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Analysis of Existing Building Structures Using Laser Scanner and 3D Models

Dr. Jay Lee, California Baptist University

Dr. Lee's research interest is in information technology and strategic decision-making practices in various engineering management fields. His current research topics include using a 3D scanner for the analysis of as-built drawings and advanced Building Information Modeling (BIM) applications.

Dr. Jeyoung Woo, California State Polytechnic University, Pomona

Dr. Jeyoung Woo is an associate professor in the Department of Civil Engineering at California State Polytechnic University, Pomona (Cal Poly Pomona). He is a registered Professional Engineer (Civil - Construction) in Texas. He has worked in the industry for nine years and he has conducted several research projects about engineering education, construction labor productivity, and construction sustainability. He earned a Ph.D. and an M.S. in Civil Engineering from The University of Texas at Austin (UT-Austin) and a B.S. in Architectural Engineering from Hanyang University, ERICA. He is a member of the American Society for Engineering Education (ASEE), the American Society of Civil Engineers (ASCE) and the Project Management Institute (PMI).

Allan Ng, California State Polytechnic University, Pomona

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Abstract

The construction industry is increasingly adopting 3D scanning technology, which has gained popularity as the technology advances. Laser scanning can accurately map and visualize existing infrastructure, providing data-rich 3D point cloud models. This technology serves as a fundamental platform for Building Information Modeling (BIM) and immersive technology. Recent studies suggest that using appropriate 3D scanning techniques can enhance the reconstruction processes of existing buildings, particularly in the absence of necessary documentation. During inspections, 3D scanners not only enable safe assessments of current structural conditions but also improve the quality and accuracy of inspections compared to traditional visual methods. Additionally, 3D scanners can measure existing buildings when drawings are unavailable, leading to reduced construction time and costs. This paper presents a case study conducted on a university campus building, focusing on ensuring the accuracy of point cloud data for potential future work. The study follows a three-step process: 1) Using a 3D scanner to gather point cloud data from the existing building, 2) Measuring the existing building using the collected point cloud data, and 3) Comparing the point cloud data with in-situ measurements for validation and quality assessment using statistical analysis methods. In conclusion, this project highlights the potential of 3D scanning technology to optimize construction processes, improve inspection outcomes, and facilitate data-driven decision-making in the built environment.

1. Introduction

3D laser scanning, often referred to as simply 3D scanning, is an emerging technology with numerous applications in the built environment, such as scanning buildings or surveying areas. A 3D scanner generates point cloud data, which graphically represents an object. This point cloud data consists of data points produced by the scanner and plotted in a 3D coordinate system [1]. Once plotted, the data is registered together to create a complete image of the scanned object. The resulting point cloud can then be processed to build a 3D model [4], which is used for tracking work progress, monitoring productivity, and performing quality assessment and control during construction [5].

In recent years, 3D scanning technology has surged in popularity within the construction industry [3]. This technology can accurately map and visualize existing infrastructure, generating data-rich 3D point cloud models. It serves as a foundational platform for 3D modeling, particularly Building Information Modeling (BIM), and immersive technology used during the planning stages of construction, especially for renovating existing buildings.

Recent studies [2], [3] suggest that utilizing appropriate 3D scanning technology can significantly enhance the reconstruction processes of existing buildings, particularly when essential documentation is lacking. Beyond aiding in the production of point clouds for construction planning, 3D scanners prove beneficial post-construction. For instance, during inspections, 3D scanners enable safe assessments of current structural conditions, improving the quality and accuracy of inspections compared to traditional visual methods. Additionally, 3D scanners can measure existing buildings in the absence of original drawings, leading to reduced construction time and costs during renovations.

The usage of 3D models in the planning stages of renovation has become increasingly prominent in engineering and construction. These models offer accurate, time-saving, and cost-effective solutions compared to traditional methods. The process of creating 3D models from point cloud data begins with geometric modeling. To develop these models, three types of knowledge are required: 1) knowledge of object shapes, 2) identification of objects, and 3) understanding of the relationships between objects [4]. These areas of knowledge are essential for assembling a comprehensive 3D model that accurately represents the intended design.

