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Measurement of Work Progress Using a 3D Laser Scanner in a Structural Framework for Sustainable Construction Management

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Abstract: As interest in smart construction technology increases, various smart construction technologies are being used for sustainable construction management. Among these technologies, 3D laser scanning technology stands out for phenomena analysis and monitoring, with various applications being studied for construction management. This study aimed to identify structural members from point cloud data (PCD) obtained through 3D laser scanning and utilize them for the measurement of work progress in construction projects. The method for identifying members is to obtain location coordinate data from the BIM (Building Information Modeling) model of the project and identify the structural member in the PCD by comparing them with the member's location coordinates from the PCD obtained with a 3D laser scanner. In this study, members such as columns, beams, girders, walls, and slabs among the structural members constructed at construction sites were identified through this process. For identified structural members completed at the actual construction site, the unit price and quantity were taken from the construction project's bill of quantity (BOQ) database, and then the Earned Value (EV) was calculated. The results of the study suggest that the progress measurement process through BIM and 3D laser scanning, which was previously performed manually, can contribute to faster and more accurate work progress measurement. Ultimately, it is expected that efficient process management will be possible, contributing to the realization of sustainable construction management.

Keywords: 3D laser scanning technology; point cloud data; smart construction technology; sustainable construction management; work progress measurement

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1. Introduction

With the recent activation of Fourth Industrial Revolution technologies, the construction industry is also very interested in various applicable smart construction technologies [1]. Representative smart construction technologies applicable to the construction field include Building Information Modeling (BIM), Internet of Things (IoT), 3D laser scanning technology, drone surveying technology, Augmented Reality (AR), Virtual Reality (VR), etc. [2]. By applying these smart construction technologies to construction work and management, various application methods such as energy saving and labor saving, as well as solving problems occurring in the construction industry, are being researched [3]. This research will ultimately lead to sustainable construction management. This is because the efficient use of construction resources and the creation and management of the environment on an ecological basis result in sustainable construction management and can achieve sustainability in the construction industry [4].

Among the smart construction technologies, 3D laser scanning technology is excellent at capturing real-world phenomena and is being utilized to analyze and monitor various existing conditions. Therefore, research is being conducted on how to measure and analyze the state of construction works using this 3D laser scanning technology [5]. This technology allows the collection of the current state of objects in the form of point cloud data (PCD) [6]. Recently, research on 3D laser scanning technology is being performed to monitor and analyze the current state of an object in various fields, including the construction industry, such as crop yield measurement in agriculture [7], railway environmental modeling [8], bridge monitoring [9], forest modeling and monitoring [10], cultural heritage monitoring, etc. [11].

The 3D model created from PCD obtained using devices like 3D laser scanners, LiDAR equipment, and 2D data conversion devices has been studied in conjunction with BIM as Scan to BIM [12]. The limitation of the PCD, unless integrated with other technologies, is that it is limited to analyzing existing conditions. Recent research has focused on utilizing PCD in the construction field by overlapping it with BIM to assess work progress through similarity measurements [13] and by employing algorithms to convert point clouds into shapes, thus using surface-based recognition metrics to monitor work progress compared to BIM [14]. Various studies are ongoing on BIM in conjunction with PCD for sustainable construction management.

The accurate and up-to-date measurements of work progress on a construction site are essential to sustainable project management functions such as scheduling and cost management but are currently performed using traditional building surveying techniques and visual inspection [15]. Traditional techniques for work progress management that manually collect and manage construction progress data contain inaccurate and missing information during the construction phase [16]. Traditional work progress measurements rely heavily on manual tasks and have been criticized by construction practitioners for their repeatability, inefficiency, and potential for error [17]. Automatic techniques for progress measurement studied until recently can be divided into two categories: the first is imaging techniques such as 3D laser scanning [17–23], 3D ranging cameras [17,23–25], and 2D-based modeling [26–31], and the second is geospatial techniques such as wireless fidelity (Wi-fi) [32], Global Positioning System (GPS) [33], barcodes [34,35], Radio-Frequency Identification (RFID) [36–38], and ultra-wideband (UWB) [39]. In particular, the three-dimensional model, which is known as PCD, obtained through 3D laser scanning technology, takes a form that is very similar to reality. PCD can be used in a variety of ways because it contains various types of information such as the location, color, and intensity of the object. Therefore, when analysis of the current status of an object is required, such as progress measurement, it is considered appropriate to apply 3D laser scanning technology to compare 3D information. Therefore, this research aims to propose work progress measurement in a structural framework using 3D laser scanning and BIM model. That is, by comparing the point cloud data of the BIM model and the PCD, members for which work has been completed are extracted, and then the bill of quantity (BOQ) of work completion members is calculated, and measurement work progresses. By using PCD that closely resemble reality, this research is anticipated to contribute to resolving various issues by applying smart construction technologies in the construction site, including mediating disputes among stakeholders in construction projects.

In this research, the process of achieving the research purpose was presented by applying it to a case building, and a reinforced concrete building was selected as the case building. The reason for this selection was to first identify components in a structural framework, establish a quantitative range for the recognition scope as suggested in the component identification method [18], and then improve identification accuracy. This approach was deemed suitable for identifying members in the finishing work phase from PCD obtained from construction sites where subsequent construction activities took place. In addition, this research was executed as per Figure 1, and the detailed description of the case study in the research process is as follows.

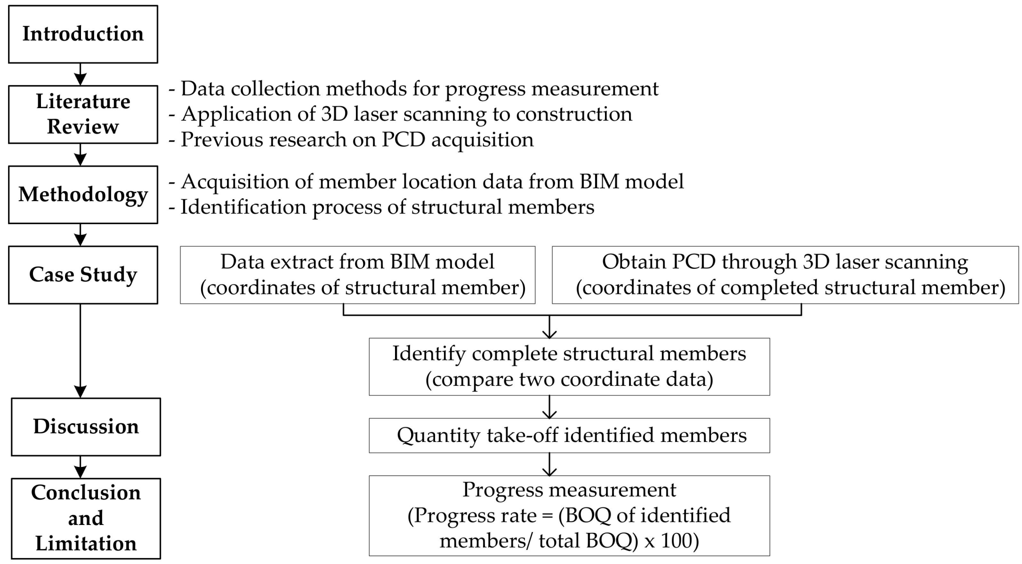


Figure 1. Research process.

(1) A BIM model for a case of a reinforced concrete building scheduled for construction is created.
(2) A PCD is created for a case of a reinforced concrete building undergoing a structural framework with a 3D laser scanner. When the target building is being scanned, the position of the 3D laser scanner is planned in advance to ensure that there are no shaded areas. If the building has many shaded areas because of its complex shape, scanning work must be performed in multiple positions, which takes a lot of time and requires several registration processes to complete the PCD.
(3) The location coordinates of each member in the PCD is compared with the location coordinates of the BIM model member, and if there are coordinates, it is determined that the member has completed its work. Here, the method for recognizing completed members is presented in detail in previous research [18].
(4) The quantity of formwork, rebar, and concrete of members for which work has been completed is calculated. In addition, unit prices for the formwork, rebar, and concrete are retrieved from the BOQ database.
(5) The quantities of formwork, rebar, and concrete are calculated in terms of their respective unit prices and added to obtain the total cost of completed construction.
(6) Work progress at the time of scanning with a 3D laser scanner is measured by comparing the total cost of the structural framework to the cost of the completed work.

