Journal of the Korean Society of Surveying, Geodesy, Photogrammetry and Cartography
Vol. 39, No. 5, 343-349, 2021
https://doi.org/10.7848/ksgpc.2021.39.5.343 ISSN 1598-4850(Print)
ISSN 2288-260X(Online)
Original article

Generation of 3D Design Data using Laser Scanning Data

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Abstract

In The process from design to construction in the existing construction work was less efficient due to the contradictory approach of identifying the 3D state in the plan view and the repeated generation of surveys, floor plans, drawings. Accurate 3D design data is essential for smart construction. However, most of the existing related studies have focused on explaining the development method and main functions of equipment or improving the productivity of smart construction. Therefore, in this study, the utility of 3D design model generation for smart construction and construction survey using 3D laser scanner was evaluated. Plane and vertical road alignment were created using the specifications of the road. The generated road alignment was created as a three-dimensional corridor design using cross-sections at intervals of 20m. In addition, it was possible to create a DTM (Digital Terrain Model) using a digital map and effectively create a 3D design model for the study area through overlapping. Construction survey using a 3D laser scanner showed accuracy within 10cm as a result of the accuracy evaluation. These results proved that construction surveying using a 3D laser scanner is possible because it satisfies the acceptable accuracy of the relevant regulations modeling of target areas using 3D design and construction survey using 3D laser scanner can be a way to address shortcomings of existing GNSS (Global Navigation Satellite System) methods. And accurate 3D data will be used as essential data as basic data for smart construction.

Keywords : 3D Design, 3D Laser Scanner, Accuracy Analysis, Construction Survey, Smart Construction

1. Introduction

There are various definitions of smart construction technology, but it is still not stipulated in a standardized form, but smart construction technology is a '4th industrial revolution technology (drone, BIM, Big Data, IoT, robot) than traditional construction technology (Lee and Kim, 2020). Efforts to innovate the productivity of the construction industry using smart construction technology and foster it as a new growth engine industry are being made in various forms in advanced countries such as the UK, Japan, Singapore, and the United States (Lee *et al.*, 2020). The UK is carrying out various activities to innovate the BIM-centered construction process. With the vision of 'Construction 2025', a safe and attractive construction industry chosen by young people, the UK's construction industry that leads the world and induces the activation of smart construction through research and innovation, and a sustainable construction industry through the integration of supply chain management. It proposes the construction industry that maximizes the value of facilities based on the life cycle value, and the implementation of a sustainable partnership between the government and the construction industry. Under this vision, the UK government is proposing to reduce the initial construction cost by 33%,

Received 2021. 10. 15, Revised 2021. 10. 19, Accepted 2021. 10. 25
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to reduce the total construction period by 50%, to reduce greenhouse gas emissions by 50% during the construction process, and to reduce the trade imbalance of construction products and materials by 50% (https://www.gov.uk/government/publications/construction-2025-strategy).

Singapore, a city-state, is striving to build a digital city model, "Virtual Singapore," with the motto of urbanization. Under the slogan "Construction 21" as a strategy for the construction industry, the adoption of BIM is mandatory for major construction projects. Singapore aims to optimize the management of buildings and infrastructure and solve urban problems by managing all data collected from various public institutions. Singapore will improve the productivity of the construction industry through 'Construction 21', and show seven core technology areas such as automation equipment and robots, BIM and virtual design technology. In addition, it is carrying out various activities, such as mandating the application of BIM to the business (https://www.nrf.gov.sg/programmes/virtual-singapore).

Japan is adopting the "I-Construction" strategy to improve the conditions for entry into the construction industry by automating construction equipment in response to the aging of construction workers and the decrease in manpower. Japan's Ministry of Land, Infrastructure and Transport aims to increase the productivity of construction sites by 20% by promoting construction automation using ICT technology in all construction production processes, from survey and survey, design, construction, inspection, maintenance and renewal(https://www.mlit.go.jp/en/index.html/).

In Korea, some cases of BIM, drones, and ICT-based on-site management technologies have been introduced and used or applied in a pilot manner, but the overall introduction and utilization is still in a passive situation (Im *et al.*, 2019; Chang, 2020).

