed model, while positive results suggest that the surface of the scanned element is inward within the designed model.

First, the Undet Indexer is installed and loading the plugin into Revit. Next, the point cloud file is processed using the Undet Indexer. The designed model is then opened and the processed point cloud data is loaded into the Revit model using the Undet plugin. The point cloud data is aligned with the designed model using the rotate and move functions. After alignment, the Undet Surface Analysis Tool is used to compare the point cloud data with the designed model. The user adjusts the options, selects the host, and starts the analysis. Once the analysis is complete, the Undet Indexer automatically generates the results using colors, and each colors have their own assigned measurements describes in the legend.

In the first trial, the software's default parameters are used which are inward tolerance level was set to 60*mm* and the outward was 100*mm*, as shown in Fig 26 and the function was run for structural shear walls and the terrace floor.

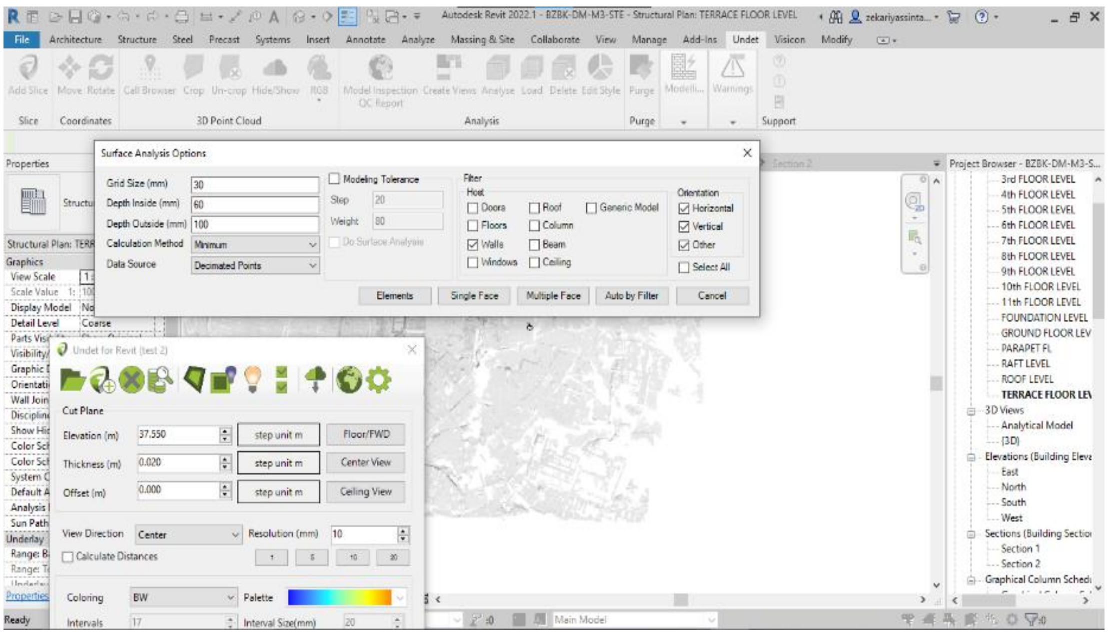

Figure 26: *Surface analysis option and setting up*

After the analysis, the results showed that the tolerance varied from -100*mm* to +60*mm* with most walls appearing in red and most parts of the terrace floor in yellow. However, it was not possible to determine whether the elements had shifted inward or outward relative to the designed model because the legend used one color palette for two tolerance values.

