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Efficiency Analysis of Construction Automation Using 3D Geospatial Information

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The size of the global construction market is expected to increase to about $14 trillion by 2025, with fierce competition expected in emerging markets. However, construction is the only industrial sector whose productivity has declined over the past 50 years. Over the past two decades, the world economy has grown by 2.8% and manufacturing productivity has grown by 3.6% annually, but labor productivity growth in the construction sector has averaged less than 1%. Recently, construction companies have made various attempts to increase productivity, for example, by implementing 'smart construction' based on 3D data at all stages such as investigation, measurement, design, and construction. Many construction sites are increasing the utilization of building information modeling (BIM), laser scanners, unmanned aerial vehicles (UAVs), and automated construction equipment. However, studies on applying and analyzing 3D geospatial information in the construction process have been insufficient. In this study, an experiment on using 3D geospatial information technology in road construction was performed and analysis was conducted. The Global Navigation Satellite System (GNSS), static light detection and ranging (LiDAR), UAV LiDAR, and so forth were used to effectively build 3D geospatial information of the study area, and 3D designs were generated using the acquired data. The accuracy of data constructed through static LiDAR and UAV LiDAR was found to be within 0.025 m in the X, Y, and Z directions. A 3D design reflecting the actual terrain was created, and various sensors were installed on construction equipment to conduct experiments on construction automation. The productivity of construction automation was evaluated by comparing the results of traditional and automated construction processes. In the future, construction automation using 3D geospatial information technology will contribute to improving productivity not only for roads, but also at many other construction sites such as tunnels.

1. Introduction

The Fourth Industrial Revolution (4IR) will lead to a marked improvement in productivity through convergence with information and communication technology (ICT) such as artificial

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intelligence technology, the Internet of Things and big data, and the intelligentization of products and services, resulting in innovative changes in the economy and society as a whole.(1) In January 2016, the 4IR became known through the World Economic Forum, and in 2017, the Korean government announced its response strategy as the basic direction of its innovation policy.(2–4) The 4IR response strategy of the Ministry of Land, Infrastructure and Transport (MOLIT) consists of smart national land creation, transportation service industry innovation, and public infrastructure safety innovation to improve the quality of people's lives through public service innovation and industrial competitiveness.(5–7) In the meantime, the digital revolution has achieved much in the manufacturing and service industries.(8–10) For example, the process of designing and interpreting robots and 3D simulations through artificial intelligence technology have considerably improved the productivity of the automobile and consumer goods industries.(11–12) In contrast, the construction industry has changed little, while other industries have been undergoing such drastic innovations.(13) However, construction has a lot of potential to improve productivity and efficiency through digitalization, innovative technology, and new construction technology.(11) Augmented reality, unmanned aerial vehicles (UAVs), 3D laser scanning, building information modeling (BIM), robot construction, and more advanced building materials have begun to be applied.(7) Through this, construction companies can improve productivity and improve quality and safety by effectively carrying out project management. Global construction-related spending is $10 trillion, and the construction industry employs 7% of the world's workforce.(8) The construction industry, which accounts for 25 to 40% of total global carbon emissions and is the largest consumer of raw materials, has a great impact on the economy, environment, and society, with all economic value creation processes linked to other industries. The size of the global construction market is expected to increase to about $14 trillion by 2025, with fierce competition expected in emerging markets. Construction, however, is almost the only industrial sector whose productivity has declined over the past 50 years. Over the past two decades, the world economy has grown by 2.8% and manufacturing productivity has grown by 3.6% annually, but labor productivity growth in the construction sector has averaged less than 1%.(9)

Recently, construction companies have made various attempts to increase productivity, for example, by implementing 'smart construction' based on 3D data at all stages such as investigation, measurement, design, and construction.(14) Many construction sites are increasing the utilization of BIM, laser scanners, UAVs, and automated construction equipment. However, studies on applying and analyzing 3D geospatial information in the construction process have been insufficient. In this study, an experiment on using 3D geospatial information technology in road construction was performed and analysis was conducted. Figure 1 shows the study flow.

2. Data Acquisition

In this study, a site located in Gyeonggi-do, Korea, was selected as a study area to conduct experiments using 3D geospatial information technology for road construction. Figure 2 shows the study area. Surveying was needed for the 3D design of the study area, and data acquisition was performed in consideration of the difficulty in obtaining ground data due to vegetation.