The ultimate purpose of the smart construction is to realize the automation of earthwork tasks such as establishing an earthwork plan, calculating earthwork volume through earthwork survey, and operating earthwork equipment (Hwang *et al.*, 2019; Hong *et al.*, 2019). Since the mid-1990s, various studies have been conducted on intelligent excavation systems for earthwork automation. This means technology that can improve construction quality and productivity through information technology and efficient equipment operation (Hong *et al.*, 2017). Most of the existing smart construction related studies have focused on explaining the development method and main functions of equipment or improving the productivity of smart construction. There were also studies that selected tasks that need automation and analyzed their priorities (Shim and Choi, 2019).

However, there are insufficient methods or analytical studies on 3D design, which can be said to be the basis for smart construction. 3D design and accurate surveying on the construction site are the most basic things to be prepared for smart construction. Looking at the process from design to construction in the existing construction work, similar problems are due to the contradictory approach to understand the three-dimensional status in a plan view and the operation method to separate surveys, plans, drawings and quantities, details, and various outsourcing. It can be seen that it has been repeatedly generated. In addition, there was a problem that it was difficult to work efficiently due to overlapping work. In this study, the utility of 3D design for smart construction and construction survey using laser scanner was analyzed. 3D design of roads and structures was performed for road construction. And construction survey was performed using a 3D laser scanner, and accuracy was evaluated. It was intended to propose a 3D design and construction survey method for smart construction. Fig. 1 shows study flow.

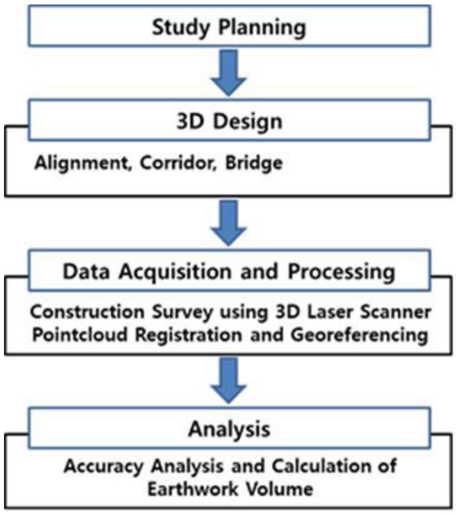


Fig. 1. Study flow

2. Generation of 3D Design

In this study, for 3D design and construction survey for smart construction, a road construction site near Gimpo, Gyeonggi-do was selected as the study area. Part of the entire construction section, including bridges, was selected as the study site, and 3D design of roads and bridges was performed. Fig. 2 shows the study area.

Fig. 2. Study area

The 3D design of the road was carried out in the stages of alignment design, corridor design, DTM Creation, and structure generation. In this process, the DTM was created using the contour lines of the digital map. Fig. 3 shows the 3D road design process.

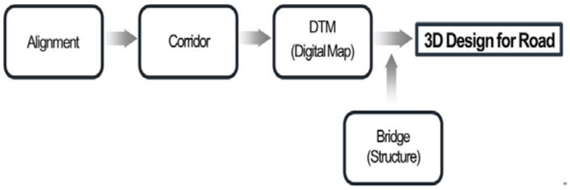


Fig. 3. 3D Road design process

2.1 Road alignment

Road alignment can be divided plane alignment and vertical alignment. Plane alignment is a linear element representing the planar shape of a road. The plane alignment is two-dimensional and can be divided into straight lines, circular curve, and clothoid curve. In this study, the design for the road was created using the specifications for alignment and TBC (Trimble Business Center) software. Fig. 4 shows the plane alignment of the entire study area.

Fig. 4. Plane alignment of the entire study area

The vertical alignment is a three-dimensional alignment that represents the uphill and downhill roads. In areas where the slope of the road changes rapidly, a curve is inserted so that the road can smoothly connect. Fig. 5 shows a specifications for alignment and Fig. 6 shows the process of inputting the vertical alignment specifications.