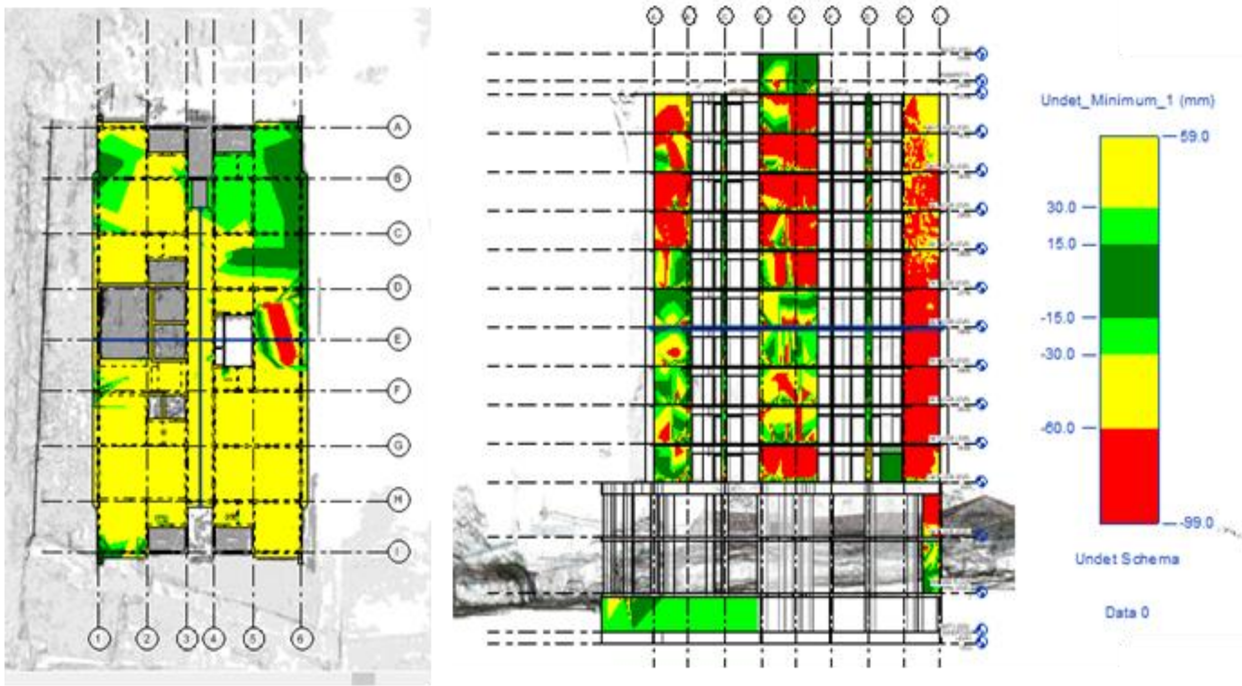

Figure 27: First trial terrace floor level and shear walls quality checking using drone scanned model vs 3d design model

In the second trial, the parameters were adjusted to 100*mm* inside depth and 100*mm* outside depth. The function was then run again for the building elements from the first trial, as well as for interior walls and floors on the 1st floor that were scanned using a mobile device.

