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Cost–Benefit Analysis of Scan-vs-BIM-Based Quality Management

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Abstract: Terrestrial laser scanning (TLS) and building information modeling (BIM) play an important role as smart construction technologies introduced to increase productivity in the architecture, engineering, and construction (AEC) industry. However, these smart construction technologies have not been well introduced due to their high initial investment cost and poor performance reliability. Therefore, this study presents the results of a cost–benefit analysis to prove the investment value of terrestrial laser scanning and building information modeling. First, the reliability of this study data was increased through a case analysis of a real-world multi-project conducted by a single organization. Second, this study quantitatively proposed the economic value of terrestrial laser scanning and building information modeling by applying cost–benefit analysis (CBA). The effects of the application of terrestrial laser scanning and building information modeling on manpower input and time reduction were quantitatively analyzed through the cost–benefit analysis. The results showed that the cash value flows of terrestrial laser scanning and building information modeling could be considered to make value-for-money decisions for the adoption of terrestrial laser scanning and building information modeling in construction engineering organizations.

Keywords: terrestrial laser scanning (TLS); building information modeling (BIM); Scan-vs-BIM; cost–benefit analysis (CBA)

Citation: Kim, T.; Yoon, Y.; Lee, B.; Ham, N.; Kim, J.-J. Cost–Benefit Analysis of Scan-vs-BIM-Based Quality Management. *Buildings* **2022**, *12*, 2052. https://doi.org/10.3390/buildings12122052

Academic Editor: Amos Darko

Received: 27 October 2022
Accepted: 21 November 2022
Published: 23 November 2022

1. Introduction

The architecture, engineering, and construction (AEC) industry has relatively low productivity and growth rates compared with other industries [1]. As part of its digital transformation, the AEC industry is leveraging smart construction technologies such as building information modeling (BIM) to improve the productivity and stability of construction sites [2]. Digital transformation involves the adoption of innovative technologies to improve planning, procurement, staffing, productivity, and value creation [3,4]. However, the introduction of digital transformation has been delayed for various reasons, e.g., problems with company structure or culture, insufficient visibility into digital transformation strategies and investment returns, lack of awareness of benefits, lack of professional technical personnel, lack of infrastructure, and lack of funds [4].

Project management refers to the application of knowledge, skills, and tools to project activities to meet project requirements, e.g., with regard to time, cost, quality, risk, and resource management [5]. In the AEC field, the importance of quality control and project management is increasing, along with the need for three-dimensional (3D) image data extraction [6]. Terrestrial laser scanning (TLS) can provide detailed point data for the surface of an object to be photographed [7]. BIM is one of the key technological advancements in the construction industry [8] and is employed for the design, construction, and maintenance of buildings [9]. While these new technologies benefit the industry significantly, their adoption has been hampered by a lack of national standards, high application costs, a lack of skilled manpower, and organizational and legal issues [8]. Despite technological advances, work in the construction industry is still performed manually [10].

In academia, research is underway to introduce TLS and BIM to the construction industry. Bosché [11] proposed an approach that uses TLS and a 3D computer-aided design modeling project to automatically track the 3D as-built status of a construction site. Castañeda et al. [12] accelerated the intersection design process and improved the decision-making process using a methodological framework of traffic analysis with BIM. Previous studies have mainly focused on process and productivity improvement through TLS and BIM. However, few studies have suggested an economic rationale for practical technology introduction.

The following research gap was addressed in the present study.

First, in previous studies, the economic effects of introducing TLS and BIM to the project were not directly compared with the traditional methods [7,13,14]; thus, the reliability of the results were poor. Second, previous studies mainly focused on the analysis of a single project [15–17]. It can be risky to make investment decisions for expensive equipment based on a single-case economic analysis. In addition, because each study was performed in a different organization, there may be differences depending on the capabilities of the institution. In general, users who introduce expensive equipment are organizations that use it continuously to carry out multiple projects. Therefore, the reliability was low in judging the investment value of expensive equipment. Third, previous studies did not focus on projects that are in use or under construction [18–20]. Studies have been performed under specific conditions or in laboratories. The results of a study limited to a particular situation, location, or scope are unlikely to be considered as an economic basis for an actual project.

Therefore, the objective of the present study was to analyze a real-world multi-project case with TLS and BIM in a single organization. The economic feasibility was evaluated by comparing the high-performance Scan-vs-BIM-based research method, which has a high initial investment cost and high uncertainty regarding economic benefits, with the traditional human-resource-based research method. By presenting an economic justification for Scan-vs-BIM, we aimed to help construction organizations make decisions about digital transformation.

2. Literature Review

2.1. Scan-vs-BIM-Based Digital Transformation

TLS and BIM are digital technologies that were introduced to the construction industry to streamline processes, save time, and increase precision [21]. According to Succar [22], BIM is defined as "a set of interacting policies, processes and technologies generating a methodology to manage the essential building design and project data in digital format throughout the building's life-cycle." BIM is also used as a general term for new methods of design, construction, and maintenance [9]. BIM provides benefits such as (1) improved engineering design quality, (2) improved labor productivity [23], (3) construction site management [24], (4) improved structural engineering design productivity [25], and (5) cost and time savings [9]. However, BIM has not been well introduced in the construction industry. According to Liu et al. [8], the adoption of BIM has been hampered by (1) high implementation costs, (2) a lack of national standards, and (3) a lack of skilled engineers, with costs being the most significant factor. However, the problem of a lack of national standards is being mitigated by the issuance of PAS 1192 and ISO 19650.

In the construction industry, TLS has been used to solve problems caused by inaccurate or outdated building information [26]. This method can be used to scan large structures and measure surface information at high speeds, calculate the scan target with a millimeter-level accuracy and spatial resolution through point-cloud data, and provide advantages such as long-distance measurement of up to 6000 m [27]. As the scan data represent the existing shape as it is, they can be used to create an as-is BIM model [26]. However, the adoption of TLS has been hampered by (1) a reluctance to change, (2) price sensitivity or high execution costs, (3) expensive equipment and programs, and (4) anxiety regarding construction errors and inaccuracies [28].

Methods for enhancing the performance (e.g., process, productivity, economics) by using TLS and BIM together have also been studied. Scan-to-BIM is the process of transferring laser scan data to a BIM model [29]. This method is used to create a BIM model after manually applying laser scan data to a BIM tool such as Revit. However, the Scan-to-BIM process is a human-based work method [30] that is labor-intensive and error-prone for large-scale projects or complex objects [26]. Although the process of acquiring scan data is automated, the data processing is still manually performed. Scan-vs-BIM can automatically identify 3D model objects by aligning a laser scan of a construction site with a design 3D BIM model and comparing the two models according to metrics [31]. In this method, both the acquisition and processing of scan data are digitally transformed, but not all processes are automated.

The literature indicates that research being conducted to introduce digital transformation to the AEC industry through TLS and BIM is in progress. With the development of technology, TLS and BIM have been used together, and their performance is improving. However, the current AEC industry has a low overall growth rate, as it maintains a manpower-oriented work system despite the technological development.

2.2. Research Gaps in TLS and BIM

Table 1 presents the scanning targets, purposes, countries, types, and research gaps from previous TLS- and BIM-related studies in the architecture field.

Table 1. Details of the gaps in research areas related to TLS.

Scanning Target	Purpose	Country	Type	BIM Application	Impossible to Comparison As-Is and To-Be	Single Case	Not Real-World Project	Reference
Hydropower station	Reverse modeling	China	Plant	•	•	•	-	[7]
Roads in Wuhan	Automatic road-marking detection and measurement	China	Road	-	•	-	-	[13]
Free-form structure	Dimensional accuracy and structural performance assessment	China	Structure	•	•	•	-	[14]
Pipelines of a plant	Automatic 3D modeling	Korea	Plant	-	•	-	-	[32]
Industrial plant	Reconstruction of as-built 3D industrial instrumentation models	Korea	Plant	-	•	•	-	[33]
Railway of Niksic–Podgorica	Tunnel geometry inspection	Serbia	Tunnel	-	•	•	-	[34]
Landslide site	Landslide earthwork volume estimation	Taiwan	Mountain	•	•	•	-	[35]
Johnny Rosenblatt baseball stadium	Assessment of target types and layouts	USA	Stadium	•	•	•	-	[36]
Construction site of a pet farm	Quality assessment of structural columns	Singapore	Construction site	-	-	•	-	[15]
Administrative city construction of building	Fire-situation analysis	Korea	Construction site	•	-	•	-	[16]
Ulsan H plant	Structural safety diagnosis	Korea	Plant	•	-	•	-	[17]
Oil refinery	Automated approach to generate as-built 3D pipeline model	Algeria	Oil refinery	•	-	•	-	[37]
Tunnel	Extraction of sections	Korea	Tunnel	-	-	•	-	[38]

Table 1. *Cont.*

Scanning Target	Purpose	Country	Type	BIM Application	Impossible to Comparison As-Is and To-Be	Single Case	Not Real-World Project	Reference
Construction site of Concordia University	Measurement of construction work	Canada	Construction site	-	•	•	-	[39]
Concrete wall	Quantitative evaluation of peeling and delamination on infrastructure surfaces	Japan	Experimental subject	•	•	-	•	[18]
Highway curve road	Reconstruction	China	Road	•	•	•	•	[40]
Prefabricated MEP modules	Quality inspection	Singapore	Experimental subject	•	•	-	•	[19]
Common building material set	Automatic classification	Singapore	Experimental subject	-	-	-	•	[20]
Dewan Muafakat Johor	As-built survey	Malaysia	Public hall	-	•	•	•	[41]
Placement of precast bridge deck slabs	Automated dimensional quality assessment and automated optimal placement	Singapore	Experimental subject	-	-	-	•	[42]
Bridge structure	Structural condition assessment	USA	Experimental subject	•	•	•	•	[43]
Precast concrete elements	Quality assessment	Hong Kong	Experimental subject	•	-	-	•	[27]

• (Fulfillment for each title).

Some studies did not directly compare the benefit of TLS and BIM introduction with existing methods. In these studies, TLS and BIM were used for reverse engineering automation [7,32], detection and measurement [13,34,35], accuracy improvement [36], and structural performance evaluation [14]. Through these studies, work efficiency and performance were improved. However, these studies were not directly compared before and after the introduction of TLS and BIM. The investment value could not be proved because it was not revealed by how much work efficiency was numerically increased through direct comparison with the existing method.