VIP STATION 0+420.0000

구 분	STATION	지반고	계획고	ELEV	절성고	종 거	구 배	길 이
BVC	0+320.0000	5.78	21.36	21.36	+15.58	0.0000	+1.0000	200.00
VIP	0+420.0000	6.36	21.91	22.36	+15.55	-0.4492		
EVC	0+520.0000	6.54	21.57	21.57	+15.03	0.0000	-0.7966	

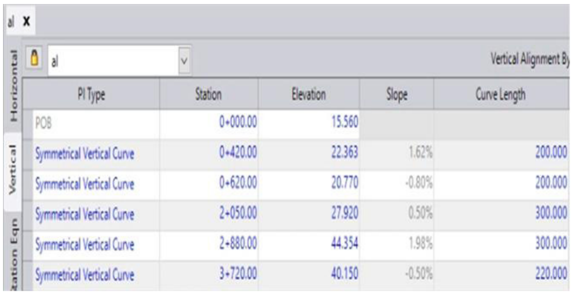
종단곡선변화비율(K) =111.3

VIP STATION 0+620.0000

구 분	STATION	지반고	계획고	ELEV	절성고	종 거	구 배	길 이
BVC	0+520.0000	6.54	21.57	21.57	+15.03	0.0000	-0.7966	200.00
VIP	0+620.0000	7.50	21.09	20.77	+13.59	0.3242		
EVC	0+720.0000	9.38	21.27	21.27	+11.89	0.0000	+0.5000	

종단곡선변화비율(K) =154.24

Fig. 5. Specifications for vertical alignment



PI Type	Station	Elevation	Slope	Curve Length
POB	0+000.00	15.560		
Symmetrical Vertical Curve	0+420.00	22.363	1.62%	200.000
Symmetrical Vertical Curve	0+620.00	20.770	-0.80%	200.000
Symmetrical Vertical Curve	2+050.00	27.920	0.50%	300.000
Symmetrical Vertical Curve	2+880.00	44.354	1.98%	300.000
Symmetrical Vertical Curve	3+720.00	40.150	-0.50%	220.000

Fig. 6. Inputting the vertical alignment

2.2 Corridor

The result generated by road alignment creation is an alignment of a three-dimensional road consisting of plane and vertical elements. In order to design a road for smart construction, it is necessary to design a three-dimensional road shape using this result. A 3D road shape was created by inputting a cross section at intervals of 20m into a 3D road alignment and interpolating between the longitudinal sections. The corridor created through road alignment and cross section at intervals of 20 meters is a design having a three-dimensional shape of a road. Fig. 7 shows the 3D design of the road in the study area.

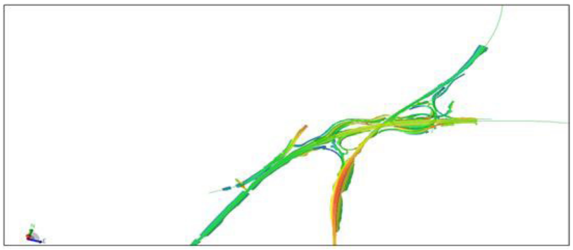


Fig. 7. 3D road design

2.3 DTM

In order to calculate the amount of earthwork using the 3D design of the completed road, the DTM of the study area was created. DTM was created using contours of a scale 1:5,000 digital map. TIN (Triangulated Irregular Network) was created using the contour lines of the digital topographic map and DTM was created. Fig. 8 shows the DTM.

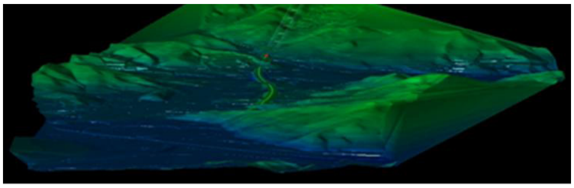


Fig. 8. DTM

The data for the initial earthwork volume calculation was created by overlapping the 3D design with the DTM created using the digital map. Using this data, the volume of cut and fill for road construction can be calculated.

2.4 Bridge Modeling

Bridge to be constructed on the roads of the study site was modeled using the design drawings. Sketchup software was used to model the bridge. The bridge was modeled by dividing it into a pier and a deck, and the bridge modeling result was placed in the 3D design in consideration of the location of the actual bridge. The modeled bridge will be able to be used for future inspection of bridge construction. The initial earthwork volume for the study area was calculated by overlapping the 3D design of roads and bridges and DTM. Earthwork volume was compared with the 3D design based on DTM, and was output in the form of a report using software. Fig. 9 shows the bridge modeling.