When inspecting existing buildings, the current conditions are typically diagnosed through visual evaluation. The initial visual inspection results can then be supplemented with further tests or diagnoses to determine the next steps in the renovation process. This traditional visual inspection technique can now be enhanced by assessing the building's condition using a scanned image. By overlaying a point cloud of the scanned image onto the original building model, inspectors can easily identify glaring errors, such as defects or displacement of structural elements.

While 3D scanning technology offers numerous benefits, it is essential to recognize that various errors can potentially arise when creating 3D models from point cloud data. Quality assurance is necessary once the scanning process is complete. Two of the most common errors are: 1) geometric inaccuracies within the 3D model, and 2) inaccurate shape representations [6]. These errors must fall within acceptable margins, even though they could not be completely avoided; otherwise, the scanned image may fail to accurately represent the building.

This study employs a 3D scanner to conduct a case study by scanning a room within a university campus building. Figure 1 illustrates the procedures and methodology of this study. The paper details the procedures for point cloud data collection and measurements of the existing building using the point cloud data, and it discusses the results of the comparison between the point cloud data and in-situ measurements.

2. Procedures of Point Cloud Data Collection

This section details the procedures for point cloud data acquisition using a commercial 3D scanner. As illustrated in Figure 1, the procedures encompass preparation for scanning, scanning itself, post-processing of scanned images, and 3D modeling of a room. Among the various strategies for object scanning, this study employs target-based scans. This choice allows for the processed point cloud data to be registered using target-based registration in the commercial software, Trimble RealWorks.

RealWorks is post-processing software for 3D scanning, offering users a suite of tools to process 3D point clouds and generate data and information. Post-processing involves two main modules: Registration and Production modes.

- Registration Mode aligns scans correctly and prepares data for processing and point cloud cleanup.

- Production Mode enables the creation of 3D models or the fitting of point clouds into existing models. It also includes 3D model modification functions and tools to aid in the creation or alteration of 3D models.

The following subsections detail the procedures for collecting point cloud data and subsequent post-processing in RealWorks.

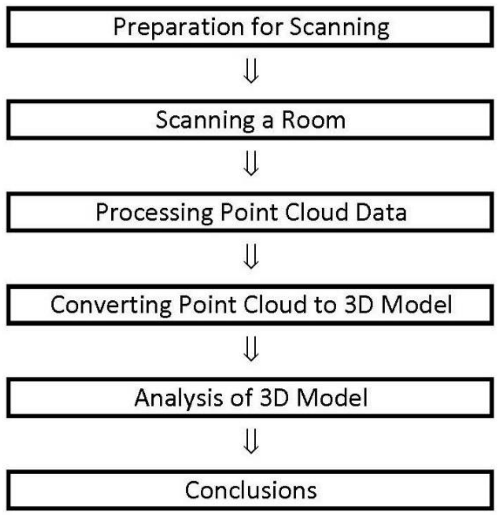


Figure 1. Methodology of Study

2.1 Scanning an existing building

In this study, a room within a classroom building on a university campus is used for the project. Prior to scanning the room, four black and white flat targets are strategically placed on the interior walls at various locations and elevations to establish a robust geometry for registration. These four targets are essential for registering point cloud data in RealWorks during post-processing. Once the targets are positioned on the walls, the scanner is placed at a randomly selected spot in the room, ready for scanning to begin. This study utilizes a total of five stations to ensure complete coverage of the room. The scanner setup mirrors that of traditional surveying equipment on a tripod, featuring auto-leveling and auto-calibration for ease of use.