There was also a study that analyzed the benefits of introducing TLS and BIM through a single case. In these studies, TLS and BIM were used for quality evaluation [15], structural safety diagnosis [16,17], reverse engineering [37], and detection and measurement [38,39]. These studies also improved work efficiency and performance, but the reliability of the research results was reduced by analyzing a single case. In general, users who introduce equipment such as TLS and BIM do not pay for expensive equipment to carry out one project. In addition, each study was conducted in different organizations, and there was also a difference in institutional competencies. For these reasons, the reliability of the work efficiency and performance of TLS and BIM analyzed through a single case was lowered.

Some studies did not prove their performance through actual projects. In these studies, TLS and BIM were used for detection and measurement [18], reverse engineering [40,41], quality inspection [19,27], detection and measurement [20], placement optimization [42], and structural diagnosis [43]. These studies have improved work efficiency and performance, but the results have not been verified through real projects. General users generate revenue from real projects. However, these studies were conducted under certain conditions or in a laboratory. As such, it is difficult to see the results of research limited to a specific situation or scope, rather than an actual project, as an economic basis for general users.

Research has been conducted in the fields of processes, productivity, and economics to introduce TLS and BIM. However, as the studies were conducted by different organizations, there were differences based on the organizations' capabilities, and it was difficult to generalize the results according to a single project case. In addition, it is difficult to generalize the results of a place or range where data extraction can be concentrated, such as a laboratory, for typical organizations that generate revenue from real-world projects. Because of this research gap, it is difficult to make an investment decision for the introduction of TLS and BIM, which has a high initial investment cost. Even innovative technologies are difficult to be introduced if the economic feasibility, accuracy, and long-term human resource training are inadequate. From a profit-seeking standpoint, it is undesirable to make decisions about technology adoption without supporting information and research [15]. Therefore, in this study, the economic rationale for the introduction of TLS and BIM was analyzed to present an economic basis for a multi-project case of a single organization.

2.3. Economic Effects of Technology Investment

Consumers, such as AEC companies and other private customers, are wary of investments to adopt new technologies such as BIM [44]. An economic foundation is needed to sustain the adoption of technology in the competitive world of business [45]. All technology adoption must be financially justified [46]. The economic impact of TLS and BIM has been investigated. Walasek and Barszcz [47] found through a return-on-investment (ROI) analysis that the design fees of companies using BIM are likely to increase. Lee et al. [46] proposed an ROI method for BIM based on the cost of avoiding rework due to design errors and demonstrated its economic feasibility by analyzing the ROI for each cause of design error. Ham et al. [48] developed a TLS-and-BIM-based framework for improving the capacity management and accessibility of cultural heritage archives. In previous studies, the economic impact of TLS and BIM was investigated through ROI and effect analyses. However, previous studies do not calculate cash value [48] or take into account changes in cash value over time [45,47]; it was not analyzed in quantitative monetary units. Therefore, it is difficult to quantitatively judge from the perspective of the user who will actually perform TLS and BIM.

Cost–benefit analysis (CBA) is a policy evaluation method that quantifies the positive and negative effects of a project and quantifies programs, projects, and policies in monetary terms [48]. Various studies have focused on the value or decision-making ability of CBA's investment. Đukić and Zidar [49] used CBA to analyze three examples of energy-efficient and non-energy-efficient projects and to analyze the economics of investment projects in public buildings. Jin et al. [50] conducted a CBA for transmission and conversion investment projects to increase the economic profit efficiency and the future value of the investment. The economic benefits and profitability of the investment projects were confirmed. Benardos et al. [51] confirmed the accuracy of CBA through ex ante and ex post CBA of subway infrastructure investment projects and helped establish criteria for the accurate evaluation of investments. Hsu [52] analyzed the three methods presented using CBA and selected a method for the efficient recycling of agricultural waste in Taiwan. As described previously, CBA is used to evaluate the costs and benefits of projects, policies, and decisions proposed in various fields from a financial viewpoint [51]. Abbas [53] argued that CBA provides a basis for determining whether investment decisions are justified and comparing as-is and to-be.

The papers analyzing the economic benefits of the introduction of new technologies using a cost–benefit analysis are as follows. Alqahtani et al. [54] showed economic benefits by analyzing the life cycle cost of green recycled plastic lightweight aggregate, a material for reducing the amount of plastic waste. Lu et al. [55] proposed a development decision-making framework for existing buildings through energy simulation and cost–benefit analysis to improve energy efficiency for sustainable urban development. Krishnan et al. [56] provided the technical and economic advantages of the CP strategy through a cost–benefit analysis of patch repair without galvanic anodes (PR strategy) and cathodic protection using galvanic anodes (CP strategy) of reinforced concrete structures. Krarti and Howarth [57] analyzed the benefits of converting existing equipment specific to residential buildings in the Kingdom of Saudi Arabia to high-efficiency air conditioning equipment.

In this study, two methods (as-is vs. to-be) were simultaneously applied to one project and the economic effect was analyzed through direct comparison. We investigated the cost and benefits of the existing visual inspection method and the TLS and BIM methods based on data for 12 projects over 2 years obtained from a structural safety inspection company. The purpose of this study was to present an economic basis for decision making by analyzing the economic effect of as-is vs. to-be when a single organization continuously uses TLS and BIM and performs actual multi-project and profit-seeking activities. In this regard, CBA provides an economic basis for decision making for digital transformation by comparing the economic effects of the existing visual inspection method and TLS and BIM methods.

3. Preliminary Investigation of the Problem Situation of the Case Project

3.1. CBA Framework of Scan-vs-BIM-Based Digital Transformation

The research method is described in this section. In this study, we aimed to analyze the economic impact of Scan-vs-BIM-based quality management of a structural engineering firm. In this study, the working ability of the visual inspection method and the Scan-vs-BIM method was compared in terms of value for money. As-is (visual inspection method) is a manpower-centered work method in which a worker directly inspects the site and transfers it to a drawing. To-be (Scan-vs-BIM method) is a method in which an operator conducts an investigation using a laser scanner in the field and compares the measured data with the BIM model. The visual inspection method has a human-centered work system, so it has disadvantages in that it takes a long time and has lower accuracy than the Scan-vs-BIM method. A flowchart of this study is shown in Figure 1.

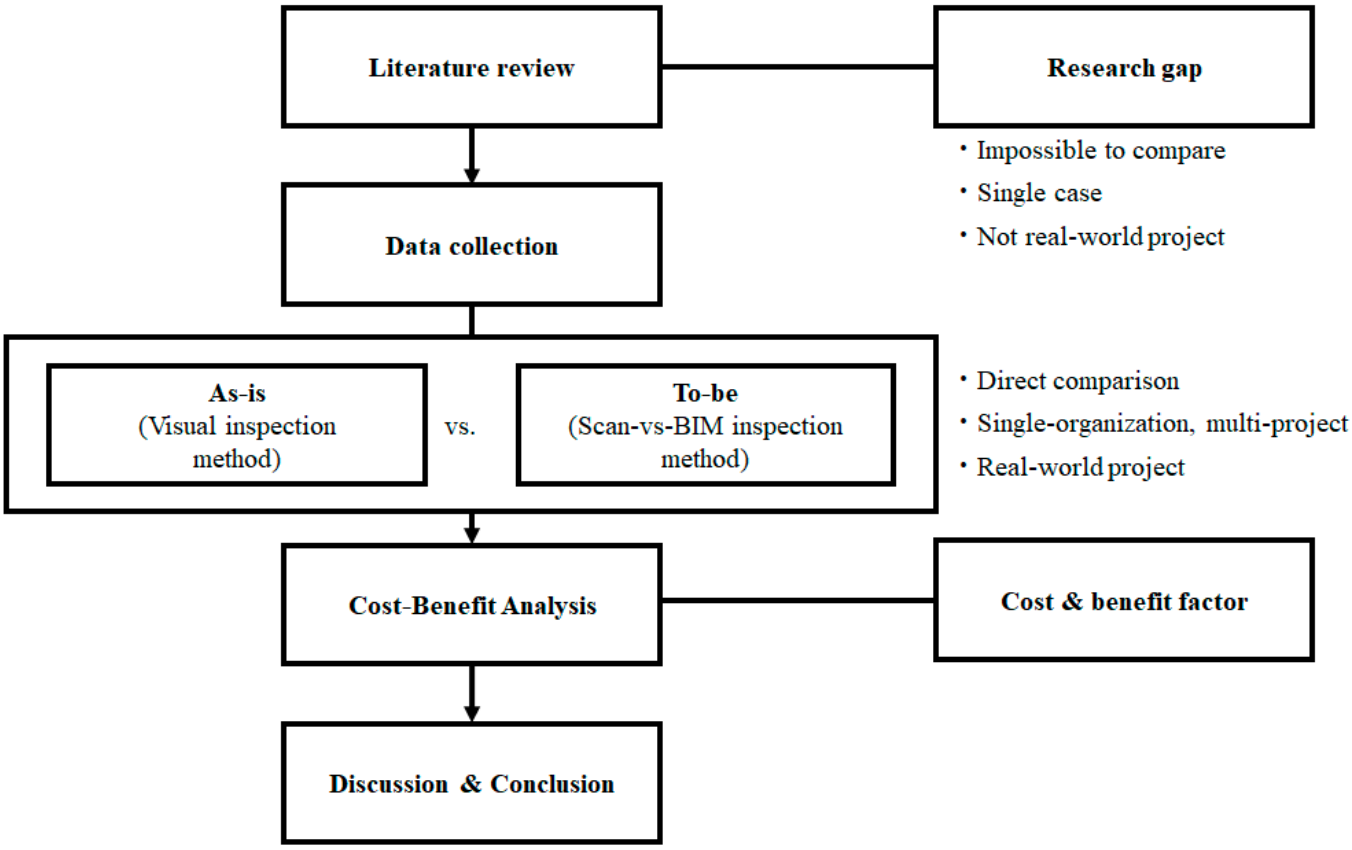


Figure 1. Framework for proving the monetary value of Scan-vs-BIM-based digital transformation.

