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Analysis of Work Effectiveness According to Application of 3D Reality Model Based on UAV Aerial Photos in Urban Development Projects

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Recently, the use of high-dimensional spatial information, such as a 3D reality model, which is built on the basis of unmanned aerial vehicles (UAVs), has become active in various industries, including the construction sector. To overcome the limitations of the current direct field survey and 2D-image-based surface utilization and the deterioration of work efficiency in the planning of urban development, in this study, we aim to verify the effectiveness of the 3D model using UAV-based aerial photography. For this purpose, six evaluation factors, namely, presence, spatial ability, conceptual understanding, aesthetics, work efficiency, and reliability, were set before and after the application of the 3D reality model, and a *t*-test was conducted. As a result, compared with the current 2D method, the survey method by applying the 3D method showed an average preference of 90.6%. In addition, as a result of the *t*-test to confirm the difference in utility between the current statuses of obstructions, significant differences between groups were confirmed in all six utility evaluation factors. As a result, the applicability and effectiveness of the 3D method according to the application of the 3D reality model could be demonstrated in terms of spatial ability, work efficiency, and reliability.

1. Introduction

The city encountered by citizens is not a 2D plane but a 3D plane, more precisely, a 3D space or a four-dimensional place.(1) However, it is difficult to grasp a map owing to its simplicity and people's lack of understanding of map expression in a 2D space.(2)

In the process of generalizing the real world to 2D objects on points and lines, data loss occurs, and limitations are inherent in the understanding and analysis of the real world.(3) In addition, when planning a city, land use may be defined as a 2D plan, but it corresponds to a 3D spatial plan because it stipulates the sizes and use of buildings within it.(4) However, as designers are still calculating 2D-based supplies when designing, there has been a problem that designers make mistakes because of errors in design drawing preparation and number calculation.(5)

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Owing to the recent development of information processing technology and computers, a large amount of spatial information has been converted into a database, and visualization has been achieved.(1) We live in an increasingly visual culture,(6) where the visualization of information has become an integral part of decision-making processes.(7) Through technological advancement, 3D visualization is increasingly being adopted to assist visual communication in urban planning.(8) In addition, the development of a geographic information system and 3D technologies and technology development on virtual reality implementation on the Internet have been carried out.(1) The importance of using 3D spatial information construction has increased in response to the demand for digital twin construction to support such virtual spaces and smart cities.(9)

In this study, the latest technology for building 3D spatial information using an unmanned aerial vehicle (UAV) was produced and presented as an alternative technology to compensate for the shortcomings of the current urban planning system. Moreover, we aimed to explore the effectiveness and applicability of urban development and management using a 3D reality model to overcome the limitations of current 2D urban planning by introducing UAV aerial photography processing technology to provide 3D urban information.

2. Research Design

In this study, we aim to verify the effectiveness of planning a city by establishing a 3D reality model using 3D spatial information technology to solve the problems of using flat technology based on 2D images using existing spatial information. To this end, a 3D model was produced on the basis of large-scale UAV aerial photographs taken in urban areas. The effectiveness of this model was measured and analyzed by comparing data pairs using existing methods and urban application items.

For the 3D reality model, we referred to "Guidelines for Public Survey on the Use of UAVs",(10) "Work Regulations for UAV Survey",(11) and "Work Regulations for 3D Geospatial Information Construction".(12) It was designed to be produced following the standards for detail and visualization information for dimensional building and 3D terrain data, and quantitative and qualitative evaluations were performed on the produced 3D reality model.

To analyze the effectiveness of the 3D reality model for its application in the urban field, six evaluation factors were set: presence, spatial ability, conceptual understanding, aesthetics, work efficiency, and reliability. Among the items in the essential survey conducted in the planning stage of the urban development project, the effectiveness of the applicable basic investigation items was verified for the statuses of obstacles, slope and elevation, and forest and ecological nature. Furthermore, as an evaluation method used to analyze the effectiveness of the 3D method through pairwise comparison after constructing and applying the existing 2D method and platform before applying the 3D reality model using UAV aerial photographs, a survey was conducted targeting workers in related fields such as civil engineering, architecture, and transportation.

Through this, frequency analysis and paired *t*-tests were conducted for the six efficacy evaluation factors. The existing 2D method was used by applying the pre-/post-test design method for a single group for objective analysis. Moreover, the effectiveness of the 3D method according to the application of the 3D reality model was compared and verified.