To obtain the point clouds used in this research, a Trimble's X7 device (Trimble Inc., Westminster, CO, USA) and the creation of the PCD using Trimble's Realworks 12.2 software was employed. Although there are a variety of 3D laser scanners on the market, Trimble's device was chosen because it simplifies the process from device operation to data collection compared to other products. Additionally, the density and accuracy of collected data were superior to other 3D laser scanners. Figure 2 is an example project of PCD using a laser scanner. As for software, a product from the same company as the device to work with the .tzf file format provided by the hardware was chosen. To obtain location data for members used as a reference in the same coordinate system as the PCD, we created a BIM model based on 2D design drawings by Autodesk products' Revit. A separate software was programmed in C++ language to calculate the number of points in the process of identifying the members of the case building from the PCD.

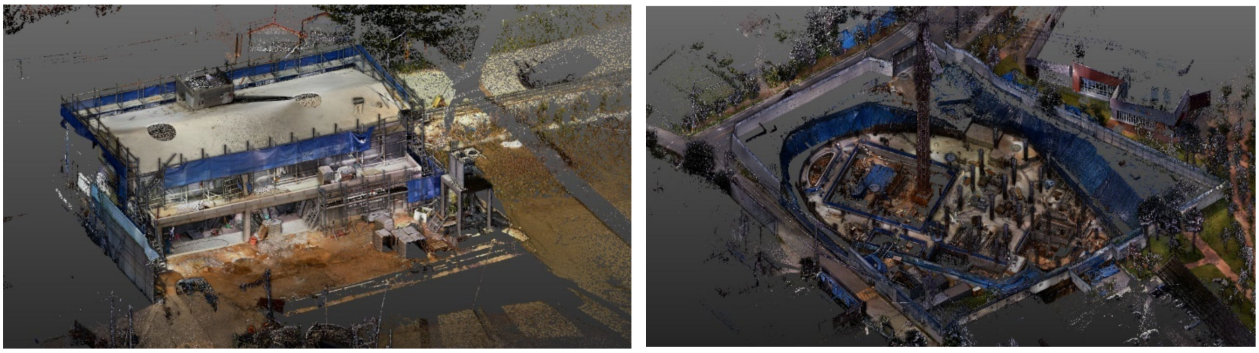


Figure 2. Example of construction site PCD using a 3D laser scanner.

2. Literature Review

2.1. Data Collection Methods for Construction Progress Measurement

In construction projects, progress measurement is utilized as a metric to track the progress of construction [40]. To achieve accurate progress measurement, it is essential to first have a precise understanding of the construction project's progress [41]. However, due to factors such as the increasing scale of construction projects and the concurrent progress of various facilities, obtaining reasonable and accurate information for progress rate measurement has limitations [13]. Research related to the automatic acquisition of information on construction progress on construction sites can be categorized into imaging techniques [17–31] and geospatial techniques [32–39]. The types and characteristics of these technologies are presented in Table 1.

Table 1. Data collection methods for progress measurement.

Category	Type	Characteristic	Refs.
Imaging techniques	3D laser scanning	• Automated collection, high accuracy, data timeliness • High cost, operations specialist	[17–23]
	3D ranging camera	• Portable, relatively cheap, wide texture information • Short-range applications, limited site information	[17,23–25]
	Image-based modeling	• Low cost, compactible, high resolution, texture information • Sensitivity to data acquisition according to site environment	[26–31]
Geospatial techniques	Wi-fi	• Convenience, portable, easy deployment • Increased installation and disassembly cost	[32]
	GPS	• Wide positioning range, strong adaptability • Low precision, limited to outdoor	[33]
	Barcode	• Low cost, compactible • Time-consuming, sensitive data	[34,35]
	RFID	• Wide practicability, adaptability • Time-consuming, error-prone	[36–38]
	UWB	• Reliable signal, long reef range, provide 3D positioning • High cost, daily-necessity-embedded	[39]

Imaging techniques include 3D laser scanning, 3D ranging cameras, and image-based modeling. Among these techniques, 3D laser scanning utilizes measurement techniques based on LiDAR or LaDAR to construct laser points received in a three-dimensional coordinate system in the form of a point cloud. This technique allows for the automatic collection of data that closely resemble reality, contributing to high accuracy and improved timeliness of data. However, it has disadvantages, including the need for experts to operate 3D laser scanners and the relatively high cost of hardware [17–23]. There are also 3D ranging cameras, which have the advantage of being compact and portable but have limited operating distances and limited in-field data that can be obtained [23–25]. Additionally, image-based modeling has user-friendly hardware, a relatively low price, and flexible hardware operation, and it allows the collection of a variety of data [26–31]. Geospatial technologies include wireless fidelity (Wi-Fi), Global Positioning System (GPS), barcodes, Radio-Frequency Identification (RFID), and ultra-wideband (UWB). Both Wi-Fi and UWB are technologies that use transceivers to collect data. Wi-Fi is cost-efficient in terms of hardware, but with increased installation and disassembly costs because its transmission range is limited [32]. However, although UWB offers long transmission distances and 3D data-collection capabilities, its application requires significant hardware investment [39]. GPS relies on satellite signals to locate specific objects but has limitations when used indoors [33]. Barcodes are widely used for material tracking and management due to their low cost and ease of use [34,35]. RFID uses chips to handle data and has the advantage of easily accessing stored data [36–38]. Utilizing these various data collection techniques has made it possible to collect and utilize construction site data with improved reliability, accuracy, and timeliness compared to collecting data manually.

2.2. Three-Dimensional Laser Scanning Technology and Its Application in Construction

PCD refers to data that can be acquired through 3D laser scanning technology, enabling the construction of a complete 3D model by combining PCD obtained from various scanning locations. This technology receives data such as the speed, time, direction, and distance of light or laser beams reflected from the target object, allowing the representation of the object's shape in a 3D-coordinate-based point cloud [31]. Currently, a variety of equipment is used in 3D laser scanning, with the time-of-flight (TOF) method and phase-shift method commonly employed for laser scanning to detect the wavelength.

The PCD that consist of the point cloud includes several features such as three-dimensional coordinates (XYZ), color (RGB), and intensity information. Depending on the equipment's characteristics, it may contain two or more of these features. Such features allow for robust predictions about the shape of the object based on the points collected by reflections. However, there are limitations in using these physical features for the direct classification of components that constitute the object within the PCD [13].

Several studies [5,42–49] have been conducted on the application of 3D laser scanning technology in the construction field, focusing on sustainability, maintenance, and civil engineering project management. In the study by Cheng and Jin [42], 3D laser scanning technology was applied to the reverse engineering of historical architecture. Their study showed that the historical architecture, which was reconstructed using a digital 3D model from a 3D laser scanner, could record shape, construction style, and structure richly like real architecture. It also supplied basic data for record data and repair protection. Bernet et al. [43] present the results of a study in which the data obtained from 3D laser scanning became a good material to implement an analysis concerning construction and surveying in the maintenance of buildings belonging to the cultural heritage. Moyano et al. [44] compared two scanners used in geodetic measurements for the purpose of BIM in historic buildings. The results of their study revealed that the differences in measurements from two laser scanners (Personal Laser Scanning and Terrestrial Laser Scanning) are not excessively large and admissible for a Scan-to-BIM procedure. Ding, Z. et al. [45] developed a digital framework integrating BIM and reverse engineering (RE) to reduce mistakes and reworks for renovation projects. Their study proposed a digital construction framework for improving information utilization, which integrated BIM, RE, and other advanced tools such as 3D laser scanning technology and prefabricated construction. A review study by Hosamo and Hosamo [46] presented a comprehensive and state-of-the-art review of digital twins using laser scanners in bridge maintenance and engineering. The study by Park and Kim [47] aimed to verify the feasibility of earthwork digitalization technology by applying 3D laser scanning technology to actual sites. The usefulness of its use in construction management was verified by numerically measuring changes in earthwork volume at actual earthwork sites. In a review study by Singh et al. [48], even though the lack of infrastructure in underground mines for data transfer, geodetic networking, and processing capacity remain limiting factors, the 3D laser scanning technology is becoming an integral part of mine automation because of its affordability, accuracy, and mobility, which should support its widespread usage in years to come. In a study by Wang J. et al. [49], the application of 3D laser scanning technology in the field of curtain wall design and installation, including scanning operations, point cloud data collection and processing, 3D BIM model reconstruction, and related BIM model exercises, was addressed. Kim and Kim [5] applied 3D laser scanning technology to check the quality of structural frame construction using a case study, in which it was possible to check the spacing, verticality, and thickness of wall rebars, and to check the dimensions of concrete walls, and the horizontality and thickness of concrete slabs during frame construction.