In the first step of this study, we found a gap in previous studies dealing with TLS and BIM. The literature review confirmed that TLS and BIM benefit the AEC industry. By analyzing previous studies, we were able to identify research gaps in previous studies. The previous studies had research gaps such as 'impossible to compare as-is and to-be', 'single case', and 'not a real-world project'. Therefore, in this paper, the results of previous studies, which were difficult to generalize by filling the research gaps (e.g., impossible to compare, single case, not real-world project), were supplemented. The second step was an analysis of the work processes that have changed owing to TLS and BIM. Various tasks (e.g., reverse engineering, displacement analysis, and fire-scene analysis) were compared and analyzed through the Scan-vs-BIM method and the existing manpower-based survey method. The changes in the work process due to TLS and BIM were identified, and the cost and benefit factors for the application of Scan-vs-BIM-based quality management to the process were analyzed. The third step was to analyze the productivity of Scan-vs-BIM-based quality management. The productivity of the changed process was defined as the reduction in the resource consumption when the Scan-vs-BIM method is adopted compared with the existing visual inspection method. A comparison and analysis of the two methods were performed. The scope of the study was the work of a single organization, and it was assumed that the results of the work were identical between the two methods. Therefore, we focused on the reductions in time and manpower. The fourth step was to analyze the economics of Scan-vs-BIM-based quality management. Using CBA, a quantitative analysis of the economic feasibility of introducing TLS and BIM in monetary units was performed. The control group was based on the productivity data measured in the third step.

3.2. Cost-Benefit Analysis (CBA)

Bosché et al. [29] analyzed Scan-to-BIM and Scan-vs-BIM to demonstrate the robustness of Scan-vs-BIM. However, the new approach of Scan-vs-BIM was not calculated as a monetary value. CBA is a basic methodology for selecting effective projects [58]. Economic feasibility is determined by the benefit and benefit–cost ratio (BCR); a BCR of >1 confirms the economic value of investing in the project [59]. In this study, the cost and benefits of a project were estimated in terms of monetary value, converted to the present value, and then analyzed as the project's net present value (NPV) or BCR. This is because NPV and BCR are realistic evaluation values considering the discount rate to the time value of money. The NPV is the difference between the present value of the benefits generated over the entire project period and the present value of the costs. An NPV of >0 indicates that the project is economically feasible. In this study, $r = 0.045$ was applied as the social discount rate (r) of monetary value according to the guidelines for conducting a preliminary feasibility study set by the Ministry of Strategy and Finance of Korea. The present value of benefit (PVB) is the total present benefit. The present value of cost (PVC) is the total present cost. The NPV and discount rate are calculated as follows:

$$NPV = PVB - PVC = \sum_{i=0}^{n} \frac{B_i}{(1+r)^i} - \sum_{i=0}^{n} \frac{C_i}{(1+r)^i} \tag{1}$$

$$Discount\ rate = \frac{1}{(1+r)^i},\ i = 0,\ 1,\ 2,\ \cdots \tag{2}$$

where B represents the benefit, C represents the cost, r represents the discount rate, i represents the year, and n represents the analysis period.

The BCR is the ratio of the total benefits converted to the present value divided by the total costs converted to the present value. It indicates the feasibility of a project; a higher BCR corresponds to better economic feasibility. The BCR is calculated by applying a discount rate, and a project is economically feasible when the BCR is >1. The BCR is calculated as follows:

$$BCR\ (B/C) = \frac{PVB}{PVC} = \sum_{i=0}^{n} \frac{B_i}{(1+r)^i} / \sum_{i=0}^{n} \frac{C_i}{(1+r)^i} \tag{3}$$

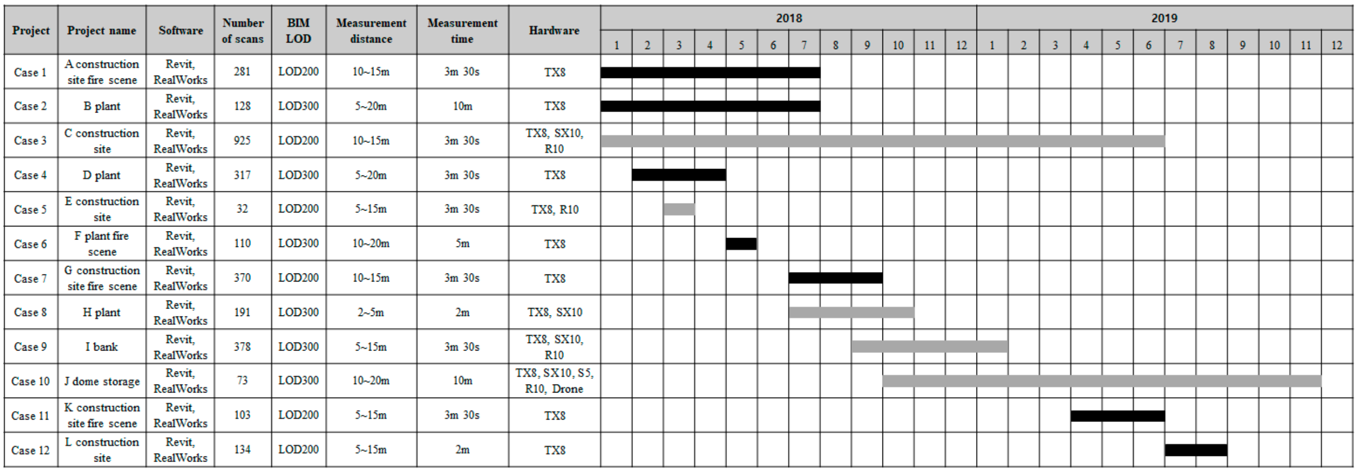
4. Case Study

In this section, we collected cases and conducted a CBA to determine whether Scan-vs-BIM-based quality management through the introduction of TLS and BIM was economically helpful for a construction project. The case data were collected through expert interviews with Dongyang Structural Engineers Group—an organization that provides integrated construction services such as structural design and engineering, construction, safety diagnosis, and maintenance.

4.1. Project Description

Dongyang Structural Engineers Group is a Korean company that was established in 1995 and specializes in the field of building structures. Currently, it is a structural engineering design office that performs various tasks, such as structural design and engineering, construction quality control, the revamping of aged facilities, safety diagnosis, and repair reinforcement for fire-damaged buildings, through digital transformation. The company's capabilities have advanced from basic visual inspection methods to BIM, TLS, and Scan-to-BIM methods. The data measurement process was automated by digital transformation, but the data processing was still manpower-centered. Therefore, Dongyang Structural Engineers Group tried to directly compare the results by conducting the existing visual inspection method together after the introduction of digital conversion to increase the reliability of Scan-vs-BIM.

Figure 2 is a diagram of twelve reverse-engineering projects conducted by Dongyang Structural Engineers Group through Scan-vs-BIM. In this study, seven projects with the same software and hardware used were selected from the twelve projects to increase the accuracy of the results.



Project	Project name	Software	Number of scans	BIM LOD	Measurement distance	Measurement time	Hardware
Case 1	A construction site fire scene	Revit, RealWorks	281	LOD200	10~15m	3m 30s	TX8
Case 2	B plant	Revit, RealWorks	128	LOD300	5~20m	10m	TX8
Case 3	C construction site	Revit, RealWorks	925	LOD200	10~15m	3m 30s	TX8, SX10, R10
Case 4	D plant	Revit, RealWorks	317	LOD300	5~20m	3m 30s	TX8
Case 5	E construction site	Revit, RealWorks	32	LOD200	5~15m	3m 30s	TX8, R10
Case 6	F plant fire scene	Revit, RealWorks	110	LOD300	10~20m	5m	TX8
Case 7	G construction site fire scene	Revit, RealWorks	370	LOD200	10~15m	3m 30s	TX8
Case 8	H plant	Revit, RealWorks	191	LOD300	2~5m	2m	TX8, SX10
Case 9	I bank	Revit, RealWorks	378	LOD300	5~15m	3m 30s	TX8, SX10, R10
Case 10	J dome storage	Revit, RealWorks	73	LOD300	10~20m	10m	TX8, SX10, S5, R10, Drone
Case 11	K construction site fire scene	Revit, RealWorks	103	LOD200	5~15m	3m 30s	TX8
Case 12	L construction site	Revit, RealWorks	134	LOD200	5~15m	2m	TX8

Figure 2. Project cases using TLS and BIM.

An overview of the seven selected cases is presented below.

Case 1 involved a fire that occurred during the construction of an office tower located in Suwon, Korea. The tower had five stories underground and forty-one stories above the ground, with a maximum height of 175 m. The scope of the scanning was the first basement floor and the second basement floor where the fire occurred. The contractor requested a status analysis of the fire site. The service period was January 2018 to July 2018 (7 months). The data collection comprised 3 days of scanning using Trimble TX8 and 15 days of data processing using Revit and RealWorks. Through scanning, the soot, microcracks in the concrete, explosion, and exposure and warpage of the rebar were analyzed.

Case 2 involved the displacement analysis of a large-scale plant located in Ulsan, Korea. The total scale of the site was 5,000,000 m^2, and the site included five finished car factories, a transmission factory, and an export-only pier. Built from 1968 to 1975, it is the world's largest single plant, producing an average of 6000 vehicles per day. Thus, it was necessary to conduct a structural safety diagnosis for the aging facilities. However, the safety diagnosis could not be performed because the previously designed design drawings differed from the current factory conditions at the time of the work. The scope of the displacement analysis via TLS and BIM was the main pipe rack onsite. The service period was January 2018 to July 2018 (7 months). The data collection comprised 7 days of scanning using Trimble TX8 and 20 days of data processing using Revit and RealWorks.

Case 4 was a reverse drawing example of a plant located in Mokpo, Korea. The contractor requested preservation through reverse drawing of the plant. Therefore, the entire factory was scanned. The area was 13,715 m^2. The plant is a production facility for refractory materials, which has been needed as the steel industry has developed since the 1930s. It consists of three factory buildings, three chimneys, office buildings, residential buildings, and five industrial facilities. Mechanical equipment and ancillary facilities from the 1950s to the 1970s remain, and the working process of fire-resistant materials can be seen, so it is valuable as a modern heritage site. The service period was from February 2018 to April 2018 (3 months). The data collection comprised 4 days of scanning using Trimble TX8 and 20 days of data processing using Revit and RealWorks.