2.2 Processing point cloud data

Once scanning is complete, the collected point cloud data is registered for post-processing in RealWorks. This study utilizes five different stations, each producing a set of point cloud data. Therefore, the point clouds from these stations must be properly aligned. Figure 2 illustrates the five sets of point clouds (marked by numbers counterclockwise) before they are processed for the next step.

The scanning equipment assumes an arbitrary coordinate (X,Y, and Z = 0,0,0) for station 1, and the author registers or moves the other stations to align with station 1. For large projects, users can choose to georeferenced scans to a common datum or reference, such as the State Plane Coordinate System, to meet larger project requirements.

As mentioned previously, this study scans a university campus building, opting for target-based registration in RealWorks without georeferencing. Figure 3 shows the merged point cloud after the registration is complete.

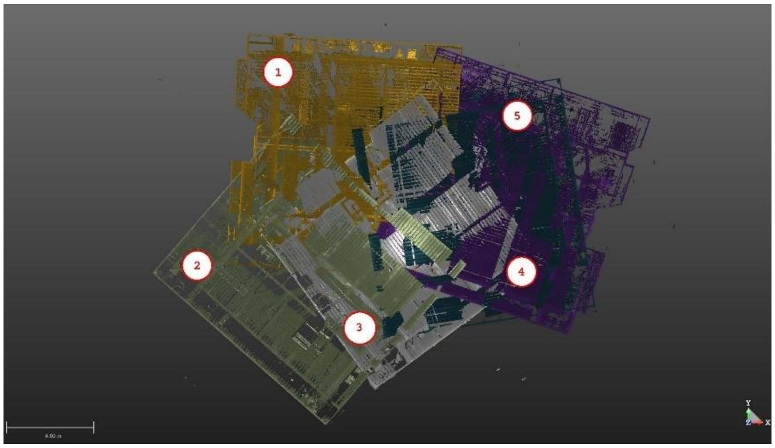


Figure 2 Scanned Images before Registration (Top View)

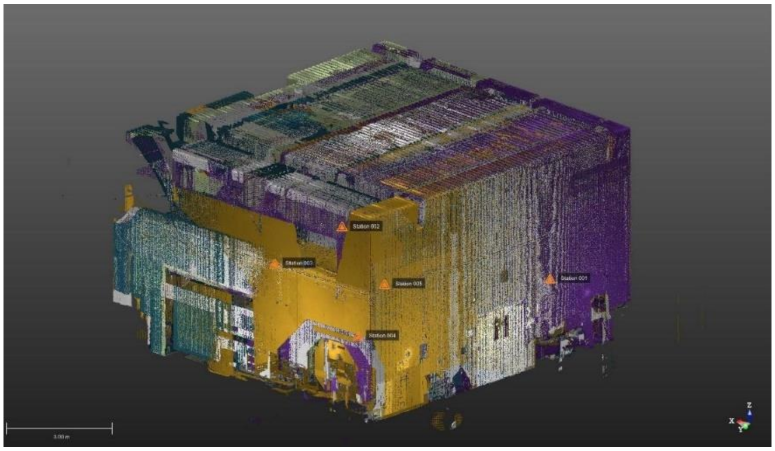


Figure 3 Registered Point Cloud in RealWorks (3D View)