Applying 3D laser scanning technology to the construction field makes it possible to create 3D models, enabling advanced management and sustainable analysis in various fields. The previously mentioned studies primarily used 3D laser scanning technology for understanding and analyzing the shape information of PCD. However, this means that more precise and accurate analysis is possible by utilizing 3D laser scanning technology by taking advantage of the various characteristics of PCD.

2.3. Previous Research on PCD Acquisition

Currently, research on using PCD for accurate and efficient progress measurement in construction projects can be broadly classified into two approaches depending on the data collection method: studies that employ cameras to capture images [50–52] and convert them into PCD for analysis and those that directly collect PCD using LiDAR-based 3D scanners [13,14,18,53].

These approaches offer various methods for identifying members of the structure within PCD, each with its own advantages and potential applications depending on project requirements and data availability. Han and Golparvar-Fard [50] proposed a method that involves identifying members of the structure by integrating image-based object recognition with 4D BIM. This method automatically generates a 3D point cloud model from images captured at various times. This involves aligning the BIM and PCD in the same coordinate system using at least three corresponding points. Subsequently, the algorithm identifies the image patch corresponding to each object and performs material classification through the visualization of the acquired image patches. Tuttas et al. [51] studied an image-based object recognition approach that was applied. Their study used a triangulation-based representation algorithm on field-captured image data to determine image visibility. These data were then used to create a 3D point cloud, which was compared to the BIM. Braun et al. [52] studied images captured on-site to create a point cloud model using a semi-global matching (SGM) algorithm. The point cloud data were aligned with the BIM to recognize the members of the structure. Kim et al. [53] employed a method that aligns 3D laser scanning models with the BIM to identify the members of the structure. Using Besl and McKay's 3D shape-registration method [54], it differentiated between columns, beams, slabs, and other members based on member features. An algorithm was then developed to identify members from the 3D model. Turkan et al. [14] used an object-recognition algorithm presented by Bosché [55]. This algorithm involved loading the 3D model into a triangular mesh and manually matching pairs of points between the 3D model and PCD for initial registration. Subsequently, precise alignment was carried out between the initially registered 3D model and PCD using the Iterative Closest Point (ICP) algorithm. Object recognition was performed based on a recognition metric using the 3D model's surface. Kim [13] manually modeled the acquired 3D laser scanning data in an as-built model, transforming point cloud data into polygonal models. The created as-built model was then compared to the BIM to identify components based on the differences between the two models. A study by Kim and Kim [18] proposed the use of location information (XYZ) obtained from BIM created from design drawings. This location information was then utilized to identify structural members from the PCD. The method proposed by Kim and Kim [18] can be divided into two stages: extracting necessary information from the BIM and using the extracted information to identify structural members from the PCD.

Similar to previously mentioned research, PCD can be collected through various methods, and the information within the collected PCD, including position, color, and intensity, among other attributes, is applied. When applying PCD information in the field of construction progress measurement, it has been observed that the analysis of PCD offers a more precise, sustainable, and automated means of information collection compared to traditional 3D laser scanning technologies. Furthermore, the application of this technology in construction progress measurement has the potential to enhance the rationality, accuracy, and timeliness of decision-making, contributing to efficient, sustainable construction management. However, there are a limited number of studies that have confirmed the practical applicability of those technologies in real-world scenarios, and existing research has often failed to consider the various factors that can arise in field applications. Different from previous studies, this study attempted to analyze the results of applying PCD to collect and measure construction progress information by applying it to practical construction cases.

3. Methodology

The overall research methodology of this study is shown in Figure 3. Section 3.1 explains in detail how to obtain the location data of structural members from the BIM model, and Section 3.2 explains how to identify completed structural members using location data extracted from the BIM model. Also, in order to utilize the PCD created using 3D laser scanning technology in this study, it is essential to set reference coordinates between the drawing and the PCD. Additionally, in order to utilize the PCD created using 3D laser scanner in this study, it is essential to set reference coordinates between the drawing and the PCD. Therefore, the coordinates between the design drawing and the PCD model must be matched using traverse point (TP) or topographic surveying drawing.

3.1. Acquisition of Location Data from the BIM Model

The BIM utilized in this study can be described as a 3D model created based on design documents like drawings, specifications, etc., serving as a physical model that incorporates various information presented in the design documents. Various tools exist to extract information from BIM, and Dynamo, a C++-based programming tool developed by Autodesk, is a particularly prominent tool in the field of BIM deployment due to its high utility. The process of extracting location information necessary for identifying members of the structure from the PCD and acquiring member information required for quantity take-off can be outlined as follows.

Firstly, each structural member is seperated in the BIM model. Recently, integrated library management has emerged to analyze and manage the components that make up the BIM [56]. A library can be seen as a collection of information pertaining to components. Therefore, it is important to precede the definition of components according to user classification criteria, such as columns, beams, and slabs, in the created BIM.

Secondly, plane information is extracted to obtain the location information, and then normal vectors are obtained from these extracted planes. The normal vectors were utilized to create a plane equation to find an arbitrary point on the surface of the member of the structure. In order to create the plane equation on the memeber's surface, normal vectors must be obtained from the recognized member of the structure. Normal vectors can be calculated using three vertices at each edge of the extracted plane, from which two tangents can be derived for the purpose of finding the normal vector. The obtained normal vector can be used to calculate the desired plane equation.

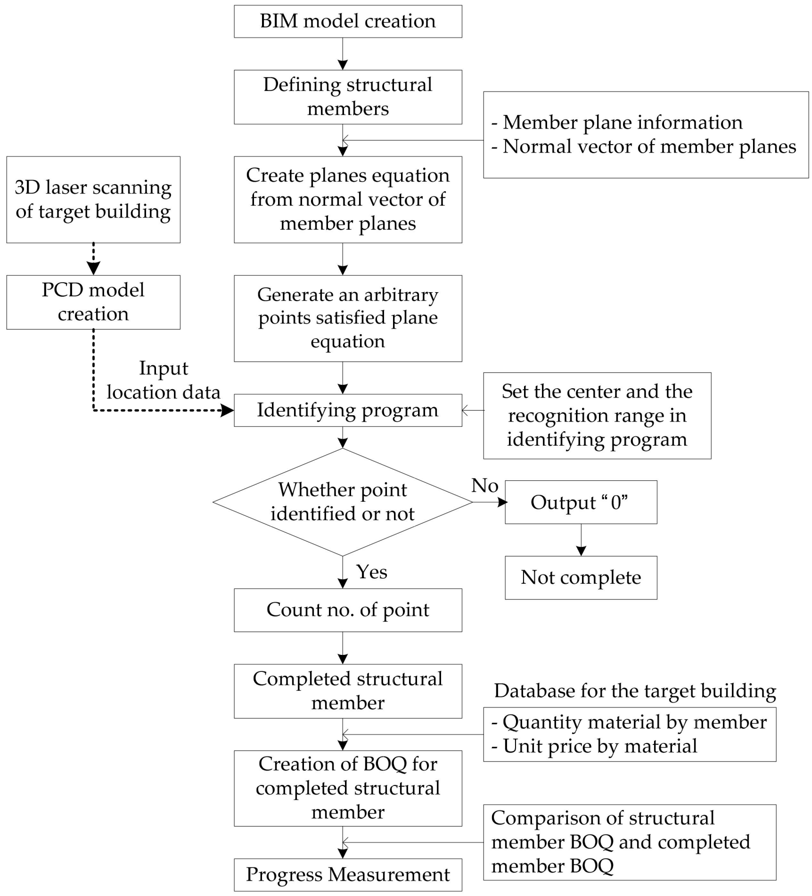


Figure 3. Research methodology.