Case 6 involved a fire at a plant located in Miryang, Korea. The contractor requested an analysis of the current state of the fire damage on the site, structural safety diagnosis, and design for repair and reinforcement. The plant had two stories above the ground. The service period was May 2018 (1 month). The data collection comprised 2 days of scanning using Trimble TX8 and 4 days of data processing using Revit and RealWorks. A 3D BIM model was created using 3D scan data, and a drawing was created that was more accurate than the existing 2D drawing. Additionally, using the scan data for repair and reinforcement design, a preliminary review was conducted to prevent interference.

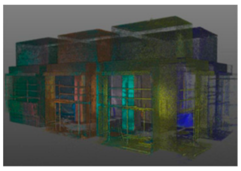
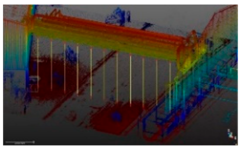
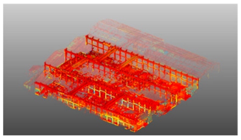
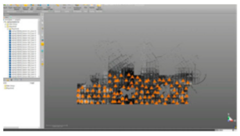
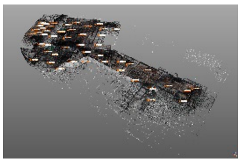
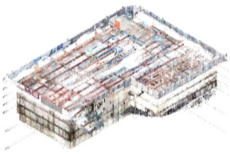
Case 7 involved a fire that occurred during the construction of a residential complex located in Sejong, Korea. The contractor requested an analysis of the fire damage status and a calculation of the repair and reinforcement quantities. The building had two basement floors and twenty-four floors above the ground. The fire damage ranged from the second basement floor to the second floor above the ground. The service period was from July 2018 to September 2018 (3 months). The data collection comprised 4 days of scanning using Trimble TX8 and 10 days of data processing using Revit and RealWorks. Through this process, the concrete explosion, exfoliation, rebar exposure, and damages to the members were analyzed. In addition, damage such as early cracks in the concrete and soot was analyzed in the periphery.

Case 11 involved a fire that occurred at the new construction site of a multipurpose building containing a shopping mall and an apartment in Yongin, Korea. The contractor requested an analysis of the fire damage status. The building had seven stories below the ground and twenty-two stories above the ground. The scanning range was from the fourth floor to the twentieth floor. The service period was from April 2019 to June 2019 (3 months). The data collection comprised 2 days of scanning using Trimble TX8 and 10 days of data processing using Revit and RealWorks.

Case 12 involved an office tower new construction site located in Pohang, Korea. The contractor requested a structural safety diagnosis and safety evaluation of the construction site. The building had six stories below the ground and twenty-two stories above the ground. The scope of the safety diagnosis was from the fourth basement floor to the first floor. The service period was from July 2019 to August 2019 (2 months). The data collection comprised 2 days of scanning using Trimble TX8 and 10 days of data processing using Revit and RealWorks. Through this process, it was confirmed that the cantilever beam was damaged and deformed and that the steel column was pushed.

Table 2 presents details of the projects, including the purposes, scan areas, and main structures. The projects consisted of seven cases with the same input equipment selected from twelve projects conducted from 2018 to 2019. The purposes of the projects included fire scene analysis, displacement analysis, and conversion design through reverse engineering using TLS and BIM. The main structures included a reinforced-concrete (RC) structure, a steel frame, a steel-frame reinforced-concrete (SRC) structure, and a wooden structure.

Table 2. Scan-vs-BIM cases.

Project	Picture	Purpose	Location	Scan Area	Main Structure			
					RC	Steel	SRC	Timber
Case 1		Fire scene analysis	Suwon	6090 m^2	•			
Case 2		Displacement analysis	Ulsan	2.97 km		•		
Case 4		Reverse drawing	Mokpo	12,066 m^2		•		•
Case 6		Fire scene analysis	Miryang	6750 m^2		•		
Case 7		Fire scene analysis	Sejong	13,156 m^2	•			
Case 11		Fire scene analysis	Yongin	4120 m^2	•	•	•	
Case 12		Displacement analysis	Pohang	6480 m^2		•	•	

• (Fulfillment for each title).

4.2. Data Collection

In this study, a CBA of the method of quality management was performed through the introduction of Scan-vs-BIM. The employees used in this study were workers at Dongyang Structural Engineers Group. They had no knowledge of TLS. They did not conduct training on TLS separately but proceeded until the performance of TLS-based measurement was the same as or higher than that of visual-inspection-based measurement. Therefore, the standard of CBA conducted in this study meant a financial analysis of the costs and benefits required for generating and analyzing information at the same level as or higher level than when using the existing visual inspection method. These cost and benefit factors were defined through expert interviews, and the monetary value of each factor was considered. Table 3 provides the cost and benefit factors that were obtained through expert interviews.

Table 3. Cost and benefits factors of Scan-vs-BIM.

Classification	Factor	Detail Factor	Calculate in Monetary Value
Cost	Investment cost	Hardware	Able
		Software	Able
	Insurance cost	Hardware	Able
		Software	Able
	Education cost	Hardware	Able
		Software	Able
Benefit	Manpower input	Measurement time	Able
		Data processing time	Able
	Accuracy	Error of measurement	Unable
		Error of data processing	Unable
	Corporation value	Reliability	Unable
		Customer service satisfaction	Unable

Cost factors may vary depending on the size and function of the organization, as well as the main work content. In this study, we established a general standard by developing a model of basic cost factors through expert interviews. A CBA should establish a general basis by presenting a model of basic cost components. Common cost factors for Scan-vs-BIM-based quality management include the initial costs and maintenance costs of hardware, software, and human resources. However, the capabilities of Dongyang Structural Engineers Group have advanced from the visual inspection method to the Scan-vs-BIM method through continuous digital transformation. Therefore, in this study, CBA was conducted only on cost factors (e.g., software and hardware investment cost, insurance cost) that were additionally used for Scan-vs-BIM-based quality management. The benefit factors were classified into quantitative factors that could be measured in monetary units and qualitative factors that could not be measured in monetary units. CBA should be performed in terms of monetary units. Therefore, in this study, the reduction in work time, which could be converted into monetary units, and the reduction in manpower input were measured as benefit factors. The data used in this study were prepared by extracting only onsite data measurement and data processing tasks during the work of each case. Data collection was measured through the visual inspection method and the TLS method. Dongyang Structural Engineers Group assigned both the conventional visual inspection team and the TLS team to the reverse-engineering case project.

The visual inspection team's onsite investigation process was as follows. The first step of reverse engineering for structural displacement analysis, field analysis, and conversion design was to conduct a preliminary investigation through a review of design documents and related data before measuring the structure. During the operation of the building, if there was insufficient information, such as the absence of drawings, inconsistency with the drawings, or deterioration, information was supplemented through onsite measurements. For the visual inspection method, at least two onsite inspections are required in this process. Additionally, more time, money, and personnel are invested compared with the case where TLS equipment is used, because the inspection is conducted with the naked eye. Furthermore, in the case of current status analysis through reverse engineering, accurate data cannot be calculated, and economic loss may occur because the entire result is inferred by sampling from a severely damaged area.

The Scan-vs-BIM team's onsite investigation process was as follows. To determine the purpose, scope, and method of scanning and to efficiently measure point-cloud data, a preliminary investigation of the site was conducted. Three-dimensional scanning data were acquired after establishing the scanning equipment usage plan, scanning interval, and arrangement plan according to the site conditions. In this case, more accurate information could be obtained by scanning at various locations. Through this process, the problem of deriving the entire result from partial measurements in the visual inspection method is mitigated. Figure 3 presents a comparison of the conventional method and the TLS method.

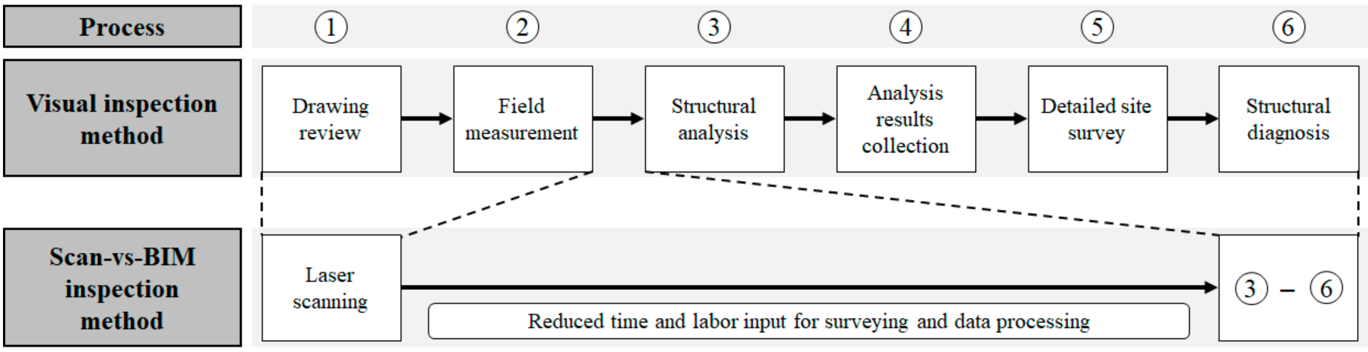


Figure 3. Comparison of traditional and Scan-vs-BIM processes.

The Scan-vs-BIM-based quality management had software and hardware that were shared with the existing method. Therefore, in this study, only the newly added software and hardware were considered for the CBA factor of the Scan-vs-BIM-base quality management. Dongyang Structural Engineers Group purchased Trimble's RealWorks (software) and Trimble's TX8, SX10, R10, S5, and Drone (hardware) for digital transformation. There were also management costs (e.g., insurance) for the purchased software and hardware. In the process of digital transformation from the existing visual inspection method through TLS and BIM, there were no additional costs, such as training costs, for smooth use. In this study, we analyzed seven cases in which identical software and hardware were used. Therefore, the purchase cost and management cost of RealWorks and TX8 were selected as the cost factors.