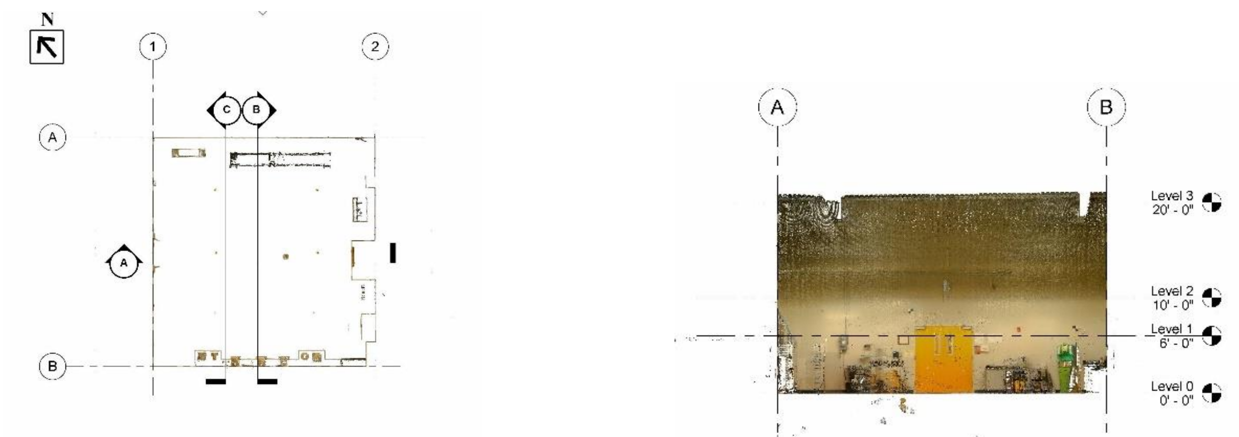
2.3 Quality assurance of point cloud data

Once the point cloud data are registered and processed, they can be converted into a 3D model using Autodesk Recap Pro and Revit software packages. The process involves two main steps. First, the registered point cloud data from RealWorks is exported to Recap Pro. This step is crucial as it converts the point cloud data into a format compatible with Revit. Figure 4 illustrates the (a) exterior view and (b) interior view of the scan in Recap Pro. Second, the point cloud data from Recap Pro is imported into Revit, where it can be viewed in different perspectives, such as plan view, elevation view, and cross-section view.

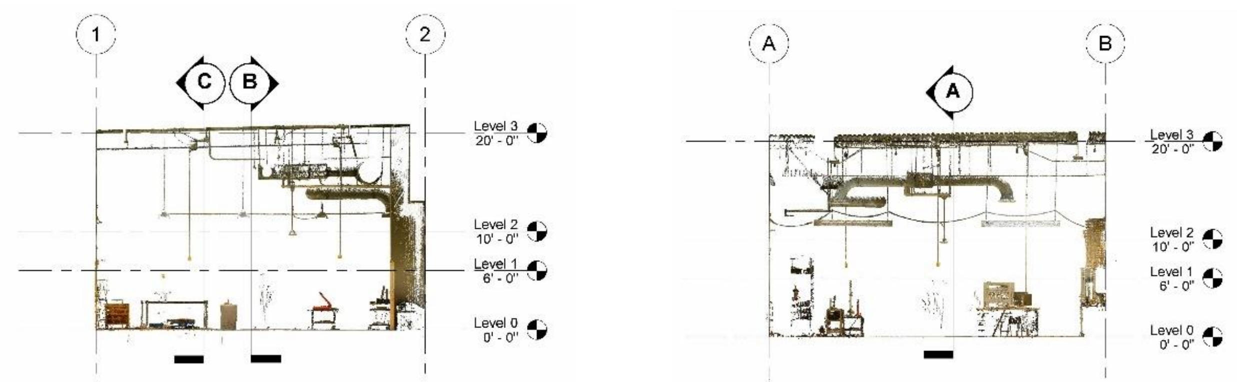
(a) Exterior View (b) Interior View

Figure 4 Imported Point Cloud in Recap

Figure 5 presents four distinct perspectives: (a) a plan view, (b) an elevation view, (c) cross section A, and (d) cross section B. These views can subsequently be utilized for measuring room elements and conducting quality assurance of the point cloud data by comparing it to in-situ measurements in the subsequent phases of this study.