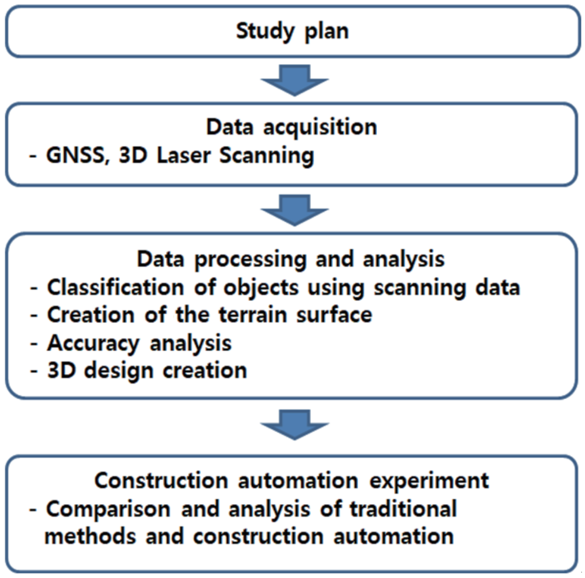


Fig. 1. Study flow.

Fig. 2. (Color online) Study area.

GNSS and two types of scanner were used for surveying to obtain geospatial information for the area. GNSS was used for reference point surveying and data calibration, static light detection and ranging (LiDAR) was used for 3D laser scanning, and UAV LiDAR was used for data acquisition. The GNSS and LiDAR equipment used in this study are shown in Figs. 3–5. Data acquired by static LiDAR were used for georeferencing the data acquired by UAV LiDAR. Figure 6 shows static LiDAR data.

Fig. 3. (Color online) GNSS equipment.(15)

Fig. 4. (Color online) Static LiDAR equipment.(16)

Fig. 5. (Color online) UAV LiDAR equipment.(17)

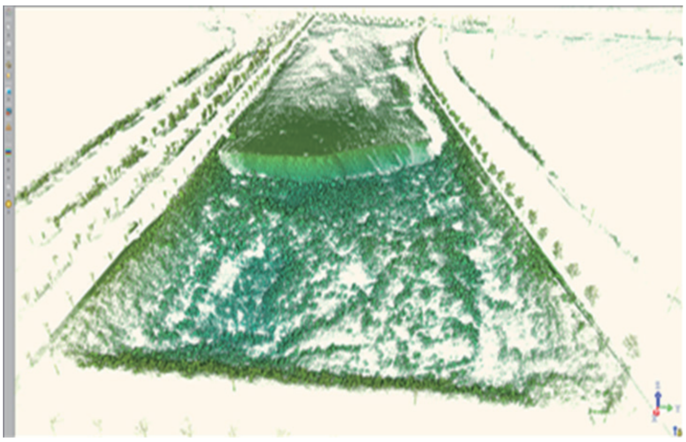


Fig. 6. (Color online) Static LiDAR data.

Static LiDAR data provide very accurate results because reference point data are used. However, as shown in Fig. 6, there are some areas with no data. Data acquisition must be performed at many points to overcome the lack of data, which was achieved using UAV LiDAR in this study. UAV LiDAR has a lower data accuracy than static LiDAR but has a high efficiency for data acquisition. To acquire data using UAV LiDAR, a mission plan for the study area was created and data acquisition was performed.

Data acquisition using UAV LiDAR took about 6 min, with a GNSS base station installed on the ground to improve accuracy, and data were logged at 1 s intervals. The coordinates of the base station were used for data processing. Finally, registration was performed using the static LiDAR data. Figure 7 shows the data acquired by UAV LiDAR.

3. Data Processing and Analysis

Ground data were generated using UAV LiDAR data for use in the design. The land and vegetation were classified using Trimble Business Center (TBC) software. Ground was classified

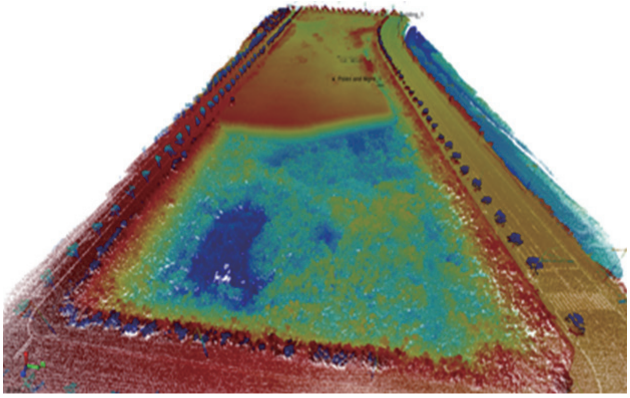


Fig. 7. (Color online) UAV LiDAR data.