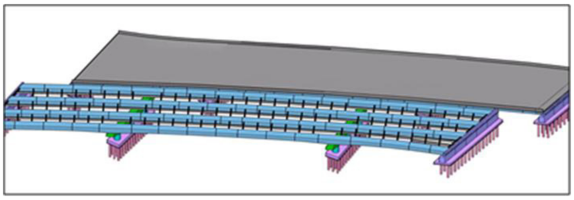


Fig. 9. Bridge modeling

Fig. 10 shows the final 3D design of the study area using DTM. In this study, the initial earthwork volume was calculated using this data. This value is important data for road construction and can be used to establish a construction plan.

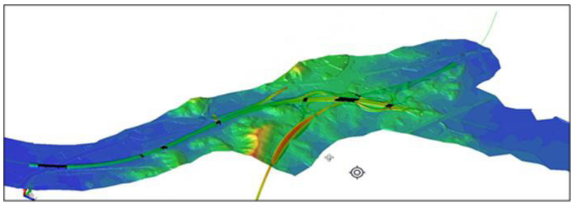


Fig. 10. Final 3D design of the study area

The 3D design of the study site was visualized using Google Earth. Fig. 11 shows the overlap of Google Earth and the 3D model.

Fig. 11. Overlap of Google Earth and the 3D model

As shown in Fig. 10, it was possible to create data with excellent visibility by superimposing the model designed in 3D and this data can be used for construction planning. Data with good visibility can replace part of the field survey, which will help improve work efficiency.

Existing 2D designs had limitations that could not but represent the current status of construction sites in a plane, and there was a waste of manpower due to repetitive surveying and correction. However, 3D design can represent the situation in the field closer to reality than 2D design, the process of revising drawings is simple, and the revised earthwork volume can be calculated effectively.

3. Construction survey and accuracy evaluation

In this study, a 3D design of the study site was created as basic data for the smart construction, and a survey was performed using a 3D laser scanner in the actual construction stage, and accuracy was analyzed. The 3D laser scanner used for construction surveying is the SX10 model. Part of the study site was scanned using this equipment, and cross-section survey was performed using GNSS for accuracy evaluation. Accuracy evaluation was performed by comparing with GNSS survey results. The 3D laser scanner was used to calculate the actual earthwork volume and the difference between design and construction through construction survey. Fig. 12 shows the point cloud data acquired by 3D scanner.

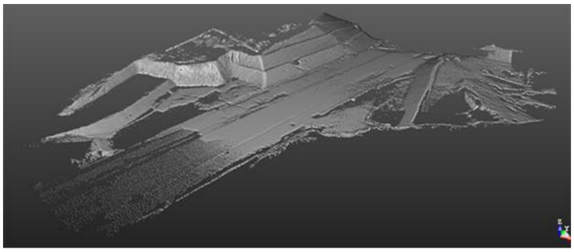


Fig. 12. Point cloud data acquired by 3D laser scanner

Data acquisition was performed at a total of 8 stations, and resistration and georeferencing were performed using the coordinates of known points. In order to evaluate the utility of construction survey using 3D laser scanner, accuracy was evaluated through comparison with GNSS survey values. The GNSS survey was performed on two cross-sections through the VRS (Virtual Reference System) method, and the accuracy was compared with the coordinate results extracted from the 3D model and the VRS survey value for height. Fig. 13 shows the crossing lines and points for accuracy evaluation. Accuracy evaluation was made for a total of 20 points. Fig. 14 shows the scan data for crossing line A and Table 1 shows the results of accuracy evaluation.