(a) Plan View (b) Elevation View



(c) Cross Section A (d) Cross Section B

Figure 5 3D Model in Revit

3. Measurement of Existing Building using Point Cloud Data

Before building a 3D model using the scanned image of the room, we need to inspect the point cloud data to identify any errors during the processing procedures. Errors in 3D scanning can stem from various sources, including human and computer errors. Human errors may involve data collection and modeling mistakes, while computer errors could include calibration and registration issues [3]. Such errors can result from incorrect inputs, the selection of noisy surface data points, weak registration links, or random errors generated by different software. Eliminating potential errors is crucial for using point cloud data, necessitating quality assurance throughout the entire process. To this end, this study performs a validation test comparing the point cloud data with in-situ measurements.

This study involves 30 randomly selected data points within the room, comprising three horizontal distance measurements on the floor and 27 spot elevations. For instance, Figures 6 through 8 illustrate seven points arranged in a hexagon for each respective view. Table 1 presents a comprehensive data set used in this study, comparing point cloud data with in-situ measurements using a total station.

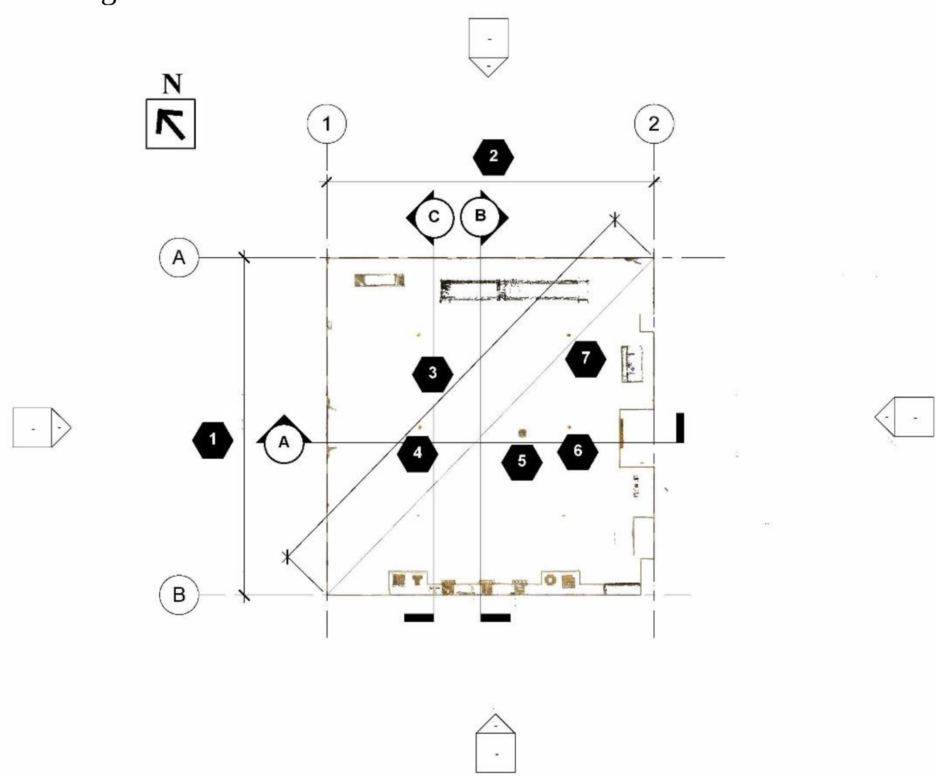


Figure 6 Plan View of Room

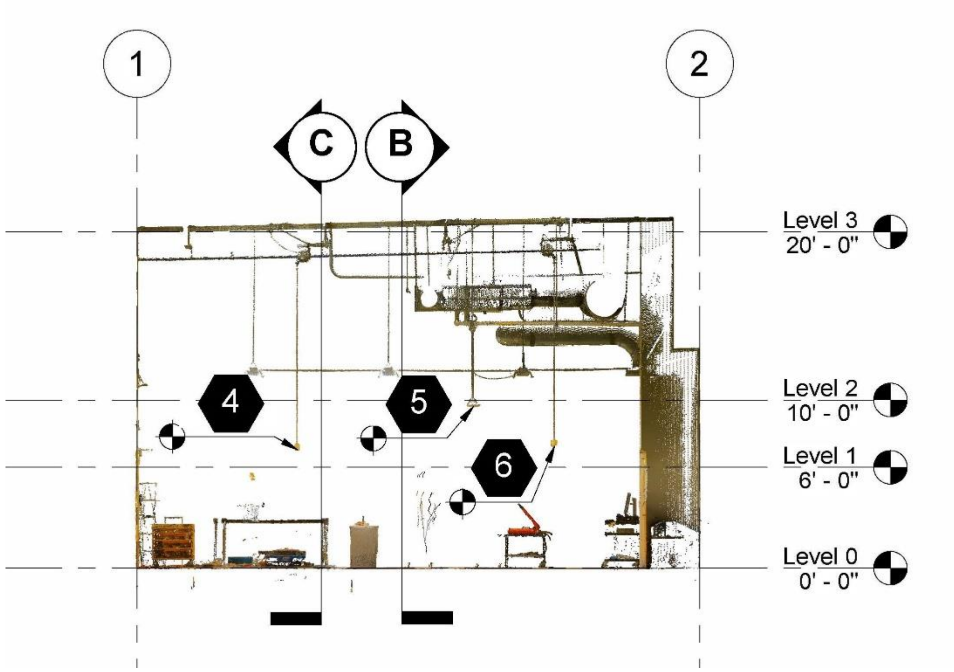


Figure 7 Cross Section A

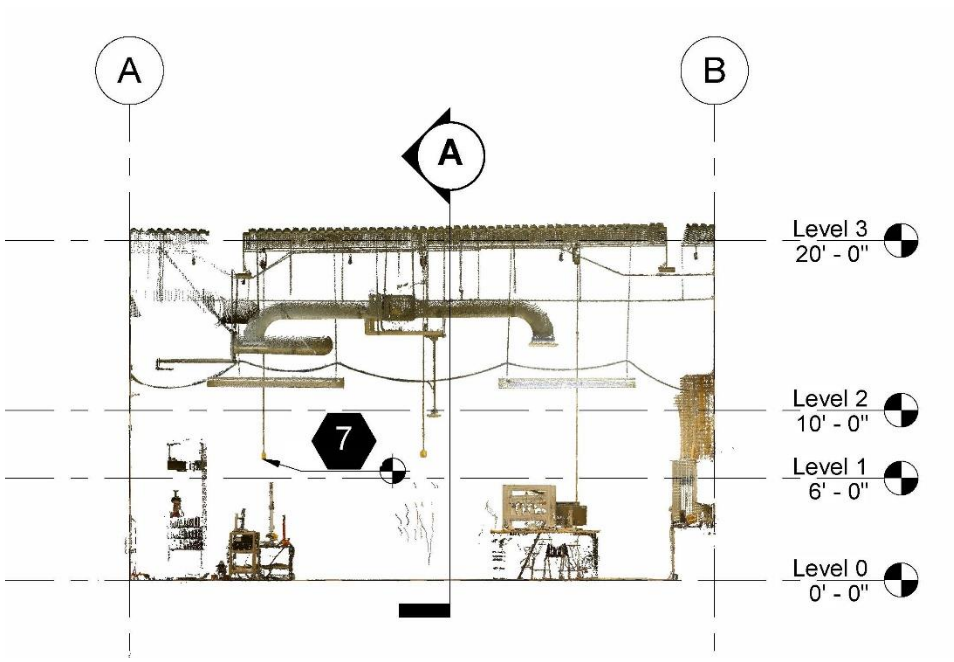


Figure 8 Cross Section B

4. Validation of Point Cloud Data with Existing Building Measurements

In this study, we validate point cloud data using a t-test on 30 sets of paired measurements. The measurements from the point cloud data are compared to actual in-situ measurements collected with a total station. We analyze the data to determine if there is no significant difference between the two sets of measurements, allowing us to assess whether the errors in the point cloud data are within the standard error. Additionally, we measure the Mean Squared Error (MSE) to gauge the accuracy of the point cloud data in comparison to the total station measurements.