3. Production of a 3D Reality Model

We selected a study site where an urban development project is currently in progress to produce a 3D reality model based on large-scale images obtained using a UAV. The target area of this study was initiated by the Ministry of Land Infrastructure and Transport and Land Housing (LH) in 2010. In addition, a housing construction project is underway in a public housing district under the Special Act on Public Housing. By the end of 2023, a total of 3200 households, about 9000 people, are expected to move in.

3.1 Acquisition of basic data

For the pilot production of a 3D reality model, large-scale aerial photographs of the topography and features of the research site were taken using a UAV. The rotary-wing UAV DJI Inspire-2 (T650A), which is capable of low-altitude flight and close-up photography of the target object, was selected (Fig. 1). Lens calibration was performed to correct image distortion for the camera (ZENMUSE X5S DSLR) mounted on the UAV.

In addition, the "Work Regulations for UAV Survey" was referred to for shooting the research site, and a shooting plan was established, as shown in Table 1. Finally, a total of 1340 aerial photographs of the study site with a spatial resolution (GSD) of 5 cm were acquired at a shooting altitude of 100 m. Pix4Dcapture was used to take aerial photographs of the study area.

In addition, a ground control point (GCP) and a check point are required to assign absolute coordinates and verify the accuracy of the 3D reality model being produced. "Work Regulations for UAV Survey" stipulates the installation of nine or more GCPs per km^2 and more than 1/3 of GCPs as check points. Eleven and three points were selected as ground control and inspection points, respectively, by clearly identifying them from the captured images and through good

Fig. 1. (Color online) Zenmuse X5S DSLR camera (https://www.dji.com/kr/products/camera-drones#inspire-series).

Table 1
Shooting plan for research site.

Classification	Contents	
Flight plan	Shooting route	Grid type (7 north–south, 7 east–west)
	Lens calibration	ZENMUSE X5S DSLR Radial distortion, tangential distortion
	Approval	Approval for aerial photo.
Aerial photo shoot	UAV model	DJI Inspire-2 (T650A)
	Application	Pix4Dcapture
	Dates of shooting	April 2019, April 2021
	Shooting altitude	100 m
	Percent of lap	Percent of end lap: 85% or more Percent of side lap: 80% or more
	GSD	5 cm
	Related regulations	Guidelines for Public Survey on the Use of UAVs

accessibility in actual ground surveying, and the results of the VRS-Network RTK survey are presented in Table 2. At this time, the TOPCON HiperV receiver was used as the GNSS equipment for the GCP survey.

3.2 Generation of high-density point cloud data and orthoimage

3D point cloud data and true orthoimages were produced through a series of processes, such as the preprocessing, image registration, and aerial triangulation of the aerial photographs taken using the UAV. To support the creation of 3D point cloud data and orthoimages, Pix4D mapper Pro was used, and 3D maps were set as an option to proceed with the work. Then, the absolute coordinates obtained from the GCP survey were entered, and aerial triangulation was performed. After the aerial triangulation work was completed, image matching was performed using the SIFT algorithm, and automatic point cloud data were generated using the SfM algorithm. Figure 2 shows the 3D high-density point cloud data produced using UAV aerial photographs taken at the end of the development project for the research site. In addition, a digital surface model (DSM) was created using 3D point cloud data, and a true orthoimage was produced by processing it together with aerial photographs.

Image resampling was performed in the numerical differential deviation correction process for ortho correction. Colinear interpolation was applied as an interpolation for this process, and the minimum interval for image rearrangement was set to 2 pixels or less. Figure 3 shows the true orthoimage produced for the study site.

3.3 3D reality model production and quality evaluation

For the production of a 3D reality model, we referred to “Work Regulations for UAV Survey”. To produce a 3D reality model for various facilities in the urban area, we referred to “Work Regulations for 3D Geospatial Information Construction” and used 3D building and 3D topographical data, which are standard data sets for 3D national spatial information. Moreover,

Table 2
GCP survey performance (2021.04) (unit: m).