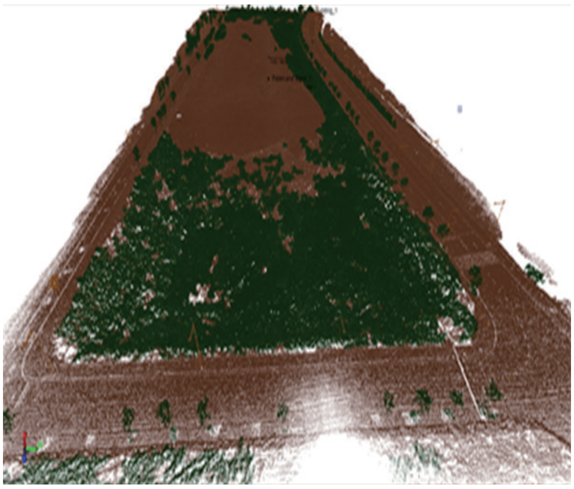


Fig. 8. (Color online) Classification result.

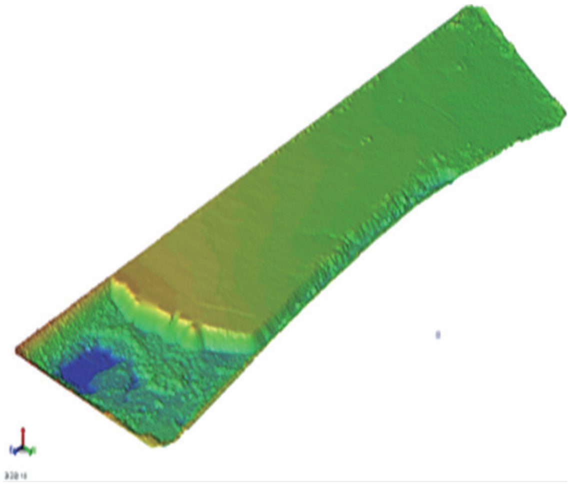


Fig. 9. (Color online) Mesh data for ground.

as brown and other (unnecessary) objects were classified as green. Through this classification, the data about the ground were generated, and mesh data were created to use the ground data for design. Since LiDAR data are point-cloud-type data, it is difficult to directly use them for design. Figure 8 shows the classification result and Fig. 9 shows mesh data for the ground.

3D design data must be applied to construction equipment in preparation for automated construction. For data preparation, the data obtained through static LiDAR and UAV LiDAR were registered and georeferenced, and accuracy was checked by comparison with GNSS survey results using 34 targets installed on the road around the study area. Table 1 shows the results of the accuracy check.

As shown in Table 1, the accuracy of data constructed through static LiDAR and UAV LiDAR was found to be within 0.025 m in the *X*, *Y*, and *Z* directions. Since the study area is not large, the accuracy of LiDAR will need to be verified through additional research.

Table 1
Results of accuracy check.