After digital transformation, the manpower-oriented method was applied at the same time to produce results similar to the level of work of the conventional method, and thus, the reliability of Scan-vs-BIM was enhanced. By using both methods at the same time, Dongyang Structural Engineers Group had the effect of reducing the manpower input and input time. In addition, there were advantages such as the long-distance measurement of places that people could not enter (e.g., pipelines of the plant) or places that were dangerous for humans to directly measure in the existing manpower-centered survey method. These qualitative benefits could not be measured in terms of quantitative monetary value in the CBA. Therefore, in this study, the reductions in manpower and time were selected as the benefit factors.

Table 4 presents the manpower input and time for the visual inspection method (as-is) and Scan-vs-BIM method (to-be) for each project. These data were compiled by collecting the number of people and time taken for the visual inspection team and the Scan-vs-BIM team involved in each project. Through the data measurement of each project, it was confirmed that the time required for measurement work and data post-processing was reduced when TLS was used.

Table 4. Comparison of labor input between the traditional and TLS methods (as-is vs. to-be).

Project	Number of Scans	BIM LOD	File Weight	Classification of Work	Methods				Reduction Rate (%)	
					As-Is		To-Be			
					People	Days	People	Days	People	Days
Case 1	281	LOD 200	48 GB	Measurement	6	10	2	3	66.7	70.0
				Data processing	6	30	4	15	33.3	50.0
Case 2	128	LOD 300	23.8 GB	Measurement	7	20	5	7	28.6	65.0
				Data processing	7	40	5	20	28.6	50.0
Case 4	317	LOD 300	57.4 GB	Measurement	5	5	3	4	40.0	20.0
				Data processing	5	20	3	20	40.0	0.0

Table 4. *Cont.*

Project	Number of Scans	BIM LOD	File Weight	Classification of Work	Methods				Reduction Rate (%)	
					As-Is		To-Be			
					People	Days	People	Days	People	Days
Case 6	110	LOD 300	28.1 GB	Measurement Data processing	3 3	3 10	2 2	2 4	33.3 33.3	33.3 60.0
Case 7	370	LOD 200	37.2 GB	Measurement Data processing	4 3	10 20	3 4	4 10	25.0 −33.3	60.0 50.0
Case 11	103	LOD 200	113 GB	Measurement Data processing	4 4	10 20	2 2	2 10	50.0 50.0	80.0 50.0
Case 12	1134	LOD 200	7.9 GB	Measurement Data processing	3 2	5 20	3 2	2 10	0.0 0.0	60.0 50.0

Table 5 presents the time and cost reductions for the scan-vs-BIM method (to-be) relative to the visual inspection method (as-is) for each case. The workers involved were paid workers. Therefore, it was not possible to calculate the amount of manpower input and the reduced time as monetary value. For the convenience of analysis and comparison, the calculation of the benefit increment for each case was based on 292,249 KRW/d, which is the labor cost of an express engineer based on the Korea 2020 engineering fee. Assuming an 8 h workday, the labor cost was 36,531 KRW per hour. This indicated the reduced cost per unit time when using TLS instead of the visual inspection method.

Table 5. Time and cost comparison between the traditional and TLS methods (as-is vs. to-be).

Project	Type of Work	Method		Total Time Saving (hour)	Cost Reduction (1000 KRW)	Reduction Rate (%)
		As-Is (hour)	To-Be (hour)			
Case 1	Measurement Data processing	480 1440	48 480	1392	50,851	72.5
Case 2	Measurement Data processing	1120 2240	280 800	2280	83,291	67.9
Case 4	Measurement Data processing	200 800	96 480	424	15,489	42.4
Case 6	Measurement Data processing	72 240	32 64	216	7891	69.2
Case 7	Measurement Data processing	320 480	96 320	384	14,028	48.0
Case 11	Measurement Data processing	320 640	32 160	768	28,056	80.0
Case 12	Measurement Data processing	120 320	48 160	232	8475	52.7

4.3. Data Analysis

The factors included in the CBA were analyzed for the cost increment (ΔC) and benefit increment (ΔB) when switching from the conventional visual inspection method to the Scan-vs-BIM method. Before analyzing the data, Dongyang Structural Engineers Group's work ability was assumed for seven cases conducted in 2018. Therefore, a CBA was conducted assuming that the seven selected projects were conducted for one year. Table 6 presents a CBA for the seven selected projects. As cost factors for the method of Scan-vs-BIM-based quality management, there were software and hardware investment costs. The investment cost was 25,000,000 KRW for software and 110,000,000 KRW for hardware, and the annual management cost was 135,000,000 KRW, i.e., 10% of the total investment cost. For the software and hardware, only the cost of annual maintenance (e.g., insurance), without additional costs after the initial input cost, was used.

Table 6. CBA of the TLS method for 1 year (1000 KRW).

Classification	Initial Cost	Case 1	Case 2	Case 4	Case 6	Case 7	Case 11	Case 12
Investment cost	−135,000	0	0	0	0	0	0	0
Maintenance cost	0	0	0	0	0	0	0	−13,500
Accumulated cost	−135,000	−135,000	−135,000	−135,000	−135,000	−135,000	−135,000	−148,500
Total benefit	0	50,851	83,291	15,489	7891	14,028	28,056	8475
Accumulated benefit	0	50,851	134,142	149,631	157,522	171,550	199,605	208,081
Cost + benefit	−135,000	−84,149	−858	14,631	22,522	36,550	64,605	59,581
Cost–benefit ratio	0	0.38	0.99	1.11	1.17	1.27	1.48	1.40

The seven cases analyzed previously were classified into reverse drawing, displacement analysis, and fire scene analysis according to the purpose of the work. A CBA was conducted assuming that the project was conducted for one year based on the average value of the cases according to the purpose. Table 7 presents the CBA for a single project conducted for one year based on the purpose.

Table 7. CBA by purpose of a single case for 1 year (1000 KRW).

Classification		Initial Cost	1st Year
Investment cost		−135,000	0
Maintenance cost		0	−13,500
Accumulated cost		−135,000	−148,500
Reverse drawing	Total benefit	0	15,489
	Accumulated benefit	0	15,489
	Cost + benefit	−135,000	−133,011
	Cost–benefit ratio	0	0.10
Displacement analysis	Total benefit	0	45,883
	Accumulated benefit	0	45,883
	Cost + benefit	−135,000	−102,617
	Cost–benefit ratio	0	0.31
Fire scene analysis	Total benefit	0	25,206
	Accumulated benefit	0	25,206
	Cost + benefit	−135,000	−123,294
	Cost–benefit ratio	0	0.17

A CBA was performed by dividing the accumulated amount by applying a social discount rate ($\Delta B/\Delta C$) by calculating the costs and benefits of the seven selected projects. The operating period was set as the average equipment lifespan of 5 years. It was assumed that the residual value of the equipment after the average equipment lifespan of 5 years was the same. The CBA for one year (from Table 7) was used as the analysis standard. A social discount rate of 4.5% was applied according to the guideline for conducting a preliminary feasibility study set by the Ministry of Strategy and Finance of Korea. It was confirmed that the reverse drawing and fire scene analysis fields were not economical because the NPV did not exceed 0 even after 5 years, which is the average life cycle. However, the displacement analysis was able to provide an economic benefit as the NPV exceeded zero in its fifth year. Table 8 presents the CBA for 5 years, i.e., the average lifespan of the equipment.

The results of the CBA for single project and multi-project by purpose through TLS and BIM are shown in Figure 4. According to the results, it was possible to see economic benefits when carrying out multiple projects as opposed to when carrying out a single project. The result of the CBA for the single case of reverse engineering was 0.10 in the 1st year and 0.38 in the 5th year. The result of the CBA for the single case of a fire site was 0.17 in the 1st year and 0.62 in the 5th year. These results indicated that the introduction of reverse engineering through TLS and BIM for short-term use in the fire site and reverse engineering work could not be cost-effective. For the displacement analysis, the result of the CBA for a single case was 0.31 in the 1st year and 1.13 in the 5th year, indicating economic advantages even for a single project. When Scan-vs-BIM-based quality management for a multi-project was used for 1 year, the cost–benefit ratio was 1.40, indicating economic feasibility due to the benefits outweighing the investment cost. The cost–benefit ratio at the 5th year—corresponding to the average lifespan of the equipment—was 5.14. The ratio could bring greater economic benefits when used longer than the average lifespan of the equipment due to user maintenance. These results can provide a quantitative basis in terms of monetary units for Scan-vs-BIM-based quality management. They are also useful for engineering firms making investment decisions, e.g., regarding whether to continue a project.