Thirdly, arbitrary points are generated, and an arbitrary point is selected that satisfies the plane equation. At this time, the location of arbitrary points must be located within the coordinates on the surface of the recognized member of the structure. This criterion is imposed to prevent the selection of arbitrary points outside the range of recognized member surfaces if the arbitrary point locations are not constrained. These points that satisfy the plane equation can be used as location data to confirm the presence of a member.

3.2. Members Identification Process Using Acquired Location Data from BIM

The location data obtained from the BIM are utilized to check the presence of the members in the PCD. In this study, the PCD 3D model acquired using a terrestrial laser scanner (TLS) was used. This model contains information that existed at the time of the scan. Consequently, it is possible to determine whether the member of the structure was constructed at the time without the need for a separate monitoring action. This process is outlined as follows.

Firstly, the PCD acquired using a 3D laser scanner in the construction field are loaded to the identifying program. PCD can be created in various file formats. In this study, models in representative file formats such as .las, .pzf, and .ply were loaded and utilized.

Secondly, the location data obtained from BIM are input to set the center and the recognition range from the identifying program. The recognition range is half the size of the structural member. For example, if the depth of the girder is 800 mm, it will be +400 mm and −400 mm because input data are centered. Here, a threshold range must be added due to vertical and horizontal construction errors of structural members according to the specification. The input location data serve as the center of the recognition range, which is set in the x, y, and z directions from the center. Consequently, it is possible to establish a recognition range in the form of a cube with its center at the input location. It should be noted that further research is required to determine an appropriate recognition range based on various factors such as component density and point clouds. Because it is collection density may depend on the 3D scanner used to collect the PCD, a point cloud may not be formed due to errors occurring during registration. In addition, in order to identify objects of finished work like wallpaper, baseboard, and molding, an appropriate recognition range must be set.

Thirdly, the number of points that make up the PCD within the defined recognition range is identified. If a point is not identified, '0' is output, and if a point is recognized, the number of points is output. The reason for outputting the number of points is that it can be used to determine the presence or absence of finishing materials on structural members based on the results obtained through PCD identification in the future. As a result, if the member of the structure to be checked is constructed, the number of points is output, and if it is not constructed, the number of points is not output, making it possible to determine the presence or absence of the member of the structure.

4. Work Progress Measurement by Identifying Built Structural Members at Construction Site

4.1. Case Overview

An overview of the case building in which work progress measurement was verified by identifying built members of structure in this study is presented in Table 2. By applying the process of identifying members of the structure in BIM to actual buildings, the work progress by built members of the structure such as columns, beams, and slabs in the PCD' 3D model was measured (refer Figure 4). Therefore, TLS equipment and Trimble X7 were used to acquire data on built structural members of case building, and PCD was generated with Trimble's Realworks 12.2. The BIM of case building was created using Revit 2017 with Autodesk. The specifications of the TLS used in this study are presented in Table 3. In this case, 3D laser scanning was performed while superstructure framing work was in progress, and the 3D laser scanning position was changed in consideration of shaded areas depending on the work progress. But if the TP is set in the instrument, it uses the same coordinates because 3D laser scanning automatically finds the location. Therefore, whenever we operated 3D laser scanning, there was no problem acquiring the PCD with the same coordinates. A 3D laser scanner was operated by one author and analyzed twice at intervals for each floor.

Table 2. Case Overview.

Location	Incheon, Republic of Korea
Construction Period	2023.04~2023.12
Number of Stairs	2 floors
Usage	Commercial Building
Structure Type	Reinforced Concrete Structure

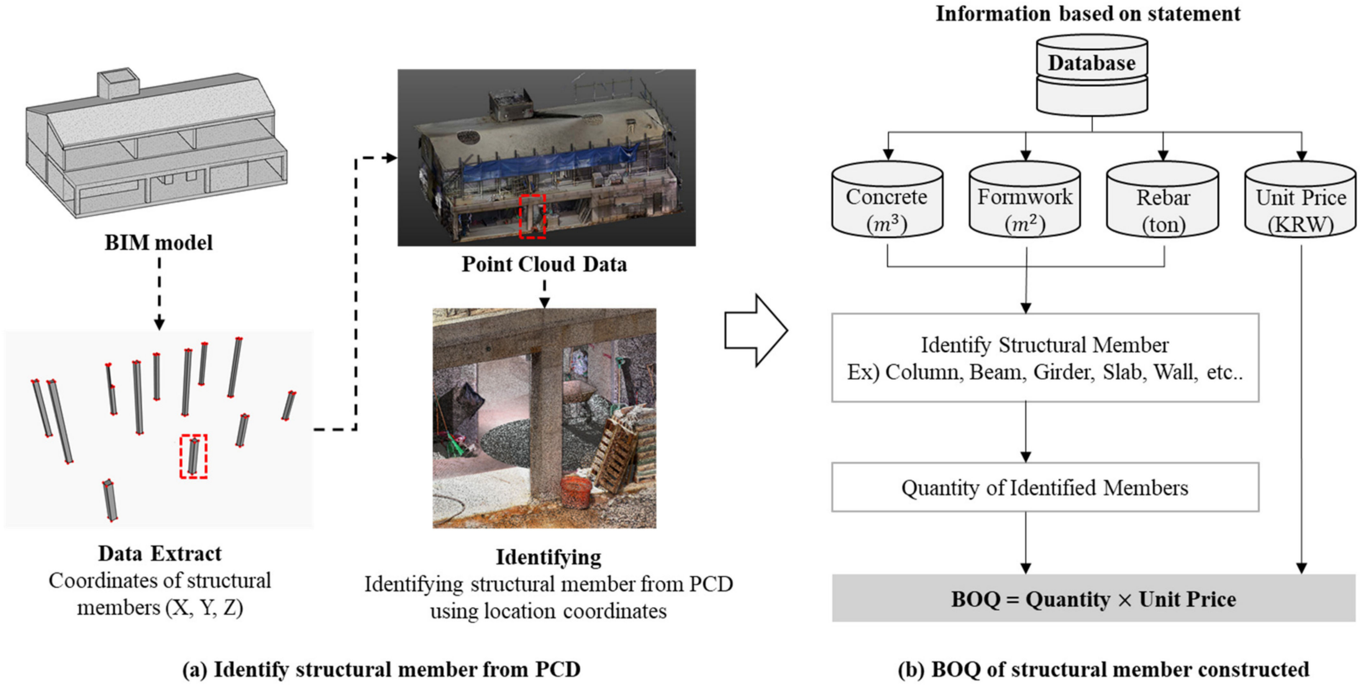


Figure 4. Schematic process from the identification of structural members constructed to the calculation of EV.

Table 3. Specification for TLS.

Trimble X7		
EDN laser class		Laser class 1, IEC EN60825-1
Speed		Up to 500 kHz
Distance		0.6~80 m
Time		2~15 min
Range	Accuracy	2 mm
	Noise	<3 mm @ 60 m on 80% albedo
	3D Point	2.4 mm @ 10 m/3.5 mm @ 20 m

4.2. Identification of Built Structural Members from PCD

Location data of structural members were acquired from the created BIM, and the recognition of range was defined. Then, the presence of the structural member was checked in the PCD, and the consistency of comparing the location data of the identified structural members in PCD with the location data extracted from BIM was verified (refer to Figure 5).