No.	X (m)	$d(X)$ (m)	Y (m)	dY (m)	H (m)	dH (m)
ch1	613155.720	0.024	207135.920	0.021	65.450	0.021
ch2	613129.710	0.021	207138.360	0.022	66.100	0.025
ch3	613101.760	0.022	207140.960	0.025	66.750	0.021
ch4	613078.820	0.022	207143.130	0.025	67.330	0.023
ch5	613067.830	0.025	207144.140	0.021	67.600	0.024
ch6	613064.130	0.026	207143.170	0.018	67.670	0.024
ch7	613061.760	0.021	207139.010	0.017	67.660	0.025
ch8	613059.880	0.018	207119.050	0.019	67.410	0.025
ch9	613057.250	0.019	207091.070	0.024	67.040	0.025
ch10	613054.520	0.022	207062.090	0.025	66.650	0.024
ch11	613051.830	0.014	207033.150	0.019	66.220	0.020
ch12	613049.590	0.020	207009.170	0.018	65.870	0.021
ch13	613046.590	0.019	206977.200	0.017	65.440	0.022
ch14	613043.490	0.021	206944.220	0.019	65.060	0.019
ch15	613040.960	0.022	206917.230	0.018	64.680	0.018
ch16	613038.980	0.021	206896.240	0.018	64.420	0.023
ch17	613037.120	0.019	206876.270	0.019	64.130	0.025
ch18	613035.430	0.017	206858.250	0.019	63.910	0.024
ch19	613034.210	0.016	206845.260	0.020	63.740	0.023
ch20	613031.790	0.021	206819.340	0.021	63.390	0.019
cp1	613032.580	0.023	206835.170	0.022	63.470	0.022
cp2	613036.660	0.024	206878.560	0.024	64.060	0.018
cp3	613044.590	0.019	206963.200	0.019	65.140	0.024
cp4	613053.220	0.018	207055.240	0.019	66.430	0.019
cp5	613058.480	0.018	207111.340	0.019	67.180	0.023
⋮	⋮	⋮	⋮	⋮	⋮	⋮

Lines were entered to create a 3D design for the road to be built. For the linear road, a vertical line and a plane line were entered. Figure 10 shows the process of inputting road parameters. After inputting the alignment, a template representing the shape of the road with respect to the plane was entered every 20 m to represent the design values in three dimensions. Figure 11 shows some of the road templates.

Through input to the road parameter and template, a 3D design similar to the actual terrain of the target site was created. Figure 12 shows the completed 3D design, comprising data for two roads, one built by traditional road construction and the other built by automated construction.

Abnormalities were checked and the quantity of earthwork was calculated using the 3D design created through the study. Figure 13 shows a design check, and Fig. 14 shows the calculation of the amount of earthwork.

4. Evaluating the Efficiency of Construction Automation

To compare the traditional road construction method with the automated method, a road with a distance of 260 m was constructed by each method. An excavator, a dozer, a grader, and a compactor were the construction equipment used. To evaluate the automated road construction,

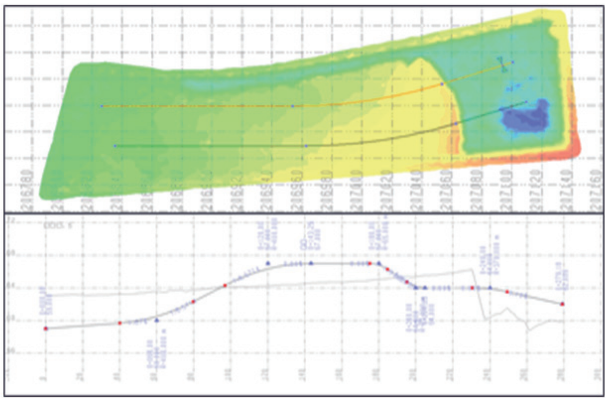


Fig. 10. (Color online) Process of inputting road parameters.

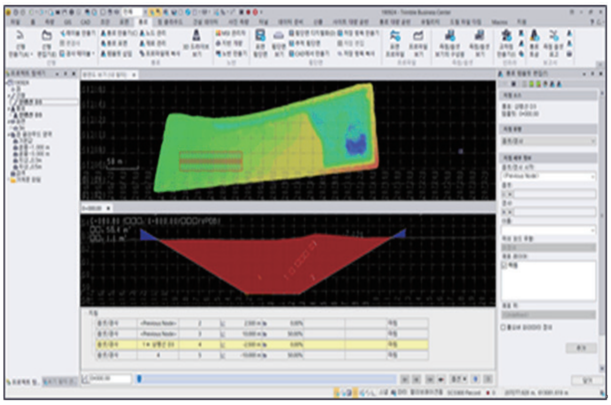


Fig. 11. (Color online) Road template.