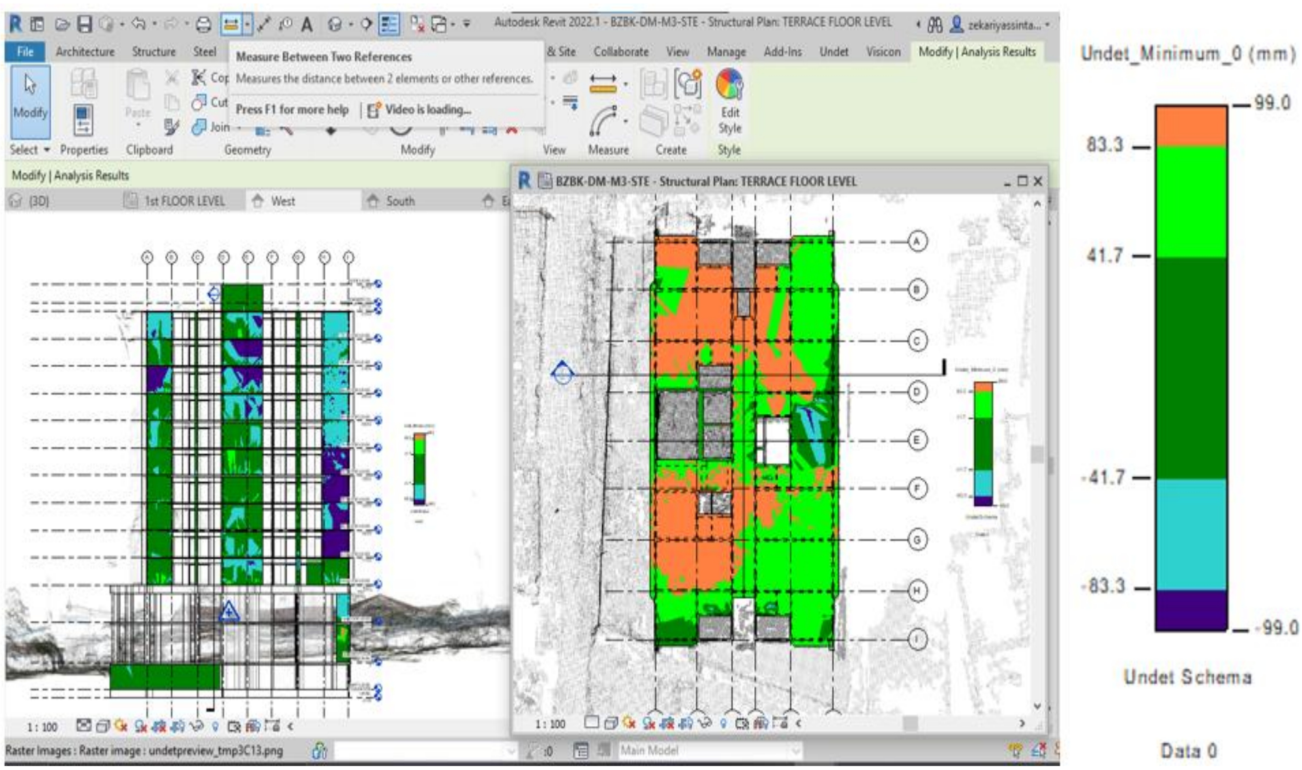

***Figure 28**: Second trial terrace floor level and shear walls quality checking using drone scanned model Vs 3D design model*

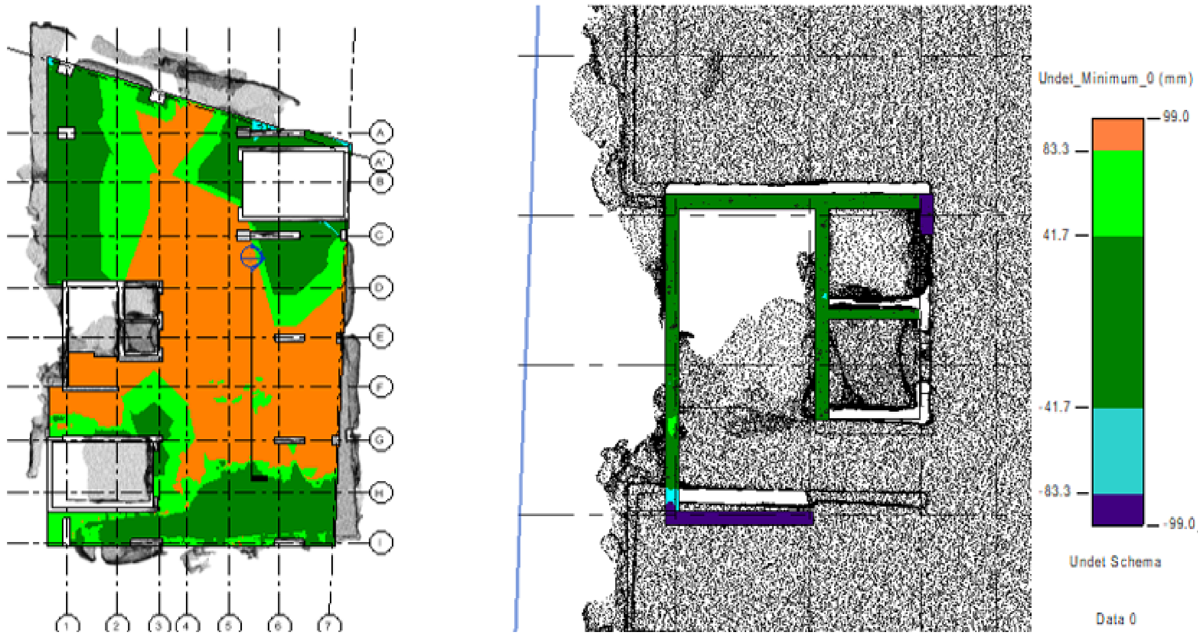

Figure 29: *Second trial quality checking using mobile scanned 1st floor model Vs 3D design model*

After the analysis, the results showed that the tolerance varied from -100*mm* to +100*mm*. This time, it was possible to determine whether the elements had shifted inward or outward relative to the designed model, as the legend used different color palettes to denote the tolerance values.

In general, The Surface Analysis Tool in the Undet Indexer software is a valuable feature that helps in comparing 3D models to point clouds. By using the Surface Analysis Tool, users can visually assess the alignment and discrepancies between the point cloud data /obtained from Drone Lidar scans and Polycam Mobile Phone Scanner/ and the corresponding designed model. The tool allows for a detailed comparison of the surfaces in the point cloud data with the surfaces in the designed model. Results with number zero indicate that the surface of the scanned element is within the designed model, while Positive and negative results suggest that the surface of the scanned element deviates from the designed model. The results are presented using a color-coded system, where each color corresponds to a specific measurement or deviation, as described in the legend provided by the software. This method is promising in enhancing the accuracy and quality of the Scan to BIM process by ensuring that the final BIM model reflects the real-world conditions captured by the LIDAR scans.