No.	*X*	*Y*	*Z*	
GCP-01	456124.4	209963.9	45.839	GCP
GCP-02	455959.6	209290.4	30.0282	GCP
GCP-03	456091.6	209578.6	40.3413	GCP
GCP-04	456338.6	209782.3	40.3075	GCP
GCP-05	456492.2	209408.8	35.0769	GCP
GCP-06	456403.7	209119.2	49.9116	GCP
GCP-07	456091.5	208854.3	34.8093	GCP
GCP-08	456308.7	209316.3	39.6202	GCP
GCP-09	456612.6	209213.3	34.8484	GCP
GCP-10	456750.4	208894.7	29.5781	GCP
GCP-11	456338.9	208854.2	38.7789	GCP

Fig. 2. (Color online) Generation of 3D high-density point cloud data.

Fig. 3. (Color online) Result of true ortho-image.

the model was produced to meet the visualization information production standards. In addition, it was designed to enable the construction of a high-quality 3D reality model by considering the characteristics of the urban area, such as topography and facilities, and various environmental factors in the urban area (Table 3). Figure 4 shows a 3D reality model corresponding to the final result of this study, using Pix4D mapper Pro.

In addition, to utilize the 3D reality model produced in this study for site selection, process management, and so forth for urban development projects, the accuracy verification and quality evaluation of the 3D reality model were conducted to secure its reliability. The evaluation of the 3D reality model is quantitative for the evaluation of the location accuracy based on the quality evaluation criteria for building 3D national spatial information and qualitative for the evaluation of the level of detail (LoD) and consistency of visualization of the target object within the research site. The evaluation was performed by classification. The location accuracy evaluation for the quantitative evaluation of the 3D reality model was performed after setting a check point with clear identification in the 3D reality model and then analyzing the GPS Network-RTK (VRS) survey results and the 3D reality model for the check points. The root mean square error (*RMSE*) was analyzed by comparing 3D coordinates. As an evaluation criterion for 3D geospatial

Table 3
3D reality model production method.

Procedure	Contents	
Input data	Aerial photos, GPS/INS data, camera verification data, GCP survey performance	
Work detail	Aerial photo preprocessing, Image matching, Aerial triangulation, Point cloud data generation, DSM generation, True orthoimage generation, 3D reality model generation	
Utilization technique	3D reality model generation	SIFT/SfM algorithm
	Ortho projection correction	Digital differential rectification Bilinear interpolation
Program	Pix4D mapper Pro	
Related regulations	Work regulations for producing image map	

Fig. 4. (Color online) Construction of 3D reality model.

information, such as a 3D reality model, we referred to National Geographic Information Institute Notice No. 2019-146 "Work Regulations for 3D Geospatial Information Construction". Figure 5 shows the deviations on the *X*, *Y*, and *Z* axes for each inspection point, and Table 4 shows the root mean square error (*RMSE*) calculation results for each of the *X*, *Y*, and *Z* coordinates.

As a result of calculating the *RMSE* after deriving the deviation for each of the *X*, *Y*, and *Z* coordinates of each check point using 20 check points, the horizontal positioning accuracy of the 3D reality model was distributed within the range from 10 to 13 cm, and the vertical positioning accuracy was analyzed within 20 cm on average. It was confirmed that these analysis results satisfied the evaluation criteria of allowable accuracy for producing 1:1000 digital maps of "Work regulations for aerial photogrammetry"[13] and "Work regulations for creating digital topographic maps".[14]

The qualitative evaluation of the 3D reality model was conducted according to "Work Regulations for 3D Geospatial Information Construction". Among the evaluation factors in the related regulations, the LoD and visualization evaluation items were selected as quality evaluation factors that could meet the purpose of this study, and then evaluation was performed. To review the consistency of LoD, it was evaluated whether it was produced by the regulations of the building data production method in the relevant rules and whether it was produced following