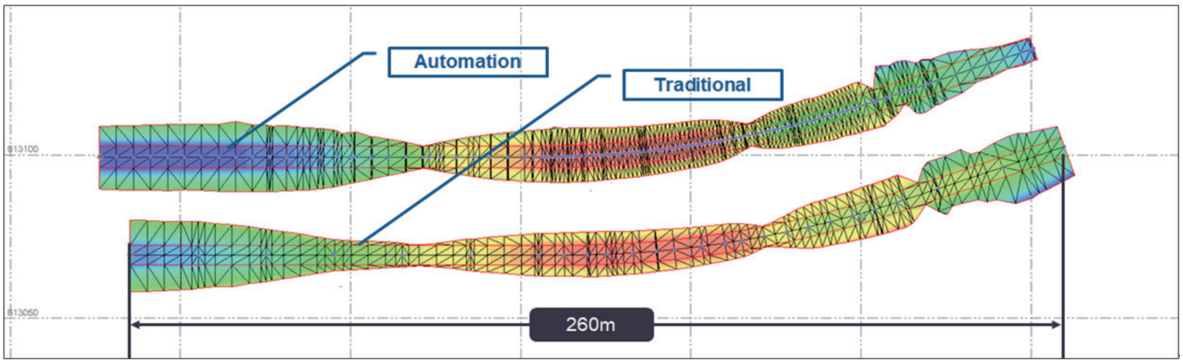


Fig. 12. (Color online) Completed 3D design.

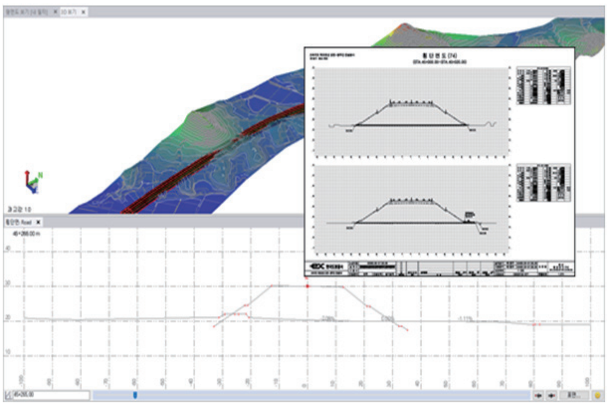


Fig. 13. (Color online) Design check.

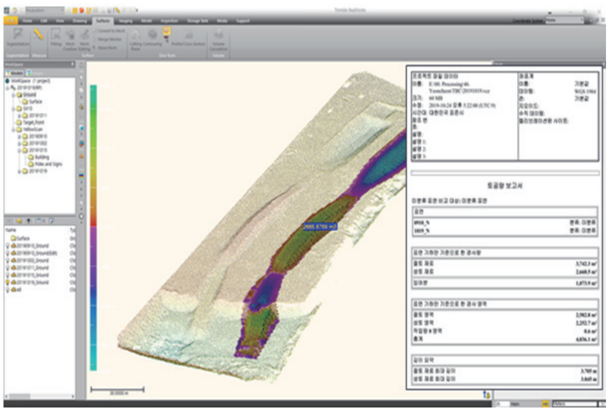


Fig. 14. (Color online) Calculation of amount of earthwork.

various sensors were installed on the construction equipment, such as hydraulic sensors and GNSS, and modems for communication were also installed. Figure 15 shows the construction equipment and sensors.

(a) (b)

Fig. 15. (Color online) Construction equipment and sensors. (a) Excavator. (b) Dozer.

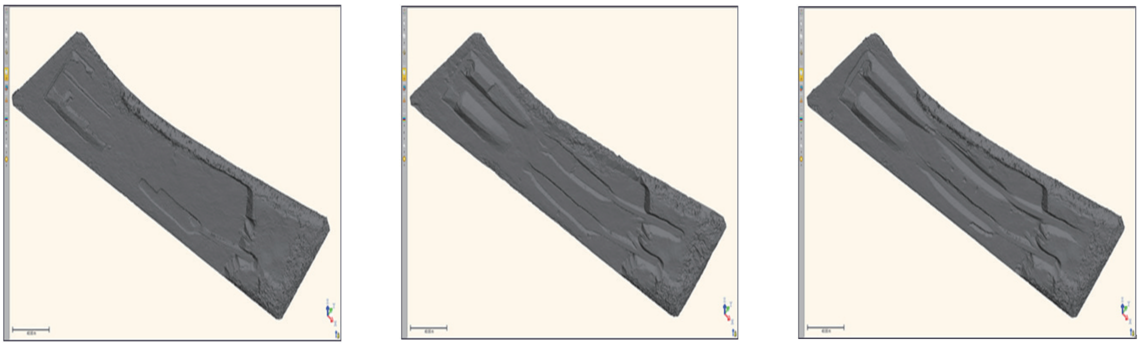
Fig. 16. (Color online) Work screen for automated construction.