Subsequently, data on the structural members' ID, Type, and Location as classified in BIM were automatically imported as mentioned previously (refer to Table 4). The term "Type" denotes the family of the components within the symbols of each structural members, which was presented in the design drawings and BIM. Extracting the "Type" from BIM is crucial because in order to measure work progress in the future, data such as the quantity and unit price of each structural member must be matched with the identified structural members in the construction database. Therefore, to extract data and identify structural members, we operated a C++-based programed author's software and Dynamo, as shown in Figure 6. The BIM model used in this study was created at a level of development (LOD) 200, which corresponds to the schematic design. This level was chosen because users at construction sites must be able to effectively create the proposed methods in this study. The LOD 200 was judged to be appropriate for utilizing the proposed method while securing the ability to verify geometric conflicts in BIM models. In addition, the analysis was performed by matching the coordinate point of the adopted 3D model to a common coordinate point using the TP of the construction site.

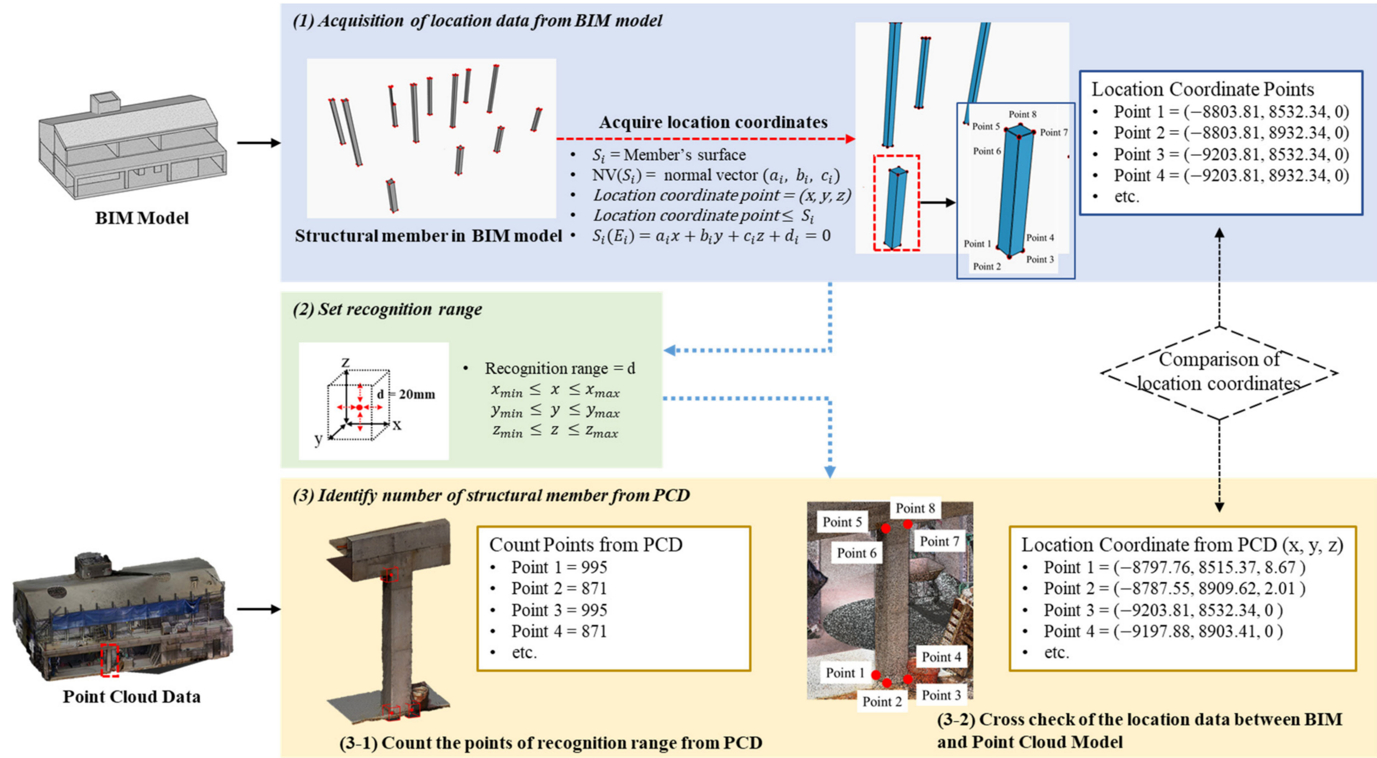


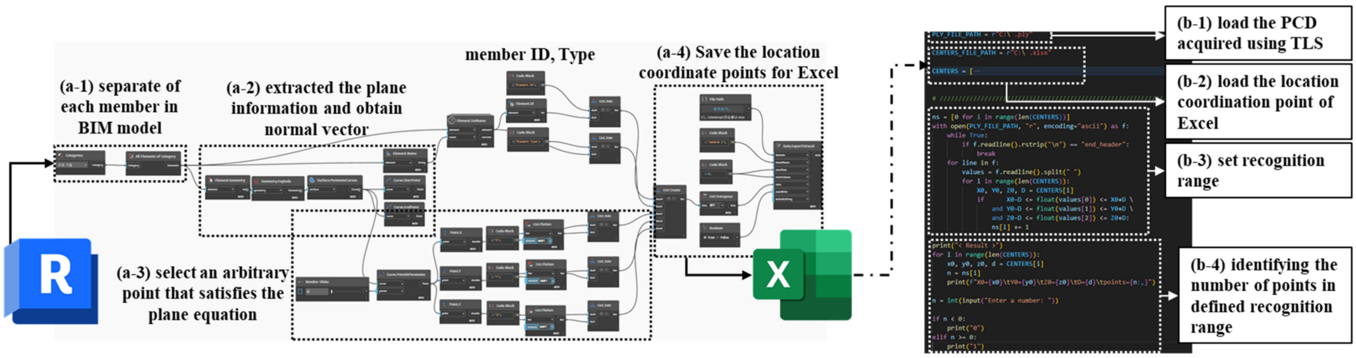
Figure 5. Identifying built structural members in point cloud data.

Table 4. Extraction Data Example from BIM model (Column).

Structural Member	ID	Type	Location Coordinates for Each Point (Excel)
Column	381776	Family = Column Type = C1	Point 1 = (−8803.81, 8532.34, 0) Point 2 = (−8803.81, 8932.34, 0) Point 3 = (−9203.81, 8532.34, 0) …
	382124	Family = Column Type = C1	Point 1 = (−1453.81, 8532.34, 0) Point 2 = (−1453.81, 8932.34, 0) Point 3 = (−1853.81, 8532.34, 0) …
	382528	Family = Column Type = C2	Point 1 = (4746.19, −4267.66, 0) Point 2 = (4746.19, −3867.66, 0) Point 3 = (4346.19, −4267.66, 0) …
	…	…	…

In this study, in order to identify structural members in PCD using the location coordinate data obtained from BIM model, the identification threshold range was set to 20 mm, which was set as an arbitrary standard for determining the presence or absence of a structural member. Threshold range settings can be changed depending on the user. In this process, whether to construct structural members was determined depending on the number of coordinate points identified in the PCD. If it was determined that structural members were constructed, a '1' was output; otherwise, a '0' was output. This process was ultimately used to measure actual work progress. Based on the location coordinates of structural members extracted from BIM, the structural member was identified in the PCD.

The results of column member identification in the case building are presented in Table 5. Table 5 shows only column members, but structural members such as beams, walls, and slabs were identified using the same process as column identification. As a result of the identifying process in the PCD of the case building, 12 columns, 43 beams, 40 walls, and 17 slabs were identified; that is, the actually constructed structural members of the case building that were checked totaled 112 (see Table 6).