4. Discussion

The integration of Building Information Modeling (BIM) and Laser Scanning technologies in construction monitoring presents a transformative approach to addressing prevalent challenges in the industry. This discussion synthesizes the findings from the research and contextualizes them within existing literature, emphasizing implications for practice and future research.

4.1 Developing a 4D BIM model

The Development of 3D BIM model enables the researchers to detect data integration issues and conflicts in the design documents which as undetected or ignored in the 2d Design documents. 3D BIM improves coordination among various disciplines, allowing teams to work independently while effectively linking their models to monitor changes and reduce conflicts and issues common in 2D models that lack a holistic view.

Additionally, the development of 4D model enables visualization of both spatial and temporal aspects of construction, enabling effective tracking of project progress over time. Overall, 4D BIM enhances communication and decision-making, for addressing most of the scheduling issues detected during the model development process, which is essential for improving project efficiency and maintaining alignment with the schedule.

Hence the development of BIM models and precise plans is crucial for progress monitoring, especially for complex projects where errors in the qualifications of works could lead to misrepresentation of the actual progress and estimated budgets as well.

4.2 Developing Laser-Scanned Model

Developing a laser-scanned model of actual project progress is crucial for accurate monitoring and quality control in construction projects. By using LiDAR technology, this approach effectively captured the physical state of the B+G+11 apartment building, allowing for a precise comparison between as-built conditions and planned designs.

The integration of both external and internal scanning methods using a DJI Mavic drone and an iPhone mobile scanner boosted the model's accuracy and detail. Before scanning, an extensive preliminary assessment and noise analysis facilitated the creation of enhanced scanning paths, which were essential for minimizing disruptions and ensuring high-quality data capture. Effective site management, including the removal of movable elements, reducing light disruptions, etc. improved data quality.

Additionally, for drone scanning understanding and controlling flight attitude, overlap, and ground sample distance (GSD) were critical for precision in applications like aerial surveying and mapping, ensuring accurate and complete data collection. The capability to generate a 3D model from the scanning process provided significant benefits, making the laser-scanned model a vital tool for tracking project progress and verifying alignment with the planned construction timeline.

4.3 Evaluating Construction Project Progress Using 4DModel and The Laser Scanned Model

The Quantities of work extracted from BIM models were used to detect and validate quantity estimation errors presented in the conventional progress report document. Moreover, possible errors in data collection of concrete works also identified. The findings of this analysis clearly demonstrate the need for improved project Planning and monitoring methods.

The evaluation of construction project progress using the 4D model and laser-scanned model is a fundamental aspect of modern project management. This study highlights the integration of these technologies to assess the actual progress of a selected B+G+11 apartment building construction project. By utilizing the 4D model, which combines the 3D representation of the building with the project schedule, stakeholders can visualize the timeline and identify discrepancies between planned and actual progress. The use of Augmented reality technologies would further enhance the quality of visualization planned vs scanned models for improved progress tracking.

The findings indicate that the integration of these models facilitates a broad understanding of project status, enabling the identification of delays and quality issues. For instance, the laser scanning revealed that many finishing works were not completed as scheduled, confirming the project's lag behind the planned timeline. This empirical evidence underscores the effectiveness of combining BIM and laser scanning technologies in monitoring construction progress and highlights the potential for improved project management practices through enhanced data accuracy and workflow efficiency.

The above results comparing and evaluating the designed 3D model and laser scanned model have a promising outcome that we automatically generated the deviation between the two models. However, the study's findings were limited to visual inspection and understanding of the plan vs scanned model for progress tracking, due to the scanning device quality limitation and accessibility of tools to extract quantities of work executed from the scanned model. Hence comparisons of quantities of as built model vs as planned model have not been conducted.

The quality of the progress tracking can be enhanced and automated furthermore using high-quality scanners and with the aid of comparison tools as recent studies in this area indicated (Ibrahimkhil, et al., 2023; Kavaliauskas, et al., 2022; Yelda, et al., 2019). For instance, the development of extracting quantities from scanned models has been experimented by Ibrahimkhil, et al(2023) on masonry walls that show a promising result. Utilizing tools for automatic extraction of the percentage of completion from the laser-scanned model would further enhance this evaluation by providing precise measurements of the physical structure, allowing for a detailed comparison against the 4D model.