In the traditional road construction method, it is necessary to continuously perform GNSS surveys during the work and compare and correct the design values. However, automated construction has the advantage of being able to know the design values and the condition of the site in real time using the sensors installed on the equipment. Figure 16 shows the work screen for automated construction.

The traditional and automated construction methods were applied at the target site, and the data obtained using static LiDAR and UAV LiDAR were acquired at stages corresponding to 20, 80, and 100% of the construction being completed. Figure 17 shows geospatial information of the study area for each stage of construction.

A method of visualizing the process in real time at the construction site was also tested. This method uses augmented reality (AR), a GNSS receiver, and a smartphone, and can be used to manage construction in the field (Fig. 18). This method has the advantage of being able to check the process in real time at the construction site by comparing it with the design.

The LiDAR data acquired during construction work can be used for monitoring and checking construction. In addition, if a network is established, it will greatly help in managing construction in real time by using the data from the sensors attached to the equipment and 3D-built design data. Through an experiment on automated construction, an analysis was



(a) (b) (c)

Fig. 17. (Color online) Geospatial information of the study area for each stage of construction: (a) 20, (b) 80, and (c) 100%.

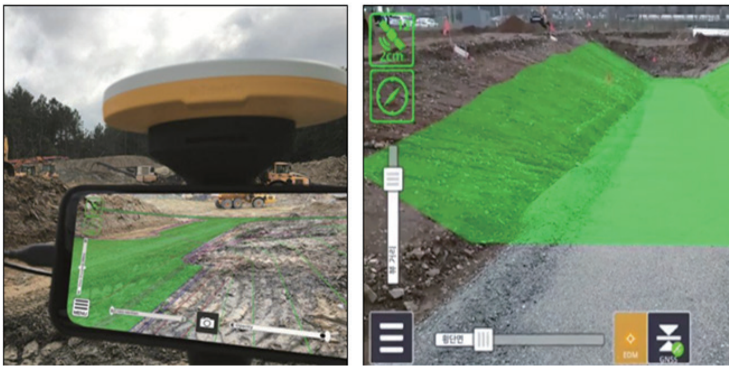


Fig. 18. (Color online) Construction management using AR.

conducted to evaluate the improvement in productivity compared with the traditional construction methods. Tables 2 and 3 show the results of the comparison between traditional construction and automated construction.

Table 2
Comparison of workload per minute (m^3/min).

Method	Excavator	Dozer	Grader	Compactor
Traditional construction	1.70	1.36	0.41	6.32
Automated construction	2.41	2.22	0.97	8.42

Table 3
Comparison of total working time (min).

Item	Traditional construction	Automated construction	Reduction in working time
Excavator	981	660	321
Dozer	1413	1202	211
Grader	349	147	202
Compactor	303	242	61
Sum			795

Construction automation reduced the working time by about 13 h compared with the conventional method. Assuming 8 h of work per day, the number of work days was reduced by 1.6 days. Considering that the section of the road in the experiment was only about 260 m, productivity will be considerably improved if construction automation is applied to an entire road construction site. In the future, construction automation using 3D geospatial information technology will contribute to improving productivity not only for roads, but also at many other construction sites such as tunnels.

5. Conclusion

In this study, an experiment on using 3D geospatial information technology in road construction was performed. The conclusions were as follows.

1. GNSS, static LiDAR, and UAV LiDAR were used to effectively build 3D geospatial information of the study area, and 3D designs were generated using the acquired data.
2. The accuracy of data constructed through static LiDAR and UAV LiDAR was found to be within 0.025 m in the X, Y, and Z directions. Since the study area is not large, the accuracy of LiDAR will need to be verified through additional research.
3. A 3D design reflecting the actual terrain was created, and various sensors were installed on the construction equipment to conduct experiments on construction automation. Construction automation has the advantage of being able to know the design values and the condition of the site in real time using the sensors installed on the equipment.
4. The productivity of construction automation was evaluated by comparing the results of traditional and automated construction processes. In addition, a method using geospatial information and AR can visualize the process in the field, contributing to effective construction management.
5. In the future, construction automation using 3D geospatial information technology will contribute to improving productivity not only for roads, but also at many other construction sites such as tunnels.

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