(a) Acquisition of location data from BIM model using Dynamo (b) Identify program based on C++

Figure 6. Example of the program that actually operated the structural-member-extraction process in the BIM model and the identification process of the structural member constructed in PCD.

Table 5. Identifying structural members in the PCD (Column).

Structural Members	ID	Type	Location Coordinates	Threshold Range (mm)	No. of Coordinate Points	Result
Column	381776	Family = Column Type = C1	Point 1 = (−8803.81, 8532.34, 0) Point 2 = (−8803.81, 8932.34, 0) Point 3 = (−9203.81, 8532.34, 0) …	20	Point 1 = 995 Point 2 = 1139 Point 3 = 1262 …	1
	382124	Family = Column Type = C1	Point 1 = (−1453.81, 8532.34, 0) Point 2 = (−1453.81, 8932.34, 0) Point 3 = (−1853.81, 8532.34, 0) …	20	Point 1 = 995 Point 2 = 1262 Point 3 = 995 …	1
	…	…	…	20	…	1
	382528	Family = Column Type = C2	Point 1 = (4746.19, −4267.66, 0) Point 2 = (4746.19, −3867.66, 0) Point 3 = (4346.19, −4267.66, 0) …	20	Point 1 = 995 Point 2 = 871 Point 3 = 995 …	1
	…	…	…	20	…	1
Total	-	-	-	-	-	12

Table 6. Results of the identification of built structural members.

Structural Member	Family	Type	No. of Identification (EA)	Total (EA)
Column	Structure Column	C1/C2	8/4	12
Beam & Girder	Structure Frame	B1	3	43
		G1/G2/G3/G4	6/9/10/10	
		WG1	5	
Wall	Wall	Wall	40	40
Slab	Slab	Slab	17	17

4.3. Summation of Construction Earned Value

The objective of this study is to identify structural members that were actually constructed in the PCD and then to measure the work process based on the identification results. The quantity of construction materials for each structural member and floor taken from the database is presented in Table 7. Construction work progress is measured by taking construction material quantities from the database. In the case of walls and slabs, even if they are the same type, the sizes are different, so it is difficult to determine the quantity just by the number of members. Therefore, in the case of walls and slabs, the quantity for each floor was determined and utilized. Work progress measurement is based on the number of actually built structural members identified in the PCD and the bill of quantity (BOQ) and quantity data in the database. The measurement results for the actual construction portion are shown in Table 8.

Table 7. Quantities of structural members.

Structural Member		Concrete (m^3)	Formwork (m^2)	Rebar (ton)
Column	C1	0.91	9.06	0.11
	C2	0.45	4.48	0.05
Beam & Girder	B1	0.85	4.27	0.10
	G1	0.85	4.27	0.10
	G2	0.94	4.48	0.11
	G3	0.69	2.57	0.08
	G4	0.49	2.71	0.06
	WG1	0.64	3.06	0.08
Wall		58.74(1f)/34.08(2f)	515.12(1f)/356.02(2f)	7.05(1F)/4.09(2F)
Slab		113.36(1f)/51.05(2f)/39.20(roof)	69.6(1f)/296.27(2f)/229.28(roof)	13.60(1F)/6.13(2F)/4.70(Roof)

Table 8. Comparison of earned value (EV) in the case.

Work	Name of Item	Descriptions		Unit Price (won)	Total Quantity	Item Amount (won)	Identified Quantity	Amount (won)
Reinforced Concrete Work	concrete pouring (rebar)	slump 15 cm	m^3	13,400	415	5,561,000	223.2	2,990,880
	concrete pouring (plain concrete)	slump 8~12 cm	m^3	11,800	63	743,400	-	-
	plywood formwork	complex 3 times, vertical height at 7 m	m^2	57,500	603	34,672,500	131.6	7,566,080
	euroform formwork	commonly 3 times, vertical height at 7 m	m^2	31,900	1359	43,352,100	1487.1	47,437,000
	rebar work	Type-I	ton	651,400	53.005	34,527,457	40.39	26,307,830
	spacer	Magic Spacer 150	ea	-	3924	-	-	-
	Total Amount (KRW)					**118,856,457**		**84,301,790**

The earned value (EV) of work completed to date is KRW 84,301,790, so KRW 84,301,790 was ultimately constructed out of the total reinforced concrete work cost of KRW 118,856,457. Therefore, it can be confirmed that the work progress rate is approximately 71%.

5. Discussion

As interest in smart construction technology increases, various smart technologies are being combined with current construction management in various areas, such as reducing labor and reducing construction accidents, in the construction industry, to realize sustainable construction management. Among smart technologies, 3D laser scanning technology stands out as a notable smart construction technology that most realistically captures and analyzes the conditions of construction status. In this study, 3D laser scanning technology was used to obtain the PCD of an actual case building to determine the actual construction status of the structural members of the building.

It is important to ensure the validity of new methods proposed in this study by comparing them with results obtained using traditional methods. However, the traditional progress-measurement method involves the engineer calculating the EV by checking the structural members for which construction has been completed and then taking off the quantity. This may vary depending on the engineer's sincerity, and since construction is still ongoing, each judgment criterion among the project parties at a specific point in time is adapted. This may be different. In other words, if progress can be accurately checked, there will be no difference or concern between the method and results proposed in this study, and the only difference will be that the results can be obtained quickly.

The utilization of structural member status identified from PCD enables the precise monitoring of work progress. The result of monitoring is used to calculate the EV combined with quantity and BOQ of construction database, and EV calculations for construction projects provide data for progress measurement. Traditional work progress management techniques that manually collect and manage construction progress data have raised concerns that they contain inaccurate and missing information during the construction phase. However, applying 3D laser scanning could solve the problems raised. Ultimately, quick and accurate process management will be possible, saving management resources.

Also, accurate work progress measurement enables the use of EV-related data to resolve disputes, preventing problems such as disputes relate to the amount of work completed between stakeholders in the construction industry. There are always disputes over the amount of work among stakeholders in construction projects such as the owner, contractor, and subcontractor. The reason is that construction fees are paid at regular intervals according to the contract, depending on the amount of work completed. However, because it is possible to quickly and accurately measure the amount of work completed, the potential for disputes between stakeholders can be reduced.

El-Omari and Moselhi's [57] study uses photogrammetry and 3D laser scanning results to measure the progress of construction work and simply confirms it with 3D visuals. Also, Turkan et al. [14] studied a comparison of 3D models created by Autodesk's Revit with the 3D model created by 3D laser scanning, and as a result of the experiment, the precision rate was measured at 96%. The difference from this study is that this study recognizes completed structural members by comparing the coordinates of structural members in the BIM model and in the 3D-scanned model and calculates work progress using the completed BOQ, so the accuracy can be said to be 100%. This study has the advantage of being able to confirm the completed BOQ.

In other words, as discussed earlier, construction cost management becomes transparent, more accurate, and faster than manual management. Cost management is a very important factor that can determine the success or failure of construction work. When 3D scanning technology is applied to construction work, it becomes possible to quickly and accurately determine whether costs have been overinvested. In the case of manual cost management, it can be said that it takes a lot of time and is highly likely to cause errors because a person must visually check the work progress, calculate the quantity of completed work, and then create the BOQ of the completed work. However, to solve problems caused by shaded areas during 3D laser scanning, selecting the appropriate scanning timing and position for specific construction situations must be prioritized.

By comparing the PCD generated by a 3D laser scanner with BIM or analyzing the PCD, it will be possible to manage the quality of structural work, such as the verticality, horizontality, and thickness of each structural member. Therefore, 3D laser scanning can be used for the quality control of construction work, which has also been suggested in previous studies. This PCD can be used as defect management and maintenance information after the building is completed, so quality control can be performed quickly and accurately, making it more efficient than manual management. Ultimately, smart construction technologies such as 3D laser scanning can perform process management, cost management, and quality management more quickly and accurately than manual management and can be managed with fewer manager's workload, which will enable sustainable construction management.