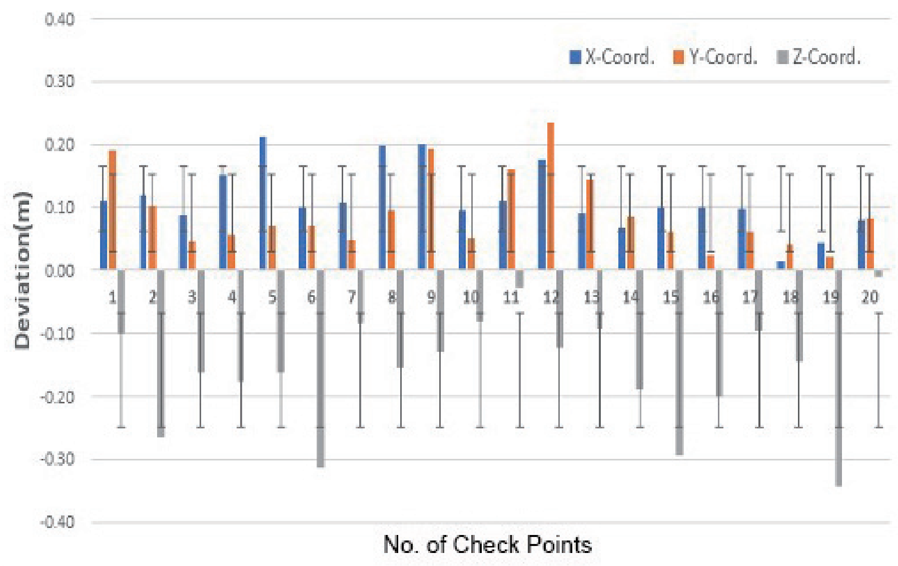

Fig. 5. (Color online) 3D deviation distribution for check points.

Table 4
RMSE analysis results for check points (unit: m).

	RMSE	
X-Coord.	*Y*-Coord.	*Z*-Coord.
0.1238	0.1092	0.1806

the visualization information production method. As a result, on the basis of the relevant regulations, the 3D reality model was found to meet the production method requirement and standards for level 4 of LoD, and visualization consistency was improved through texturing using true orthoimages to produce 3D reality models.

As a result of the quantitative and qualitative evaluations of the 3D reality model produced in this study, it was possible to prove the possibility of using the 3D reality model in the overall urban development project by securing reliability in the quality of the 3D reality model.

4. Analysis of Effectiveness According to Application of 3D Reality Model in Urban Development Project

To analyze the effectiveness of applying the 3D reality model to basic status investigation and practices for urban planning, a survey was conducted targeting workers in related fields, and the obtained results were statistically analyzed.

4.1 Survey overview

In this study, we aim to compare and analyze the existing 2D method in tasks such as a current status investigation of urban planning and the 3D method using the 3D reality model using aerial photographs of UAVs. The questionnaire used was designed using the post-test design method. The survey method was conducted through the Google form online survey, an electronic survey method. The survey subjects were randomly selected, targeting workers in related fields such as urban planning, civil engineering, architecture, and transportation.

The survey included asking what type of work would be helpful if a 3D reality model produced using a UAV was applied to field survey work, etc., and which of the six effectiveness evaluation factors could be helpful. It consists of questions that apply a 5-point Likert scale to ask whether there is a problem. It measured six effectiveness factors for the current statuses of obstacles applied to cities, slope and elevation, and forest and ecological nature. We attempted to maximize the efficiency of the survey by producing and providing comparison data for the existing method and the 3D method as a video. Table 5 shows the effectiveness analysis method and sample settings of the 3D method to which the 3D reality model is applied.

Table 6 shows six evaluation factors that are generally applied to effectiveness evaluation by examining several references and defining them. On the basis of the existing literature review to investigate the current status of the planned urban development area, the evaluation factors most related to the 3D reality model based on the UAV and related to the construction of 3D spatial information were derived. Table 7 shows the statuses of 183 respondents of the survey for effectiveness analysis.

4.2 Frequency analysis of survey results

In the case of site surveys for site selection in urban planning, among the tasks that can apply the 3D field survey method based on aerial photographs of UAV, the current statuses of obstacles,

Table 5
Effectiveness analysis method and sample of 3D method based on 3D reality model.