Table 1 Point Cloud Data vs Total Station Measurements (Unit: ft)

Data Point	Measurement	Point Cloud Data	Total Station Measurements	Difference
1	Horizontal Distance	34.500	34.445	0.055
2	Horizontal Distance	33.500	33.455	0.045
3	Horizontal Distance	48.089	48.005	0.084
4	Spot Elevation	7.033	6.978	0.055
5	Spot Elevation	9.615	9.610	0.005
6	Spot Elevation	7.271	7.234	0.037
7	Spot Elevation	7.133	7.115	0.018
8	Spot Elevation	7.083	7.078	0.005
9	Spot Elevation	6.966	6.931	0.035
10	Spot Elevation	6.966	6.964	0.002
11	Spot Elevation	6.768	6.738	0.03
12	Spot Elevation	8.573	8.538	0.035
13	Spot Elevation	9.513	9.478	0.035
14	Spot Elevation	9.161	9.140	0.021
15	Spot Elevation	13.172	13.198	-0.026
16	Spot Elevation	10.878	10.881	-0.003
17	Spot Elevation	6.435	6.403	0.032
18	Spot Elevation	3.635	3.649	-0.014
19	Spot Elevation	4.495	4.542	-0.047
20	Spot Elevation	12.896	12.938	-0.042
21	Spot Elevation	11.479	11.476	0.003
22	Spot Elevation	7.039	7.016	0.023
23	Spot Elevation	7.034	6.986	0.048
24	Spot Elevation	10.758	10.758	0
25	Spot Elevation	7.044	7.042	0.002
26	Spot Elevation	7.060	7.071	-0.011
27	Spot Elevation	4.539	4.534	0.005
28	Spot Elevation	4.583	4.545	0.038
29	Spot Elevation	7.055	7.279	-0.224
30	Spot Elevation	7.055	7.074	-0.019
				Mean Difference = 0.00757

The following shows the null and alternative hypotheses of this study.

Null Hypothesis (H_0): There is no difference between the paired measurements.
Alternative Hypothesis (H_1): There is a significant difference between the paired measurements.

Based on the t-statistic calculation, the mean difference of the 30 paired measurements is approximately 0.00757 with a standard deviation of 0.053, resulting in a t-value of 0.784. For significance level (α) of 0.05 and 29 degrees of freedom (two-tailed test), the critical t-value is approximately $\pm$ 2.045. As the calculated t-value falls within the range of the critical t-value, the study fails to reject the null hypothesis, indicating that there is no significant difference between the two measurements.

Additionally, the Mean Squared Error (MSE) of the paired measurements is approximately 0.002758 feet (0.00084 meters). This supports the accuracy of the 3D scanner and point cloud data in measuring an object, demonstrating that the measurements are sufficiently accurate for most construction projects unless a significantly higher accuracy is required for specialized construction.

5. Conclusions

This study conducted a case study on a university campus building to assess the accuracy of point cloud data for potential future use. A commercial 3D scanner was utilized to gather point cloud data from one of the rooms in an existing building. The study involved measuring horizontal distances and spot elevations of 30 randomly selected points from the collected point cloud data. These measurements were then compared with in-situ measurements using a total station for validation and quality assessment, using statistical analysis methods such as t-test and Mean Squared Error (MSE).

The t-test results indicated no significant difference between the point cloud data and the total station measurements. Additionally, the MSE of the paired measurements supports the accuracy of the 3D scanner and point cloud data in measuring an object, confirming its reliability for most practices in typical construction projects. Based on the analysis results of the point cloud data during the case study, this study suggests the potential use of 3D scanning technology to optimize construction processes, improve inspection outcomes, and facilitate data-driven decision-making in the built environment.

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