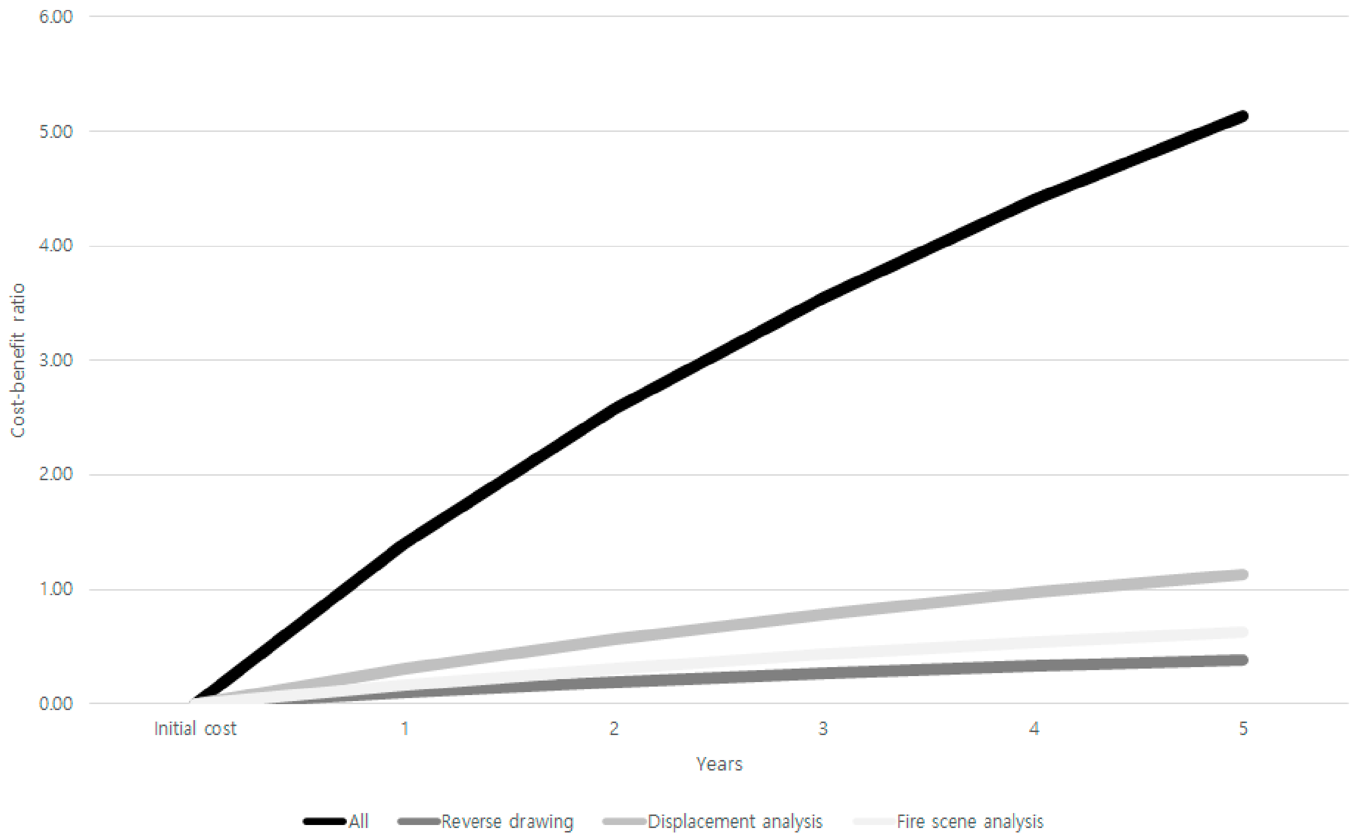


Figure 4. Cost–benefit ratio (*BCR*) graph over 5 years.

Table 8. CBA during the average lifecycle (5 years) of TLS (1000 KRW).

Classification		Initial Cost	Years				
			1	2	3	4	5
Discount rate		1	0.957	0.916	0.876	0.839	0.802
Cost		135,000	148,500	162,000	175,500	189,000	202,500
PVC		135,000	142,105	148,348	153,790	158,488	162,496
Reverse drawing	Benefit	0	15,489	30,978	46,467	61,957	77,446
	PVB	0	14,822	28,368	40,719	51,954	62,146
	NPV	−135,000	−127,283	−119,981	−113,071	−106,534	−100,350
	B/C	0.00	0.10	0.19	0.26	0.33	0.38

Table 8. *Cont.*

Classification		Initial Cost	Years				
			1	2	3	4	5
Displacement analysis	Benefit	0	45,883	91,766	137,649	183,532	229,415
	PVB	0	43,907	84,033	120,621	153,903	184,094
	NPV	−135,000	−102,617	−64,315	−33,169	−4585	21,598
	B/C	0	0.31	0.57	0.78	0.97	1.13
Fire scene analysis	Benefit	0	25,206	50,413	75,620	100,826	126,033
	PVB	0	24,121	46,165	66,266	84,549	101,135
	NPV	−135,000	−123,294	−102,184	−87,525	−73,939	−61,361
	B/C	0	0.17	0.31	0.43	0.53	0.62
All	Benefit	0	208,081	416,162	624,243	832,324	1,040,405
	PVB	0	199,120	381,092	547,022	697,955	834,874
	NPV	−135,000	57,015	232,744	393,232	539,467	672,378
	B/C	0	1.40	2.57	3.56	4.40	5.14

5. Discussion

Dongyang Structural Engineers Group performed a digital transformation of the organization's work (structural safety diagnosis, fire scene analysis, etc.) process based on Scan-vs-BIM. The use of TLS had advantages such as the high-speed scanning of facilities, millimeter-level accuracy, and long-distance scanning. Scan-vs-BIM is introduced to reduce costs, improve the service quality, and improve the working environment from an organization's viewpoint. These advantages increase the value of Scan-vs-BIM. However, the adoption of TLS and BIM has been hindered by the high initial investment costs [8,28]. Previous studies related to TLS and BIM had research gaps, e.g., it was impossible to compare the conventional and proposed methods, only a single project was examined, real-world projects were not considered, or BIM was not applied [7,15,18]. Additionally, in some studies, TLS was used but not BIM [13,20,38]. These research gaps reduce the reliability of the results. Accordingly, it is difficult for existing research results to help users such as structural engineering firms to make investment decisions for the introduction of Scan-vs-BIM-based quality management. In addition, it is difficult to find a case where two methods were simultaneously applied to one project in an industry with a large project scale, such as the construction industry, and a direct comparison was conducted. Therefore, by deploying the existing visual inspection team and the Scan-vs-BIM team simultaneously in a multi-project case, we quantitatively confirmed the economic feasibility of Scan-vs-BIM-based quality management.

In the cases of reverse engineering and the fire site, the cost–benefit ratio in the 5th year did not exceed 1. In these cases, the absolute reductions in manpower and time were small owing to the small size of the site. These results indicated that the quality management of work through TLS and BIM was not cost-effective for short-term projects and small projects. According to a previous study, it is economically viable to lease a TLS system when it is used for fewer than 15 projects in 5 years [60]. However, for the single-case displacement analysis, the cost–benefit ratio in the 5th year exceeded 1, and there was an economic benefit. For the displacement analysis, in one of the two cases used as data values for a single case, Case 2 was a large site of 5,000,000 m^2. For large-scale projects, despite the short-term use, the absolute manpower input and time reductions were large, indicating economic feasibility. Figure 5 is a graph of the NPV according to a change in the discount rate. Based on the average life expectancy of TLS of 5 years, the NPV was able to obtain economic benefits up to 32% of the discount rate. In addition, if the equipment was used for 10 or 20 years, economic gains could be made up to 20% and 11% of the discount rate. This result can help customers to make investment decisions based on the discount rate.

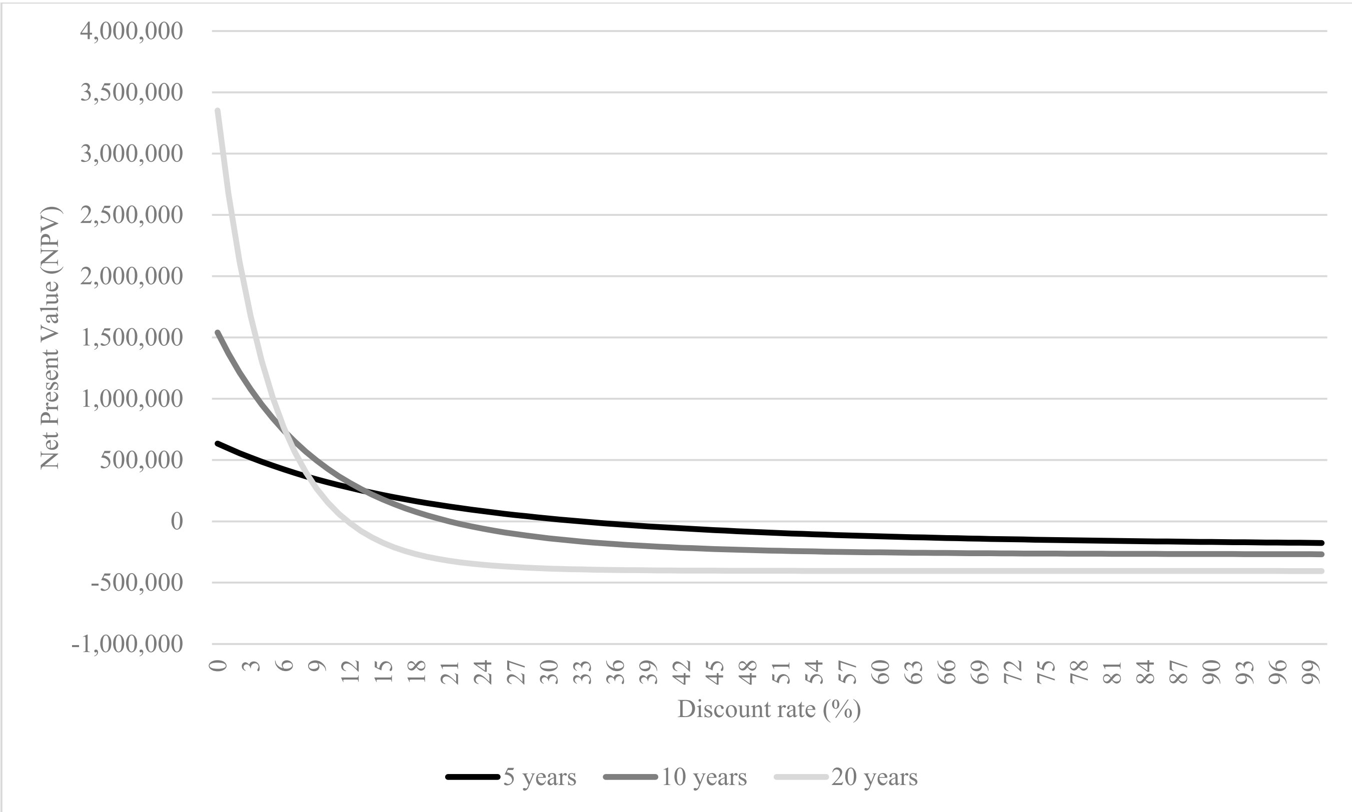


Figure 5. NPV graph according to the change in the discount rate (1000 KRW).

Scan-vs-BIM-based quality management was found to be more efficient than the existing method with regard to human resource management at the organizational level. In this study, the average manpower reduction rate for the seven cases was approximately 65% in terms of cost-effectiveness. According to previous studies, the scanning and structural safety diagnosis of large-scale facilities using TLS and BIM can reduce manpower input by 90% compared with the existing method, and the service period of 7 months can be reduced to 3 months [17]. The labor-saving effect of the TLS and BIM methods can reduce the service period required for a project. From an organization's viewpoint, the multitasking ability can be strengthened through manpower distribution and schedule management. Personnel distribution and scheduling through a reduced service period increases the workload during the same period, resulting in economic benefits.