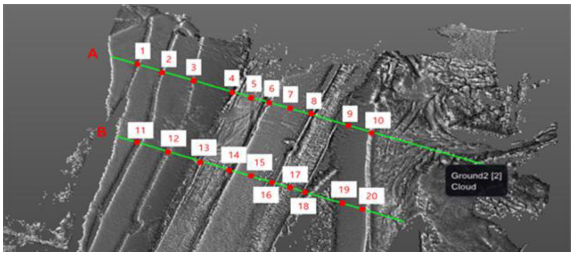


Fig. 13. Crossing lines and points for accuracy evaluation

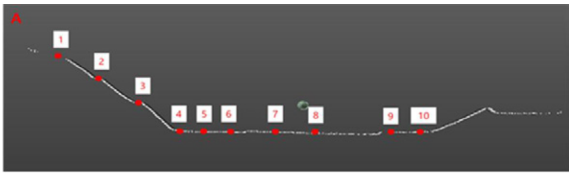


Fig. 14. Scan data for crossing line A

Table 1. Results of accuracy evaluation

No.	dH(m)	No.	dH(m)
1	0.05	11	0.10
2	0.08	12	0.09
3	0.07	13	0.08
4	0.10	14	0.05
5	0.04	15	0.04
6	0.05	16	0.08
7	0.04	17	0.10
8	0.07	18	0.09
9	0.09	19	0.09
10	0.08	20	0.08

As result of the accuracy evaluation for 20 checkpoints, the difference between the VRS survey value and the 3D laser scanner value were found to be 0.05~0.10m. This is a result that satisfies the accuracy of topographic surveying in the general survey work regulation, indicating that construction surveying using a 3D scanner is possible. Table 2 shows the allowable accuracy of Article 40 of the general survey work regulation (http://www.law.go.kr/).

Table 2. Allowable accuracy in general survey work regulation

Item	Horizontal	Height
Allowable Accuracy	0.10m	0.10m

In this study, inspection for design and construction was performed using the results of construction survey and 3D modeling of roads. Figure 14 shows the difference in earthwork volume through inspection. In Fig. 15, green represents a 3D model of the road and red represents the 3D scanning result.

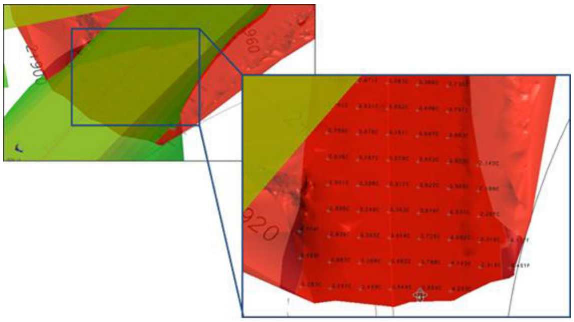


Fig. 15. Difference between 3D model and construction survey results

For inspection with design values in construction work, it is necessary to periodically perform construction surveys and compare the results. Until now, GNSS has been mainly used for construction surveying, but this does not fully reflect the shape of the actual building, and there is a disadvantage that it takes a lot of manpower and time for the survey. Table 3 shows the comparison of 3D laser scanner and GNSS about the working time.

The model of the target area using 3D design and the construction survey method using a 3D laser scanner can be a method that can solve the shortcomings of the existing method. And such accurate 3D data is essential data as basic data for smart construction.

Table 3. Comparison of 3D laser scanner and GNSS about the working time

Method	Size of work area	Working time
3D laser scanner	200m × 200m	10 minutes
GNSS	120m × 100m	30 minutes

4. Conclusions

In this study, 3D design was performed as basic data for smart construction, and construction survey was performed using a 3D laser scanner. The 3D design of the road was carried out in the stages of alignment design, corridor design, DTM creation, and structure generation. Plane and vertical road alignment were created using the specifications of the road. The generated road alignment was created as a three-dimensional corridor design using cross-sections at intervals of 20m. In addition, it was possible to create a DTM using a digital map and effectively create a 3D design model for the study area through overlapping. The 3D model created data with good visibility by overlapping with Google Earth, and this data will be available for construction planning. In addition, it was possible to calculate the initial earthwork volume using the difference between the digital map and the 3D model. 3D design can be usefully used because it can reflect the construction site more efficiently than existing 2D design and can quickly perform analysis such as correction or calculation of earthwork volume. Construction survey using a 3D laser scanner showed accuracy within 10 cm as a result of the accuracy evaluation. These results proved that construction surveying using a 3D laser scanner is possible because it satisfies the acceptable accuracy of the relevant regulations modeling of target areas using 3D design and construction survey using 3D laser scanner can be a way to address shortcomings of existing GNSS methods. And accurate 3D data will be used as essential data as basic data for smart construction.

Acknowledgments

This research was supported by Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Science and ICT (No. NRF-2021R1F1A1061677)

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