4.4 Evaluating Construction Project Quality Using 3D Model and The Laser Scanned Model

Using 3D models and laser scanning technology significantly enhances construction quality control. The laser scanning process captures precise measurements of built elements, allowing for detailed analysis against the 3D model. This analysis is crucial for detecting issues such as misalignments, dimensional inaccuracies, surface leveling problems, and other construction defects that might not be apparent through conventional inspection techniques.

Automated quality analysis revealed deviations of up to 100*mm* between planned and actual construction, highlighting the importance of advanced technologies in evaluating construction quality. Such empirical evidence underscores the importance of utilizing advanced technologies in construction quality evaluation. In addition, the automated quality control method enables to detection of defects with small-scale deviation and ignored by human error.

The evaluation of construction quality using these models significantly influences project management practices. By identifying quality issues early in the construction process, project managers can implement corrective actions quickly, thereby reducing the risk of costly rework, cost overruns, and delays. The research findings indicate that integrating BIM and laser scanning not only improves the accuracy of quality assessments but also enhances the overall efficiency of construction monitoring.

Even though the study has not accounted for material quality and rebar counting to check the quality of the work by analyzing only the physical characteristics of concrete structures visible externally, it showed a promising potential of BIM and laser scanning in automating and improving the quality-checking mechanisms of the construction works. Hence, further studies to address such limitations could make automation of construction monitoring processes one step closer.

4.5 Effectiveness of Integrated Monitoring Techniques

The results indicate that the combined use of BIM and Laser Scanning significantly enhances the accuracy of construction progress monitoring. Traditional methods were found to be inadequate, often leading to discrepancies between reported and actual progress. This contrast highlights the systemic issues in traditional monitoring practices, where subjective assessments and manual reporting can lead to inflated progress claims.

The integration of BIM with Laser Scanning allows for real-time data capture and analysis, providing a more reliable basis for decision-making. The study demonstrated that utilizing BIM models linked with actual site data from Laser Scanning can effectively detect quality problems such as vertical and horizontal alignment issues of walls, columns, and openings, thereby minimizing the risks of delays and cost overruns. This aligns with findings from other studies that emphasize the potential of automated monitoring systems to improve project outcomes by providing timely and accurate information (Ibrahimkhil, et al., 2023; Polat & Ali, 2023; Wang, et al., 2023)

4.6 Challenges Encountered in Implementation

While the integrated approach shows promise, several challenges were encountered during the implementation phase. The development of the 3D BIM model faced significant hurdles due to incomplete and conflicting architectural and structural drawings. Such issues underscore the importance of having accurate and comprehensive design documentation prior to the commencement of construction. The need for collaboration among stakeholders to ensure that all design documents are aligned cannot be overstated, as discrepancies can lead to delays and increased costs.

Moreover, the reliance on updated master schedules revealed gaps in project planning and execution. The discrepancies between the first and second schedules necessitated a thorough understanding of the project's historical context and assumptions. This points to a critical area for improvement in project management practices, where better communication and documentation can enhance the reliability of progress tracking and resource allocation.

The other a critical challenge that in relation with the availability and accessibility of various devices and raw data processing software which has limited the outputs exterior of the building which was scanned by LiDAR drone was processed and 3D model was generated by using photogrammetry.

4.7 Implications for Future Research and Practice

The findings of this study have significant implications for both academic research and practical applications in the construction industry. Future research should focus on refining the integration techniques of BIM and Laser Scanning, exploring the potential for automation in data collection and analysis by fading other aspects of construction monitoring such as budget tracking, health and safety issues. Additionally, studies could experiment on automatic extraction of the percentage of completion of the executed work from the laser-scanned model would further enhance the automation of progress tracking, which could provide accurate measurements of the actual constructed works and to make a detailed comparison against the 4D model.

From a practical standpoint, construction firms should consider investing in training for their workforce on the use of BIM and Laser Scanning technologies. As the industry shifts towards more technologically advanced monitoring systems, equipping personnel with the necessary skills will be crucial for successful implementation. Furthermore, establishing standardized protocols for data collection and reporting can enhance the reliability of project monitoring and foster greater transparency among stakeholders

5. Conclusions

The integration of BIM and Laser Scanning technologies offers a robust framework for improving construction monitoring practices. The research findings underscore the need for a paradigm shift in managing construction projects, moving away from traditional methods towards a more automated and data-driven approach.

The utilization of 4D modeling enabled to identify of discrepancies between actual work and planned schedules, revealing precise lags and current project progress. Our analysis highlighted poor planning and estimation issues, with Synchro detecting scheduling problems that could lead to time and cost overruns.