6. Conclusions and Limitations

This study aimed to contribute to sustainable construction management through work progress measurement by adopting smart technologies like 3D laser scanners in the construction industry. To achieve the goal of this study, a case building was selected and scanned with a 3D laser scanner to create PCD. The location coordinate data of the structural members were extracted from the BIM of the case building, and the structural members were identified in the PCD using location coordinate data to confirm whether the structural members had completed work. By identifying the structural members for which work was completed and creating a BOQ for the completed portion, the EV could be calculated. The goal of this study was achieved by measuring the work progress with EV. Through this process, it was confirmed that when smart construction technology such as 3D laser scanners is applied to construction management, the progress of construction work can be managed accurately and quickly. Therefore, if smart construction technology is introduced to the construction industry, it will be possible to achieve sustainable construction management that is not only accurate and fast but can also be managed with a small number of managers.

However, this study has several limitations. First of all, the object of work progress measurement was a structural framework. Therefore, additional research is needed to proceed with the entire work, including the finishing work of the building. In addition, since the work progress measurement was simply based on the results of EV calculations, a more comprehensive study including other factors will be needed. Additionally, in the process of identifying structural members of the PCD, a threshold range was set arbitrarily. This is because there was a lack of quantitative basis for the threshold range, and it will be necessary to apply the method adopted in this study to various cases to establish a reasonable setting for the threshold range for each member, including finishing materials. Also, personal computer (PC) specifications and 3D laser scanner specifications for each project size were not presented to apply the method proposed in this study to actual projects. In this study, a PC suitable for operating Trimble's Realworks software was used. PC specifications for each project size require specifications to vary depending on the size of the data, but this could not be confirmed and presented. However, in the case of 3D laser scanners, there will be large differences in the number and time of scanning depending on the shaded area in addition to the project size.

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References

1. Lee, G.P.; Choi, S.Y.; Son, T.H.; Choi, S.I. *Current Status of Smart Technology Utilization and Revitalization Plan of Construction Companies in Korea*; CERIK: Seoul, Republic of Korea, 2019; pp. 1–101.
2. Ministry of Land, Infrastructure and Transport. *Roadmap for Smart Construction Technology to Innovate Construction Productivity and Improve Safety*; Ministry of Land, Infrastructure and Transport: Sejong, Republic of Korea, 2018.
3. Chin, G.H. Smart construction technology to innovate construction productivity and enhance safety. *Constr. Technol. Ssangyong* **2019**, *76*, 9–15.
4. Shi, L.; Ye, K.; Lu, W.; Hu, X. Improving the competence of construction management consultants to underpin sustainable construction in China. *Habitat Int.* **2014**, *41*, 236–242. [CrossRef]
5. Kim, J.Y.; Kim, G.H. Application of 3D laser scanning technology to the measurement of construction precision in building structural frame construction. *J. Archit. Inst. Korea* **2022**, *38*, 245–253. [CrossRef]
6. Hong, S.; Park, I.; Lee, J.; Lim, K.; Choi, Y.; Sohn, H.G. Utilization of a terrestrial laser scanner for the calibration of mobile mapping systems. *Sensors* **2017**, *17*, 474. [CrossRef] [PubMed]
7. Méndez, V.; Pérez-Romero, A.; Sola-Guirado, R.; Miranda-Fuentes, A.; Manzano-Agugliaro, F.; Zapata-Sierra, A.; Rodríguez-Lizana, A. In-Field Estimation of Orange Number and Size by 3D Laser Scanning. *Agronomy* **2019**, *9*, 885. [CrossRef]
8. Zhu, L.; Hyyppa, J. The use of airborne and mobile laser scanning for modeling railway environments in 3D. *Remote Sens.* **2014**, *6*, 3075–3100. [CrossRef]
9. Rashidi, M.; Mohammadi, M.; Sadeghlou Kivi, S.; Abdolvand, M.M.; Truong-Hong, L.; Samali, B. A decade of modern bridge monitoring using terrestrial laser scanning: Review and future directions. *Remote Sens.* **2020**, *12*, 3796. [CrossRef]
10. Li, J.; Yang, B.; Cong, Y.; Cao, L.; Fu, X.; Dong, Z. 3D forest mapping using a low-cost UAV laser scanning system: Investigation and comparison. *Remote Sens.* **2019**, *11*, 717. [CrossRef]
11. Ham, N.; Bae, B.I.; Yuh, O.K. Phased reverse engineering framework for sustainable cultural heritage archives using laser scanning and BIM: The case of the Hwanggungwoo (Seoul, Korea). *Sustainability* **2020**, *12*, 8108. [CrossRef]
12. Leśniak, A.; Górka, M.; Skrzypczak, I. Barriers to BIM implementation in architecture, construction, and engineering projects—The polish study. *Energies* **2021**, *14*, 2090. [CrossRef]
13. Kim, S.H. The Construction Project EV Tracking Process Based on the 3D Point Cloud and 4D BIM. Ph.D. Thesis, Yeungnam University, Gyeongsan, Republic of Korea, 2019.
14. Turkan, Y.; Bosche, F.; Haas, C.T.; Haas, R. Automated progress tracking using 4D schedule and 3D sensing technologies. *Autom. Constr.* **2012**, *22*, 414–421. [CrossRef]
15. Zhang, X.; Bakis, N.; Lukins, T.C.; Ibrahim, Y.M.; Wu, S.; Kagioglou, M.; Aouad, G.; Kaka, A.P.; Trucco, E. Automating Progress Measurement of Construction Projects. *Autom. Constr.* **2009**, *18*, 294–301. [CrossRef]
16. Lee, H.-G.; Lee, H.-C.; Lee, D.-E. Developing IoT-based Construction Progress Measurement Prototype. *J. Archit. Inst. Korea Struct. Constr.* **2015**, *31*, 79–89. [CrossRef]
17. Xue, J.; Hou, X. High-Rise Building Construction Progress Measurement from Top View Based on Component Detection. *Buildings* **2022**, *12*, 106. [CrossRef]
18. Kim, J.Y.; Kim, G.H. Identifying Members of Common Structures Utilizing Three-Dimensional Detecting Information for 3D Scanning Model Application. *Sustainability* **2023**, *15*, 14073. [CrossRef]
19. Andriasyan, M.; Moyano, J.; Nieto-Julián, J.E.; Antón, D. From point cloud data to building information modelling: An automatic parametric workflow for heritage. *Remote Sens.* **2020**, *12*, 1094. [CrossRef]
20. Adan, A.; Quintana, B.; Prieto, S.A.; Bosche, F. An autonomous robotic platform for automatic extraction of detailed semantic models of buildings. *Autom. Constr.* **2020**, *109*, 102963. [CrossRef]
21. Liu, J.; Xu, D.; Hyyppa, J.; Liang, Y. A survey of applications with combined BIM and 3D laser scanning in the life cycle of buildings. *IEEE J. Sel. Top. Appl. Earth Observ. Remote Sens.* **2021**, *14*, 5627–5637. [CrossRef]
22. Zhang, C.; Arditi, D. Advanced progress control of infrastructure construction projects using terrestrial laser scanning technology. *Infrastructures* **2020**, *5*, 83. [CrossRef]
23. Pučko, Z.; Šuman, N.; Rebolj, D. Automated continuous construction progress monitoring using multiple workplace real time 3D scans. *Adv. Eng. Inform.* **2018**, *38*, 27–40. [CrossRef]
24. Wasenmüller, O.; Stricker, D. Comparison of kinect v1 and v2 depth images in terms of accuracy and precision. In Proceedings of the Asian Conference on Computer Vision (ACCV 2016), Taipei, Taiwan, 20–24 November 2016; pp. 34–45.
25. Volk, R.; Luu, T.H.; Mueller-Roemer, J.S.; Sevilmis, N.; Schultmann, F. Deconstruction project planning of existing buildings based on automated acquisition and reconstruction of building information. *Autom. Constr.* **2018**, *91*, 226–245. [CrossRef]
26. Omar, H.; Mahdjoubi, L.; Kheder, G. Towards an automated photogrammetry-based approach for monitoring and controlling construction site activities. *Comput. Ind.* **2018**, *98*, 172–182. [CrossRef]
27. Yang, J.; Shi, Z.-K.; Wu, Z.-Y. Towards automatic generation of as-built BIM: 3D building facade modeling and material recognition from images. *Int. J. Autom. Comput.* **2016**, *13*, 338–349. [CrossRef]
28. Kropp, C.; Koch, C.; König, M. Interior construction state recognition with 4D BIM registered image sequences. *Autom. Constr.* **2018**, *86*, 11–32. [CrossRef]
29. Acharya, D.; Ramezani, M.; Khoshelham, K.; Winter, S. BIM-Tracker: A model-based visual tracking approach for indoor localisation using a 3D building model. *ISPRS Ann. Photogramm. Remote Sens. Spat. Inf. Sci.* **2019**, *150*, 157–171. [CrossRef]