The Scan-vs-BIM method can represent objects more realistically than the visual inspection method. Measurement by manpower is a qualitative evaluation method involving contact measurement. Because manpower is measured by the eyes of the investigator, non-uniform data are collected according to the engineer's ability with a low precision. In addition, because the work is manpower-centered, a large amount of manpower must be input at a low work speed. In contrast, measurement by TLS is a non-contact method that involves quantitative evaluation through 3D scan data. There is little error depending on the field situation, and precise data are obtained by measuring the exact area, depth, deformation state, and quantity. Owing to the use of equipment, the work speed exceeds that of measurement by manpower. Additionally, there is a safety benefit arising from the remote measurement of parts that are dangerous for humans to measure.

The contributions of this study, which filled the research gaps of previous studies, are as follows.

First, seven cases with common input equipment among twelve real-world multi-project cases conducted by Dongyang Structural Engineers Group from 2018 to 2019 were analyzed. Previous studies had limitations such as being impossible to compare as-is and to-be, being a single case, and not being a real-world project, making it difficult to generalize the results. Additionally, in some studies, BIM was not applied; thus, it was unclear whether digital transformation was achieved. In the AEC industry, two methods are rarely applied to one project simultaneously. In the present study, the reliability of the results was enhanced by analyzing cases that filled the gaps of previous studies.

Second, the analysis results indicated that the TLS and BIM methods had economic advantages over the existing manpower-centered survey methods. A literature review revealed that the main reason for not introducing TLS and BIM methods in the AEC industry is the high initial cost. In fact, a CBA based on a single case indicated that the amount of manpower was reduced, but the introduction of TLS and BIM was not economical when considering the purchase cost of the equipment. According to these results, the adoption of TLS and BIM is economically beneficial for an engineering firm that uses them continuously rather than for short-term work. When a CBA for multiple projects was conducted, even though the purchase cost of equipment and changes in cash value were considered, the investment cost was recovered, and economic benefits were obtained. In addition, the project analyzed in this study was not an analysis of all the projects carried out by the Dongyang Structural Engineers Group. Considering this, if the work methods of other projects are also digitally transformed, additional economic benefits can be realized.

Third, the effectiveness of TLS and BIM in terms of the human resource management of the organization was analyzed through case studies. The visual inspection and TLS and BIM methods were simultaneously applied to the construction projects. The visual inspection team and the TLS and BIM teams were simultaneously deployed on the same project, revealing the differences in the manpower input and time. For the conventional visual inspection method, completing the seven projects required 8792 h. However, for the Scan-vs-BIM method, it required 3096 h. These results indicated that TLS and BIM can reduce the high personnel expenses of AEC companies.

6. Conclusions and Further Research

The economic feasibility of a structural engineering firm's Scan-vs-BIM-based quality management was quantitatively analyzed. When evaluating a project, we analyzed the economic benefits of quality management based on Scan-vs-BIM using CBA, which is a technique for analyzing the economic feasibility of a project by quantifying it in terms of monetary units. The objective was to help the construction industry, which is slow to introduce technology compared with other industries, to make investment decisions for new technologies.

Previous studies had research gaps of being impossible to compare as-is and to-be, being a single case, and not being a real-world project. In addition, because the subjects of the studies were different, there were individual variations according to the equipment operator. Therefore, in the present study, a direct comparison was performed between the human-centered visual inspection method and the Scan-vs-BIM method, which were applied to a real-world multi-project of a single organization. We derived the cost and benefit factors for Scan-vs-BIM-based quality management from the existing manpower-centered survey method. The measurements were measured at an average position of 5–20 m, and it took about 3 min to 4 min per measurement. When high-level BIM LOD was required by increasing quality, it was measured for a long time at a relatively close distance. It was confirmed that the method based on TLS and BIM had a high initial investment cost compared with the existing method but had economic advantages, i.e., reducing the amounts of manpower and time. Additionally, the results of the CBA, in which the value of money over time was applied to the cost and benefit factors, indicated that the introduction of TLS and BIM was economically effective in cases of multiple projects or large-scale projects. From the perspective of sustainability, this study confirmed the long-term feasibility of the digital transformation of various tasks using TLS and BIM, which have high initial investment costs. An organization that will use TLS and BIM in the long term can use the CBA results of this study to make investment decisions.

The limitations of this study were as follows. First, the purpose of TLS and BIM was limited to reverse engineering, displacement analysis, and fire-site analysis. Second, the compatibility with other platforms in the market or with open access was not confirmed, and the scope of the study was limited to Revit and RealWorks. Third, the Dongyang Structural Engineers Group has a lot of experience in conducting projects, so conditions such as optimal conditions, number of technical staff required to process the information, idea area, and minimum TLS scanning conditions were not considered. Through this, the monetary value of Scan-vs-BIM was proved, but standardization was not achieved in use. In addition, some operations of the Scan-vs-BIM method were still performed manually. Therefore, the future research direction is to analyze Scan-vs-BIM based on artificial intelligence and deep learning for enhancing usability and cost reliability.

Author Contributions: Conceptualization, T.K. and Y.Y.; data curation, B.L.; formal analysis, T.K.; investigation, B.L.; methodology, T.K.; project administration, N.H. and J.-J.K.; supervision, J.-J.K.; validation, T.K. and Y.Y.; visualization, T.K.; writing—original draft, T.K. and Y.Y.; writing—review & editing, N.H. and J.-J.K. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: The data presented in this study are available on request from the corresponding author. The data are not publicly available due to continuation of research.

Acknowledgments: We would like to express our gratitude to those involved in the case project and who participated in the interview during the preliminary investigation stage.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Barbosa, F.; Woetzel, J.; Mischke, J. *Reinventing Construction: A Route of Higher Productivity*; McKinsey Global Institute: San Francisco, CA, USA, 2017. Available online: http://dln.jaipuria.ac.in:8080/jspui/bitstream/123456789/2898/1/MGI-Reinventing-Construction-Full-report.pdf (accessed on 21 October 2022).
2. Ministry of Land, Infrastructure and Transport (MOLIT). Smart Construction Technology Roadmap for Construction Productivity Innovation and Stability Reinforcement. 2018. Available online: http://www.molit.go.kr/USR/NEWS/m_71/dtl.jsp?lcmspage=2&id=95081506 (accessed on 21 October 2022).
3. Sinenko, S.; Poznakhirko, T.; Tomov, A. Digital transformation of the organization of construction production. *E3S Web Conf.* **2021**, *258*, 09020. [CrossRef]
4. Ebert, C.; Duarte, C.H.C. Digital transformation. *IEEE Softw.* **2018**, *35*, 16–21. Available online: https://www.researchgate.net/profile/Carlos-Henrique-Duarte-2/publication/326241618_Digital_Transformation/links/5b4d14f3aca27217ff9b05e4/Digital-Transformation.pdf (accessed on 3 October 2022). [CrossRef]
5. Schwalbe, K. An Introduction to Project Management.-Course Technology Cengage Learning. Minnesota: Augsburg College. 2012. Available online: https://www.accord.edu.so/web/content/30371?download=true&access_token=7f66a085-fb36-4ff9-beb4-1c8e5c1ce821 (accessed on 1 October 2022).
6. Moon, D.; Chung, S.; Kwon, S.; Seo, J.; Shin, J. Comparison and utilization of point cloud generated from photogrammetry and laser scanning: 3D world model for smart heavy equipment planning. *Autom. Constr.* **2019**, *98*, 322–331. [CrossRef]
7. Liu, W.; Luo, Y.; Yang, G. Research and application of 3D laser scanning technology in reversed modeling of hydropower station. In Proceedings of the 2020 IEEE International Conference on Advances in Electrical Engineering and Computer Applications (AEECA), Dalian, China, 25–27 August 2020; pp. 32–36. [CrossRef]
8. Liu, S.; Xie, B.; Tivendal, L.; Liu, C. Critical barriers to BIM implementation in the AEC industry. *Int. J. Mark. Stud.* **2015**, *7*, 162. Available online: https://www.researchgate.net/profile/Chunlu-Liu/publication/285630389_Critical_Barriers_to_BIM_Implementation_in_the_AEC_Industry/links/5768748108ae7f0756a2277a/Critical-Barriers-to-BIM-Implementation-in-the-AEC-Industry.pdf (accessed on 21 October 2022). [CrossRef]
9. Bryde, D.; Broquetas, M.; Volm, J.M. The project benefits of Building Information Modelling (BIM). *Int. J. Proj. Manag.* **2013**, *31*, 971–980. [CrossRef]
10. Ballesteros-Pérez, P.; Phua, F.T.T.; Mora-Melià, D. Human Resource Allocation to Multiple Projects Based on Members' Expertise, Group Heterogeneity, and Social Cohesion. *J. Constr. Eng. Manag.* **2019**, *145*, 04018134. [CrossRef]
11. 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]
12. Castañeda, K.; Sánchez, O.; Herrera, R.F.; Pellicer, E.; Porras, H. BIM-based traffic analysis and simulation at road intersection design. *Autom. Constr.* **2021**, *131*, 103911. [CrossRef]