Classification			Contents
Survey	Content	Degree of help	Degree to which the 3D platform construction helps the survey items
		Importance	Importance for evaluation factors
		Evaluation factor determination	Six evaluation factors for three survey items
		Additional opinion	Technology elements needed in the future, application plan
		Personal information	Personal characteristics (gender, age, major, occupation, career, and final education)
	Method		One group pre-test/post-test design, Convenience sampling, and Electronic survey
	Scope		November 5 to 15, 2021
	Sample		183 copies
Analysis	Method		Frequency analysis of basic statistics, Paired *t*-test
	Program		SPSS 21

Table 6
Selection of effectiveness evaluation factors.[15]

Evaluation factor	Definition of evaluation factors
Presence	Feeling in the field while observing drawings and videos. The presence is considered to be ‘there’, and it is defined in three ways: personal presence, social presence, and environmental presence.
Spatial ability	It means clear and intuitive structure of space, understanding of space, and natural connection to space.
Conceptual understanding	The degree to which one understands the concept of the content presented here while experiencing the content. The degree of understanding of physical phenomena and concepts and the meaning of experiments.
Aesthetics	Aesthetics refers to the degree to which one feels that an object is beautiful and has long been an important factor in the expression of works by artists. The degree to which one feels that the contents of the video are lively, the content design is attractive, or the contents are harmoniously decorated.
Work efficiency	It is a concept that complexly refers to efficiency, effectiveness, concentration, productivity, and the possibility of achieving goals, etc. perceived by individuals in performing and processing necessary tasks.
Reliability	The construction and utilization of accurate, easy-to-understand, and quick-to-understand 3D spatial information are essential for improving the quality and reliability of related services.

Table 7
General characteristics of survey subjects ($N = 183$).

Classification		Frequency (persons)	Percent (%)
Gender	Male	146	79.8
	Female	37	20.2
Age	20s	14	7.7
	30s	35	19.1
	40s	64	35.0
	50s	52	28.4
	60s or more	18	9.8
Major field	Architecture	49	26.8
	Transportation	12	6.6
	Urban planning	72	39.3
	Civil engineering	41	22.4
	Others	9	4.9
Occupation	Public official	58	31.7
	Academia	60	32.8
	Technical expert	65	35.5
Career	Less than a year	6	3.3
	1 to 3 years	13	7.1
	3 to 5 years	9	4.9
	5 to 7 years	14	7.7
	7 to 10 years	14	7.7
	10 years or more	127	69.4
Final education	High school	4	2.2
	University	57	31.1
	Graduate school or higher	122	66.7

forest and ecological nature, and slope and elevation were selected to be investigated. In addition, a frequency analysis of the survey's results on the importance of the six evaluation factors in evaluating effectiveness was conducted. As a result, 90.7% for presence, 91.2% for spatial ability, 72.1% for conceptual understanding, 63.4% for aesthetics, 89.1% for work efficiency, and 92.3% for reliability showed importance (Table 8).

4.2.1 Investigation on status of obstructions

As a result of examining the response rate for the 3D method through the 3D current status investigation applying the 3D reality model in the obstruction status investigation, 96.2% for presence, 97.2% for spatial ability, 86.3% for conceptual understanding, 89.0% for aesthetics, 95.1% for work efficiency, and 90.7% for reliability were found (Table 9). The average response rate for the 3D method was 92.4%, which was confirmed to be significantly higher than that for the existing 2D method. In particular, in terms of presence and spatial ability, the 3D method was considered very excellent. In addition, it showed high response rates regarding work efficiency and reliability.

4.2.2 Investigation on status of slope and elevation

In the slope and elevation investigation, the existing 2D and 3D methods using the 3D reality models were compared in terms of effectiveness. As a result of examining the response rate for the 3D method, 93.4% for presence, 94.0% for spatial ability, 83.6% for conceptual understanding, 86.9% for aesthetics, 88.0% for work efficiency, and 88.0% for reliability were found (Table 10). In the current status survey of slope and elevation, the average response rate for the 3D method was 88.9%, and the presence and spatial ability showed the highest rates. Work efficiency and reliability also showed high rates; thus, it was judged that the 3D method had objective validity regarding the work efficiency and reliability of the built data.

4.2.3 Investigation on status of forest and ecological nature

In the forest and ecological nature investigation, the existing 2D and 3D methods using the 3D reality model were compared in terms of effectiveness. As a result of examining the response

Table 8
Importance of effectiveness (unit: %).

	Not very important	Not important	Normal	Important	Very important
Presence	3 (1.6%)	0 (0%)	14 (7.7%)	67 (36.6%)	99 (54.1%)
Spatial ability	3 (1.6%)	0 (0%)	13 (7.1%)	72 (39.3%)	95 (51.9%)
Conceptual understanding	2 (1.1%)	3 (1.6%)	46 (25.1%)	71 (38.8%)	61 (33.3%)
Aesthetics	2 (1.1%)	8 (4.4%)	57 (31.1%)	66 (36.1%)	50 (27.3%)
Work efficiency	2 (1.1%)	1 (0.5%)	17 (9.3%)	66 (36.1%)	97 (53.0%)
Reliability	2 (1.1%)	2 (1.1%)	10 (5.5%)	50 (27.3%)	119 (65.0%)

Table 9
Results of frequency analysis of obstruction status investigation.