Deviations in various activities on the conventional progress report indicated potential quantification and data collection errors and accuracy issues, stressing the need for improved project monitoring techniques to reflect progress accurately.

Quality analysis was visually represented through color-coding and effectively communicated quality issues such as misalignments, dimensional inaccuracies, surface leveling problems, and other construction defects that may not be visible through traditional inspection methods. These findings highlight the significant potential of integrating advanced technologies in construction project management and suggest that further research could explore refining these methods and expanding their application to enhance project outcomes across the industry.

6. Acknowledgment

First and foremost we would like to thank Debre Berhan University, for funding and providing unlimited support throughout the entire research process. The Ethiopian Information Network Security Administration (INSA), for supporting this research by providing the drone used to scan the building and their professional expert advice from Drone operators and Geo special engineers. Ovid Construction, for permitting us to scan their project and for providing us with the data we needed to conduct the research. Mr. Dereje Alemu, Nardos Nigusu, and Yohannes Mulugeta for their genuine support and professional insights throughout the project.

7. Abbreviations

1. **BIM -** Building information modeling

2. **GSD:** Ground Sample Distance
3. **LiDAR:** Light Detection and Ranging

8. References Cited

Arbad, A. P., Arifin Z., N., Martina, N., Nindya E., P., & Nurfa, M. A. (2023). Monitoring Work Progress of Dam Construction Based on Photogrammetric Point Clouds and Bim: Practical Approach to Teaching Industry. *International Conference on Geomatics Education – Challenges and Prospects (ICGE22). XLVIII*, pp. 1-5. Hong Kong SAR, China: The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences.

Birhanu, A., Kebede , G., & Legese, A. (2020). *Factors that affect monitoring and controlling practices on public building construction projects in Jimma zone.* Jimma, Ethiopia: Jimma University.

Goedert, J., & Meadati, P. (2008). Integrating Construction Process Documentation into Building Information Modeling. *Journal of Construction Engineering and Management*, *134*, 509-516.

Ibrahimkhil, M. H., Shen, X., Barati, K., & Wang, C. C. (2023). Dynamic Progress Monitoring of Masonry Construction through Mobile SLAM Mapping and As-Built Modeling. *Buildings, 13*(930). doi:https://doi.org/10.3390/buildings13040930

Kavaliauskas, P., Fernandez, J., McGuinness, K., & Jurelionis, A. (2022). Automation of Construction Progress Monitoring by Integrating 3D Point Cloud Data with an IFC-Based BIM Model. *Buildings*, *1754*(12). doi:https://doi.org/10.3390/

Lindstaedt, M., Mechelke, K., Schnelle, M., & Kersten, T. (2011). Virtual reconstruction of the Almaqah temple of Yeha in Ethiopia by terrestrial laser scanning. *4th ISPRS International Workshop 3D-ARCH 2011: 3D Virtual Reconstruction and Visualization of Complex Architectures. SPRS Archives XXXVIII-5/W16*, pp. 199–203. Trento, Italy,: The International Archives of the Photogrammetry Remote Sensing and Spatial Information Sciences.

Martins, S. S., & Evangelista, A. (2020). Evaluation of 4D BIM tools applicability in construction planning efficiency. *International Journal of Construction Management*, *22*(15), 2987–3000.

Polat, H., & Ali, N. M. (2023). A case study of quality control application with BIM-laser scanning collaboration in building construction process. *Eastern-European Journal of Enterprise Technologies*, *5/2*(125), 56-66.

Rüther, H., & Palumbo, G. (2012). 3D laser scanning for site monitoring and conservation in Lalibela World Heritage Site, Ethiopia. *International journal of heritage in the digital era*, *1*(2), 217-232.

Vassena, G. P., Perfetti, L., Comai, S., Ventura, S. M., & Ciribini, A. L. (2023). Construction Progress Monitoring through the Integration of 4D BIM and SLAM-Based Mapping Devices. *Buildings, 13*(10), 2488. doi:https://doi.org/10.3390/buildings13102488

Wang, J., Yi, T., Liang, X., & Ueda, T. (2023). Application of 3D Laser Scanning Technology Using Laser Radar Application of 3D Laser Scanning Technology Using Laser Radar. *remote sensing*, *5*(65). doi:https://doi.org/10.3390/rs15010064

Yelda, T., Michael, J., John, G., & Nisha, p. (2019). *Project progress tracking using LIDAR and 4D design models.* Washington DC: Oregon State University.