13. Zhang, D.; Xu, X.; Lin, H.; Gui, R.; Cao, M.; He, L. Automatic road-marking detection and measurement from laser-scanning 3D profile data. *Autom. Constr.* **2019**, *108*, 102957. [CrossRef]
14. Liu, J.; Zhang, Q.; Wu, J.; Zhao, Y. Dimensional accuracy and structural performance assessment of spatial structure components using 3D laser scanning. *Autom. Constr.* **2018**, *96*, 324–336. [CrossRef]
15. Guo, J.; Yuan, L.; Wang, Q. Time and cost analysis of geometric quality assessment of structural columns based on 3D terrestrial laser scanning. *Autom. Constr.* **2020**, *110*, 103014. [CrossRef]
16. Jeong, H.J.; Ham, N.H.; Lee, B.D.; Park, K.M.; Kim, J.J. A Study on the Improvement of Repair and Reinforcement Quantity Take-off in Fire-damaged Area Using 3D Laser Scanning. *J. KIBIM* **2019**, *9*, 11–21. [CrossRef]
17. Ham, N.; Lee, S.-H. Empirical Study on Structural Safety Diagnosis of Large-Scale Civil Infrastructure Using Laser Scanning and BIM. *Sustainability* **2018**, *10*, 4024. [CrossRef]
18. Mizutani, T.; Yamaguchi, T.; Kudo, T.; Yamamoto, K.; Ishida, T.; Nagata, Y.; Kawamura, H.; Tokuno, T.; Suzuki, K.; Yamaguchi, Y. Quantitative evaluation of peeling and delamination on infrastructure surfaces by laser signal and image processing of 3D point cloud data. *Autom. Constr.* **2022**, *133*, 104023. [CrossRef]
19. Guo, J.; Wang, Q.; Park, J.-H. Geometric quality inspection of prefabricated MEP modules with 3D laser scanning. *Autom. Constr.* **2020**, *111*, 103053. [CrossRef]
20. Yuan, L.; Guo, J.; Wang, Q. Automatic classification of common building materials from 3D terrestrial laser scan data. *Autom. Constr.* **2020**, *110*, 103017. [CrossRef]
21. Alomari, K.; Gambatese, J.; Olsen, M.J. Role of BIM and 3D Laser Scanning on Job sites from the Perspective of Construction Project Management Personnel. In Proceedings of the Construction Research Congress 2016, San Juan, Puerto Rico, 31 May–2 June 2016. [CrossRef]
22. Succar, B. Building information modelling framework: A research and delivery foundation for industry stakeholders. *Autom. Constr.* **2009**, *18*, 357–375. [CrossRef]
23. Kaner, I.; Sacks, R.; Kassian, W.; Quitt, T. Case studies of BIM adoption for precast concrete design by mid-sized structural engineering firms. *J. Inf. Technol. Constr. (ITcon)* **2008**, *13*, 303–323.
24. Li, H.; Lu, W.; Huang, T. Rethinking project management and exploring virtual design and construction as a potential solution. *Constr. Manag. Econ.* **2009**, *27*, 363–371. [CrossRef]
25. Sacks, R.; Barak, R. Impact of three-dimensional parametric modeling of buildings on productivity in structural engineering practice. *Autom. Constr.* **2008**, *17*, 439–449. [CrossRef]
26. Wang, Q.; Guo, J.; Kim, M.-K. An Application Oriented Scan-to-BIM Framework. *Remote. Sens.* **2019**, *11*, 365. [CrossRef]
27. Kim, M.-K.; Cheng, J.C.; Sohn, H.; Chang, C.-C. A framework for dimensional and surface quality assessment of precast concrete elements using BIM and 3D laser scanning. *Autom. Constr.* **2015**, *49*, 225–238. [CrossRef]
28. Seo, H.C. 3D Laser Scanning in the Construction Industry. *KIBIM Mag.* **2019**, *9*, 31–38.
29. Bosché, F.; Ahmed, M.; Turkan, Y.; Haas, C.T.; Haas, R. The value of integrating Scan-to-BIM and Scan-vs-BIM techniques for construction monitoring using laser scanning and BIM: The case of cylindrical MEP components. *Autom. Constr.* **2015**, *49*, 201–213. [CrossRef]
30. Xiong, X.; Adan, A.; Akinci, B.; Huber, D. Automatic creation of semantically rich 3D building models from laser scanner data. *Autom. Constr.* **2013**, *31*, 325–337. [CrossRef]
31. Bosché, F.; Guillemet, A.; Turkan, Y.; Haas, C.T.; Haas, R. Tracking the Built Status of MEP Works: Assessing the Value of a Scan-vs-BIM System. *J. Comput. Civ. Eng.* **2014**, *28*, 05014004. [CrossRef]
32. Son, H.; Kim, C. Automatic segmentation and 3D modeling of pipelines into constituent parts from laser-scan data of the built environment. *Autom. Constr.* **2016**, *68*, 203–211. [CrossRef]
33. Son, H.; Kim, C.; Kim, C. 3D reconstruction of as-built industrial instrumentation models from laser-scan data and a 3D CAD database based on prior knowledge. *Autom. Constr.* **2015**, *49*, 193–200. [CrossRef]
34. Pejić, M. Design and optimisation of laser scanning for tunnels geometry inspection. *Tunn. Undergr. Space Technol.* **2013**, *37*, 199–206. [CrossRef]
35. Du, J.-C.; Teng, H.-C. 3D laser scanning and GPS technology for landslide earthwork volume estimation. *Autom. Constr.* **2007**, *16*, 657–663. [CrossRef]
36. Becerik-Gerber, B.; Jazizadeh, F.; Kavulya, G.; Calis, G. Assessment of target types and layouts in 3D laser scanning for registration accuracy. *Autom. Constr.* **2011**, *20*, 649–658. [CrossRef]
37. Lee, J.; Son, H.; Kim, C.; Kim, C. Skeleton-based 3D reconstruction of as-built pipelines from laser-scan data. *Autom. Constr.* **2013**, *35*, 199–207. [CrossRef]
38. Han, S.; Cho, H.; Kim, S.; Jung, J.; Heo, J. Automated and Efficient Method for Extraction of Tunnel Cross Sections Using Terrestrial Laser Scanned Data. *J. Comput. Civ. Eng.* **2013**, *27*, 274–281. [CrossRef]
39. El-Omari, S.; Moselhi, O. Integrating 3D laser scanning and photogrammetry for progress measurement of construction work. *Autom. Constr.* **2008**, *18*, 1–9. [CrossRef]
40. Zhang, Z.; Li, J.; Guo, Y.; Yang, C.; Wang, C. 3D Highway Curve Reconstruction From Mobile Laser Scanning Point Clouds. *IEEE Trans. Intell. Transp. Syst.* **2019**, *21*, 4762–4772. [CrossRef]

41. Razali, A.F.; Ariff, M.F.M.; Majid, Z.; Darwin, N.; Aspuri, A.; Salleh, M.F.M. Three-Dimensional (3D) As-Built Reconstruction from Laser Scanning Dataset. In Proceedings of the 2020 IEEE 10th International Conference on System Engineering and Technology (ICSET), Shah Alam, Malaysia, 9 November 2020; pp. 150–155. [CrossRef]
42. Yoon, S.; Wang, Q.; Sohn, H. Optimal placement of precast bridge deck slabs with respect to precast girders using 3D laser scanning. *Autom. Constr.* **2018**, *86*, 81–98. [CrossRef]
43. Turkan, Y.; Laflamme, S.; Tan, L. Terrestrial Laser Scanning-Based Bridge Structural Condition Assessment. 2016. Available online: https://rosap.ntl.bts.gov/view/dot/30811 (accessed on 21 October 2022).
44. Love, P.E.D.; Simpson, I.; Hill, A.; Standing, C. From justification to evaluation: Building information modeling for asset owners. *Autom. Constr.* **2013**, *35*, 208–216. [CrossRef]
45. Lu, W.; Fung, A.; Peng, Y.; Liang, C.; Rowlinson, S. Cost-benefit analysis of Building Information Modeling implementation in building projects through demystification of time-effort distribution curves. *Build. Environ.* **2014**, *82*, 317–327. [CrossRef]
46. Lee, G.; Park, H.K.; Won, J. D3 City project—Economic impact of BIM-assisted design validation. *Autom. Constr.* **2012**, *22*, 577–586. [CrossRef]
47. Walasek, D.; Barszcz, A. Analysis of the Adoption Rate of Building Information Modeling [BIM] and its Return on Investment [ROI]. *Procedia Eng.* **2017**, *172*, 1227–1234. [CrossRef]
48. 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]
49. Đukić, M.; Zidar, M. Sustainability of Investment Projects with Energy Efficiency and Non-Energy Efficiency Costs: Case Examples of Public Buildings. *Sustainability* **2021**, *13*, 5837. [CrossRef]
50. Jin, X.; Liu, Q.; Long, H. Impact of cost–benefit analysis on financial benefit evaluation of investment projects under back propagation neural network. *J. Comput. Appl. Math.* **2021**, *384*, 113172. [CrossRef]
51. Benardos, A.; Sourouvali, N.; Mavrikos, A. Measuring and benchmarking the benefits of Athens metro extension using an ex-post cost benefit analysis. *Tunn. Undergr. Space Technol.* **2021**, *111*, 103859. [CrossRef]
52. Hsu, E. Cost-benefit analysis for recycling of agricultural wastes in Taiwan. *Waste Manag.* **2021**, *120*, 424–432. [CrossRef] [PubMed]
53. Abbas, T.; Ali, G.; Adil, S.A.; Bashir, M.K.; Kamran, M.A. Economic analysis of biogas adoption technology by rural farmers: The case of Faisalabad district in Pakistan. *Renew. Energy* **2017**, *107*, 431–439. [CrossRef]
54. Alqahtani, F.K.; Abotaleb, I.S.; ElMenshawy, M. Life cycle cost analysis of lightweight green concrete utilizing recycled plastic aggregates. *J. Build. Eng.* **2021**, *40*, 102670. [CrossRef]
55. Lu, Y.; Li, P.; Lee, Y.P.; Song, X. An integrated decision-making framework for existing building retrofits based on energy simulation and cost-benefit analysis. *J. Build. Eng.* **2021**, *43*, 103200. [CrossRef]
56. Krishnan, N.; Kamde, D.K.; Veedu, Z.D.; Pillai, R.G.; Shah, D.; Velayudham, R. Long-term performance and life-cycle-cost benefits of cathodic protection of concrete structures using galvanic anodes. *J. Build. Eng.* **2021**, *42*, 102467. [CrossRef]
57. Krarti, M.; Howarth, N. Transitioning to high efficiency air conditioning in Saudi Arabia: A benefit cost analysis for residential buildings. *J. Build. Eng.* **2020**, *31*, 101457. [CrossRef]
58. Korytárová, J.; Papežíková, P. Assessment of Large-Scale Projects Based on CBA. *Procedia Comput. Sci.* **2015**, *64*, 736–743. [CrossRef]
59. Kim, S. An Empirical Study on the Selection Method of Simple House Sprinkler using Cost-Benefit Analysis. Ph.D. Thesis, Myongji University, Seoul, Korea, 2020. Available online: https://dcollection.mju.ac.kr/public_resource/pdf/000000075384_20221021174430.pdf (accessed on 21 October 2022).
60. Tang, X.; Wang, M.; Wang, Q.; Guo, J.; Zhang, J. Benefits of Terrestrial Laser Scanning for Construction QA/QC: A Time and Cost Analysis. *J. Manag. Eng.* **2022**, *38*, 05022001. [CrossRef]