Evaluation factor		2D Frequency (persons)	2D Percent (%)	3D Frequency (persons)	3D Percent (%)
Presence	Very low	24	13.1	0	0.0
	Low	74	40.4	0	0.0
	Normal	67	36.6	7	3.8
	High	15	8.2	69	37.7
	Very High	3	1.6	107	58.5
Spatial ability	Very low	29	15.8	0	0.0
	Low	78	42.6	0	0.0
	Normal	62	33.9	5	2.7
	High	9	4.9	57	31.1
	Very High	5	2.7	121	66.1
Conceptual understanding	Very low	7	3.8	0	0.0
	Low	57	31.1	1	0.5
	Normal	89	48.6	24	13.1
	High	27	14.8	89	48.6
	Very High	3	1.6	69	37.7
Aesthetics	Very low	29	15.8	0	0.0
	Low	74	40.4	1	0.5
	Normal	73	39.9	19	10.4
	High	6	3.3	85	46.4
	Very High	1	0.5	78	42.6
Work efficiency	Very low	11	6.0	0	0.0
	Low	75	41.0	1	0.5
	Normal	76	41.5	8	4.4
	High	13	7.1	84	45.9
	Very High	8	4.4	90	49.2
Reliability	Very low	9	4.9	1	0.5
	Low	47	25.7	0	0.0
	Normal	85	46.4	16	8.7
	High	33	18.0	75	41.0
	Very High	9	4.9	91	49.7

rate for the 3D method, 93.9% for presence, 94.6% for spatial ability, 87.5% for conceptual understanding, 90.2% for aesthetics, 87.5% for work efficiency, and 90.1% for reliability were found (Table 11). In the forest and ecological nature investigation, the average response rate for the 3D method was 90.6%, and the ratio was the highest for the presence, spatial ability, and aesthetics. In addition, the work efficiency and reliability also received high rates, and the work efficiency and reliability of the 3D platform were also judged to have high objective validities.

As described above, when comparing the response rates for the existing 2D method and the 3D method to which the 3D reality model was applied, an average of 90.6% showed a preference for the effectiveness of the 3D method. In particular, the response rate for the 3D method in terms of presence, spatial ability, work efficiency, and reliability is relatively high, and the effects of the 3D method on the realistic judgment of space, the consequent increase in work efficiency, and the reliability of data were evaluated. This could be analyzed as positive, and the validity of the 3D method could be verified from the above analysis results.

Table 10
Results of frequency analysis of slope and elevation investigation.

Evaluation factor		2D		3D	
		Frequency (persons)	Percent (%)	Frequency (persons)	Percent (%)
Presence	Very low	35	19.1	0	0.0
	Low	72	39.3	0	0.0
	Normal	57	31.1	12	6.6
	High	14	7.7	71	38.8
	Very High	5	2.7	100	54.6
Spatial ability	Very low	30	16.4	0	0.0
	Low	67	36.6	1	0.5
	Normal	65	35.5	10	5.5
	High	18	9.8	65	35.5
	Very High	3	1.6	107	58.5
Conceptual understanding	Very low	14	7.7	0	0.0
	Low	55	30.1	0	0.0
	Normal	79	43.2	30	16.4
	High	27	14.8	81	44.3
	Very High	8	4.4	72	39.3
Aesthetics	Very low	33	18.0	0	0.0
	Low	81	44.3	2	1.1
	Normal	55	30.1	22	12.0
	High	12	6.6	80	43.7
	Very High	2	1.1	79	43.2
Work efficiency	Very low	16	8.7	0	0.0
	Low	68	37.2	3	1.6
	Normal	74	40.4	19	10.4
	High	17	9.3	75	41.0
	Very High	8	4.4	86	47.0
Reliability	Very low	8	4.4	0	0.0
	Low	60	32.8	1	0.5
	Normal	79	43.2	21	11.5
	High	28	15.3	71	38.8
	Very High	8	4.4	90	49.2