30. Han, X.-F.; Laga, H.; Bennamoun, M. Image-based 3D object reconstruction: State-of-the-art and trends in the deeplearning era. *IEEE T. Pattern Anal.* **2019**, *43*, 1578–1604. [CrossRef] [PubMed]
31. Liu, Y.-P.; Yan, X.-P.; Wang, N.; Zhang, X.; Li, Z. A 3D reconstruction method of image sequence based on deep learning. *J. Phys. Conf. Ser.* **2020**, *1550*, 032051. [CrossRef]
32. Sabanci, K.; Yigit, E.; Ustun, D.; Toktas, A.; Aslan, M.F. WiFi Based Indoor Localization: Application and Comparison of Machine Learning Algorithms. In Proceedings of the 2018 XXIIIrd International Seminar/Workshop on Direct and Inverse Problems of Electromagnetic and Acoustic Wave Theory (DIPED), Tbilisi, Georgia, 24–27 September 2018; pp. 246–251. [CrossRef]
33. Song, J.; Haas, C.T.; Caldas, C.H. Tracking the location of materials on construction job sites. *J. Constr. Eng. M.* **2006**, *132*, 911–918. [CrossRef]
34. Navon, R.; Sacks, R. Assessing research issues in Automated Project Performance Control (APPC). *Autom. Constr.* **2007**, *16*, 474–484. [CrossRef]
35. Tserng, H.P.; Dzeng, R.J.; Lin, Y.C.; Lin, S.T. Mobile construction supply chain management using PDA and bar codes. *Comput. Aided Civ. Infrastruct. Eng.* **2005**, *20*, 242–264. [CrossRef]
36. Chen, Q.; Adey, B.T.; Haas, C.; Hall, D.M. Using look-ahead plans to improve material flow processes on construction projects when using BIM and RFID technologies. *Constr. Innov.* **2020**, *20*, 471–508. [CrossRef]
37. Oner, M.; Ustundag, A.; Budak, A. An RFID-based tracking system for denim production processes. *Int. J. Adv. Manuf. Technol.* **2017**, *90*, 591–604. [CrossRef]
38. Araújo, C.S.; de Siqueira, L.C.; Ferreira, E.D.; Costa, D.B. Conceptual framework for tracking metallic formworks on construction sites using IoT, RFID and BIM technologies. In Proceedings of the 18th International Conference on Computing in Civil and Building Engineering, São Paulo, Brazil, 18–20 August 2020; pp. 865–878.
39. Cho, Y.K.; Youn, J.H.; Martinez, D. Error modeling for an untethered ultra-wideband system for construction indoor asset tracking. *Autom. Constr.* **2010**, *19*, 43–54. [CrossRef]
40. Land and Housing Institute. *A Study on the Measurement Method of Progress and Payment in Apartment Building Construction*; Land and Housing Institute: Seoul, Republic of Korea, 2002.
41. Li, H.; Love, P.E.; Gunasekaran, A. A conceptual approach to modeling the procurement process of construction using petri-nets. *J. Intell. Manuf.* **1999**, *10*, 347–353. [CrossRef]
42. Cheng, X.J.; Jin, W. Study on reverse engineering of historical architecture based on 3D laser scanner. *J. Phys. Conf. Ser.* **2006**, *48*, 843–849. [CrossRef]
43. Bernat, M.; Janowski, A.; Rzepa, S.; Sobieraj, A.; Szulwic, J. Studies on the use of terrestrial laser scanning in the maintenance of buildings belonging to the cultural heritage. In Proceedings of the 14th Geoconference on Informatics, Geoinformatics and Remote Sensing 2014, SGEM.ORG, Albena, Bulgaria, 17–26 June 2014; pp. 307–318.
44. Moyano, J.; Justo-Estebaranz, Á.; Nieto-Julián, J.E.; Barrera, A.O.; Fernández-Alconchel, M. Evaluation of records using terrestrial laser scanner in architectural heritage for information modeling in HBIM construction: The case study of the La Anunciación church (Seville). *J. Build. Eng.* **2022**, *62*, 105190. [CrossRef]
45. Ding, Z.; Liu, S.; Liao, L.; Zhang, L. A digital construction framework integrating building information modeling and reverse engineering technologies for renovation projects. *Autom. Constr.* **2019**, *102*, 45–58. [CrossRef]
46. Hosamo, H.H.; Hosamo, M.H. Digital twin technology for bridge maintenance using 3d laser scanning: A review. *Adv. Civ. Eng.* **2022**, *2022*, 2194949. [CrossRef]
47. Park, J.; Kim, S. Case Study Research in Earthwork Site Digitization for Smart Construction. *J. Korean Soc. Ind. Converg.* **2019**, *22*, 529–536. [CrossRef]
48. Singh, S.K.; Banerjee, B.P.; Raval, S. A review of laser scanning for geological and geotechnical applications in underground mining. *Int. J. Min. Sci. Technol.* **2022**, *33*, 133–154. [CrossRef]
49. Wang, J.; Yi, T.; Liang, X.; Ueda, T. Application of 3D Laser Scanning Technology Using Laser Radar System to Error Analysis in the Curtain Wall Construction. *Remote Sens.* **2023**, *15*, 64. [CrossRef]
50. Han, K.K.; Golparvar-Fard, M. Appearance-based material classification for monitoring of operation-level construction progress using 4D BIM and site photologs. *Autom. Constr.* **2015**, *53*, 44–57. [CrossRef]
51. Tuttas, S.; Braun, A.; Borrmann, A.; Stilla, U. Validation of BIM components by photogrammetric point clouds for construction site monitoring. *ISPRS Ann. Photogramm. Remote Sens. Spat. Inf. Sci.* **2015**, *2*, 231–237. [CrossRef]
52. Braun, A.; Tuttas, S.; Borrmann, A.; Stilla, U. A concept for automated construction progress monitoring using bim-based geometric constraints and photogrammetric point clouds. *J. Inf. Technol. Constr.* **2015**, *20*, 68–79.
53. Kim, C.; Kim, B.; Kim, H. 4D CAD model updating using image processing-based construction progress monitoring. *Autom. Constr.* **2013**, *35*, 44–52. [CrossRef]
54. Besl, P.J.; McKay, N.D. Method for registration of 3-D shapes. In Sensor fusion IV: Control paradigms and data structures. *Spie* **1992**, *1611*, 589–606.
55. Bosché, F. Automated recognition of 3D CAD model objects in laser scans and calculation of as-built dimensions for dimensional compliance control in construction. *Adv. Eng. Inform.* **2010**, *24*, 107–118. [CrossRef]

56. Shin, J.; Choi, J.; Kim, I.; Yoon, D. A Study on Development of Integrated Management System for BIM Property Information. *Korean J. Comput. Des. Engineering. Soc. Comput. Des. Eng.* **2016**, *21*, 130–1422. [CrossRef]
57. El-Omari, S.; Moselhi, O. Integrating 3D laser scanning and photogrammetry for progress measurement of construction work. *Autom. Constr.* **2008**, *18*, 1–9. [CrossRef]