4.3 Paired *t*-test

The *t*-test is a statistical method used to compare group averages when the distribution of the population is normal and the dependent variable is a quantitative variable, and it determines whether there is a difference in the population's average. After setting the hypotheses "There is a difference" and "There is no difference", the *t*-test statistic is calculated to determine the probability of a difference between the two sample means. Afterward, if the calculated value is within the significance level, it is judged whether there is a difference or not. In this study, a paired-sample *t*-test was conducted among the *t*-test methods to verify the difference before and after applying the 3D method by applying the pre-/post-test design method for a single group. The paired-sample *t*-test is a representative method for comparing the difference between two numbers from the same group.

Table 11
Results of frequency analysis of forest and ecological nature investigation.

Evaluation factor		2D		3D	
		Frequency (persons)	Percent (%)	Frequency (persons)	Percent (%)
Presence	Very low	33	18.0	0	0.0
	Low	75	41.0	0	0.0
	Normal	54	29.5	11	6.0
	High	18	9.8	59	32.2
	Very High	3	1.6	113	61.7
Spatial ability	Very low	34	18.6	0	0.0
	Low	74	40.4	0	0.0
	Normal	57	31.1	10	5.5
	High	16	8.7	62	33.9
	Very High	2	1.1	111	60.7
Conceptual understanding	Very low	29	15.8	0	0.0
	Low	60	32.8	0	0.0
	Normal	72	39.3	23	12.6
	High	19	10.4	81	44.3
	Very High	3	1.6	79	43.2
Aesthetics	Very low	38	20.8	0	0.0
	Low	76	41.5	0	0.0
	Normal	58	31.7	18	9.8
	High	8	4.4	79	43.2
	Very High	3	1.6	86	47.0
Work efficiency	Very low	22	12.0	0	0.0
	Low	74	40.4	3	1.6
	Normal	61	33.3	20	10.9
	High	22	12.0	68	37.2
	Very High	4	2.2	92	50.3
Reliability	Very low	23	12.6	0	0.0
	Low	64	35.0	0	0.0
	Normal	74	40.4	18	9.8
	High	18	9.8	72	39.3
	Very High	4	2.2	93	50.8

As a result of conducting a paired *t*-test to confirm the difference in effectiveness between the existing 2D method and the 3D method in the obstacle status survey, presence ($t = -25.349$, $p < 0.001$), spatial ability ($t = -28.881$, $p < 0.001$), conceptual understanding ($t = -17.169$, $p < 0.001$), aesthetics ($t = -25.051$, $p < 0.001$), work efficiency ($t = -22.871$, $p < 0.001$), and reliability ($t = -17.331$, $p < 0.001$) showed negative t values below the statistical significance level of 0.001, indicating that there was a difference in mean between groups (Table 12). The *t* value is negative because it is obtained by subtracting the value for the posterior from the value for the prior during statistical analysis, which means that the value for the posterior is high. Therefore, it was found that there was a significant difference under the statistical significance level, and it was found to be higher in the 3D method than in the 2D method.

As a result of conducting a paired *t*-test in the slope and elevation investigation in the same way, presence ($t = -24.336$, $p < 0.001$), spatial ability ($t = -24.958$, $p < 0.001$), conceptual understanding ($t = -15.328$), $p < 0.001$), aesthetics ($t = -23.383$, $p < 0.001$), work efficiency

Table 12
Paired t-test results of obstruction status investigation.

	2D		3D		
	Mean	Standard deviation	Mean	Standard deviation	t
Presence	2.45	0.881	4.55	0.571	-25.349^{***}
Spatial ability	2.36	0.902	4.63	0.537	-28.881^{***}
Conceptual understanding	2.79	0.799	4.23	0.691	-17.169^{***}
Aesthetics	2.32	0.798	4.31	0.676	-25.051^{***}
Work efficiency	2.63	0.873	4.44	0.607	-22.871^{***}
Reliability	2.92	0.911	4.39	0.694	-17.331^{***}

$^{*}p < 0.01$, $^{**}p < 0.01$, $^{***}p < 0.001$.

Table 13
Paired t-test results of slope and elevation investigation.

	2D		3D		
	Mean	Standard deviation	Mean	Standard deviation	t
Presence	2.36	0.966	4.48	0.619	-24.336^{***}
Spatial ability	2.44	0.935	4.52	0.628	-24.958^{***}
Conceptual understanding	2.78	0.941	4.23	0.712	-15.328^{***}
Aesthetics	2.28	0.875	4.29	0.717	-23.383^{***}
Work efficiency	2.63	0.927	4.33	0.729	-17.490^{***}
Reliability	2.83	0.897	4.37	0.705	-17.327^{***}

$^{*}p < 0.01$, $^{**}p < 0.01$, $^{***}p < 0.001$.

Table 14
Paired t-test results of forest and ecological nature investigation.

	2D		3D		
	Mean	Standard deviation	Mean	Standard deviation	t
Presence	2.36	0.944	4.56	0.607	-26.268^{***}
Spatial ability	2.33	0.916	4.55	0.599	-27.990^{***}
Conceptual understanding	2.49	0.937	4.31	0.683	-21.123^{***}
Aesthetics	2.25	0.889	4.37	0.658	-25.799^{***}
Work efficiency	2.52	0.931	4.36	0.742	-19.390^{***}
Reliability	2.54	0.912	4.41	0.664	-22.161^{***}

$^{*}p < 0.01$, $^{**}p < 0.01$, $^{***}p < 0.001$.

($t = -17.490$, $p < 0.001$), and reliability ($t = -17.327$, $p < 0.001$) were found to show significant differences. It was also found that there was a significant difference at all levels, and it was found to be higher in the 3D method than in the 2D method (Table 13).

As a result of conducting a paired t-test in the forest and ecological nature investigation, presence ($t = -26.268$, $p < 0.001$), spatial ability ($t = -27.990$, $p < 0.001$), conceptual understanding ($t = -21.123$, $p < 0.001$), aesthetic sense ($t = -25.799$, $p < 0.001$), work efficiency ($t = -19.390$, $p < 0.001$), and reliability ($t = -22.161$, $p < 0.001$) all showed significant differences at a statistical significance level. Such differences were found to be greater in the 3D method than in the 2D method (Table 14).

5. Conclusion

In this study, a 3D reality model was applied to solve the problems of using flat technology based on the current 2D method, which is conducted for the basic status investigation of the development site in the urban planning stage for urban development. The purpose was to apply the research method and verify its effectiveness. As a result of this study, the following conclusions were drawn.

First, to verify the possibility of using the 3D reality model for the basic status survey for urban development projects, aerial photographs of the research site were obtained using a UAV, and a 3D reality model was pilot-produced on the basis of these photographs. In addition, to secure reliability in the quality, the possibility of using the 3D inspection model for obtaining basic status information was demonstrated by deriving results that could comply with the relevant regulations through quantitative and qualitative evaluations.

Second, to analyze the effectiveness of the UAV-aerial-photo-based 3D reality model for application to the urban field, six evaluation factors, namely, presence, spatial ability, conceptual understanding, aesthetics, work efficiency, and reliability, were set, and an urban development project was evaluated. Among the current status investigations conducted in the planning stage, the effectiveness of the 3D method applied in this study compared with the existing 2D method was established by setting the current statuses of obstacles, slope and elevation, and forest and ecological nature as basic investigation items. Statistical analysis was performed by conducting a questionnaire survey targeting workers. A comparison of the response rates for the current 2D method and the 3D method proposed in this study in the basic status investigation showed that an average of 90.6% had a preference for the effectiveness of the 3D method.

Third, a survey was conducted asking how important the six evaluation factors were for the statuses of obstacles, slope and elevation, and forest and ecological nature. It was found that the 3D method had a positive effect on the realistic judgment of space, the increase in work efficiency, and the reliability of securing the objectivity of data. In addition, a paired-sample *t*-test was conducted to verify the validity of the difference between the investigation methods before and after the platform was established by applying the pre-/post-test design method for a single group. As a result, all six evaluation factors were negative at the statistical significance level of 0.001 or less. The analysis results showed a significant difference while showing the t value. From the results, it was possible to prove the effectiveness of the basic status investigation method using a 3D reality model for the basic status investigation.

In this study, the survey items applied to analyze the effectiveness of the 3D reality model for the basic status investigation were limited to some field investigation items. Additional research is required to analyze the effectiveness of the subsequent tasks.

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