COMPREHENSIVE QUANTITATIVE UNDERSTANDING OF THE LANDSCAPE USING TLS POINT CLOUD DATA

R.Tachikawa[1]*,Y.Kunii[2]

[1]Department of Landscape Architecture Science, Graduate School of Tokyo University of Agriculture
1-1-1 Sakuragaoka, Setagaya-ku, Tokyo, 156-8502, Japan – 12721006@nodai.ac.jp
[2]Department of Landscape Architecture Science, Tokyo University of Agriculture 1-1-1 Sakuragaoka, Setagaya-ku, Tokyo, 156-8502, Japan -y3kunii@nodai.ac.jp

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ABSTRACT:

Landscape spaces such as gardens and parks are composed of various landscape components, creating diverse landscapes. In general, the quality of the landscape in these spaces is often judged subjectively by visitors. On the other hand, if landscapes can be evaluated objectively, they can be used to create better spaces in the management and creation of landscaped spaces. In recent years, point cloud data has been acquired in urban and natural spaces. In landscaped spaces, point cloud data is increasingly used for landscape simulation and current state planning. In this study, point cloud data acquired with a terrestrial laser scanner (TLS) in the target space were used to quantitatively characterize the entire landscape using fractal analysis and visual and ecological environmental quality models (VQM). We also segmented these data into components of the point cloud data and calculated the relationship between the data and the occupancy of the components. On the other hand, focusing on environmental visual information received passively from a wide range of environments, we conducted an analysis based on panoramic images created from point cloud data. As a result, both fractal analysis and VQM showed a high correlation with previous research methods in understanding the landscape using point cloud data. In addition, the analysis of the landscape was made more efficient than the conventional photographic analysis by segmenting the components in advance at the data processing stage, demonstrating the usefulness of landscape analysis from data acquired by laser scanners.

1. INTRODUCTION

Gardens, parks, and other landscaped spaces are composed of various landscape components, creating a variety of landscapes. In general, the quality of the landscape in these spaces is often judged subjectively by visitors. When people visit landscaped spaces, they have a sequential spatial experience, continuously experiencing scenes that change one after another as they shift their viewpoints toward the landscape. For example, in the case of urban parks, visitors stroll through the park, and in the case of Japanese gardens, visitors stroll through the garden, which is called a kaiyushiki (circular garden) type of landscaped space.

In previous studies on landscape evaluation, there are examples of landscape evaluation experiments using the Semantic Differential method as a means of adding objectivity to subjective evaluations. On the other hand, as a means of understanding the landscape quantitatively, there are studies that quantified the landscape pattern of an area using an index, and examples using fractal analysis to calculate the complexity of a landscape by processing images taken by a camera.

In all the above studies, landscape analysis was conducted using photographs taken by camera, however the original landscape is a 3D space including depth, and the analysis replaced by a 2D plane using photographs is considered to have limitations in understanding the landscape. J.J.Gibson also stated that discussions based 2D visual information in the form of static retinal images are meaningless, and that the movement of the viewpoint plays an essentially important role in the perception of 3D depth. In other words, the changes in the retinal image that occur as one moves within a space are not random, however rather maintain a constant relationship with the state of the environment (J.J. Gibson,1966) (J.J. Gibson,1979).

Therefore, we believe that by analyzing the landscape in a three-dimensional and sequential manner, it will be possible to grasp the land-like expanse of the landscape and to set the viewpoint freely, thus enabling a more accurate understanding of the landscape. In addition, the index calculated by fractal analysis is the complexity of the landscape, however it is considered difficult to capture the overall characteristics of the landscape by this index alone.

In recent years, point cloud data has been acquired in urban and natural areas as a means of understanding landscapes in three dimensions. In landscaping, point cloud data has been increasingly used for landscape simulation and current plan drawing. Therefore, the use of point cloud data may be effective in landscape evaluation as well (Kumazaki,R et al 2020). The advantages of using point cloud data include once the data is acquired, the target space is represented by high-density three-dimensional coordinates, therefore it is possible to reproduce any viewpoint in the target space at any time. The first point is that it is a very easy way to make a good impression on the viewer.

In this study, we developed an evaluation model that uses point cloud data acquired by terrestrial laser scanner (hereinafter referred to as "laser scanner") in the target space to score landscapes based on fractal analysis and information such as the depth distance at which each component exists as an index for quantifying the overall characteristics of a landscape. The Visual and Ecological Environmental Quality Model (VQM) is used to quantify the overall characteristics of the landscape. The point cloud data was segmented into components, and the relationship between the occupancy of the components was calculated. These were analyzed quantitatively in terms of focal vision extracted from local elements of the environment to which conscious attention was directed, depending on the visual information from the environment and the form of its reception. On the other hand,

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focusing on ambient vision received passively from a wide range of environments, we conducted an analysis based on panoramic images created from point cloud data.

2. METHOD

2.1 Data Acquisition

The target site for this study is the Metasequoia Plaza on Tokyo University of Agriculture, Setagaya Campus, located in Setagaya, Japan. The plaza is located on the traffic line to the entrance and exit of the campus and is frequented by many people and is equipped with various plantings and benches. Therefore, it is a space where both natural and artificial elements are located and where the landscape components targeted in this study can be seen.

Measurements at the site were taken on May 28, 2021. For the acquisition of moving images, we set up a route that allowed us to grasp the entire landscape of the target site and took moving images in the direction of travel while walking along the route. The camera of an iPhone8, a common smartphone, was used as the camera equipment. The camera was positioned at the height of the viewpoint. It was positioned at the height of the viewpoint. The shooting speed was set at 1 meter per second to avoid vertical movement of the camera as much as possible. A RIEGL VZ-400i laser scanner was used to acquire point cloud data. The instrument points were determined to cover the entire space, and a total of 14 points were used for the measurement. Figure 1 shows a detailed map of the target site, the route for acquiring moving images, and the instrument points for acquiring point cloud data. Table 1 shows a summary of the survey for the acquired data and a description of each instrument.

Moving image	Date of survey	28-May-21
	Time	11:10 a.m. to 11:15 a.m.
	Weather	Fine weather
	Humidity	57%
	Equipment	iPhone8(Apple)
	Image sensors	12 megapixels
	Lens	F1.8 (equivalent to 28mm)
Point cloud data	Date of survey	28-May-21
	Time	10:30 a.m. to 11:00 a.m.
	Weather	Fine weather
	Humidity	57%
	Equipment	VZ-400i(RIEGL)
	Measurement accuracy	±5mm
	Laser wavelength	1550nm(near infrared ray)
	Beam Wide Angle	0.35mrad
	Instrument point	14 points

Table 1. Summary of investigation into acquired data.

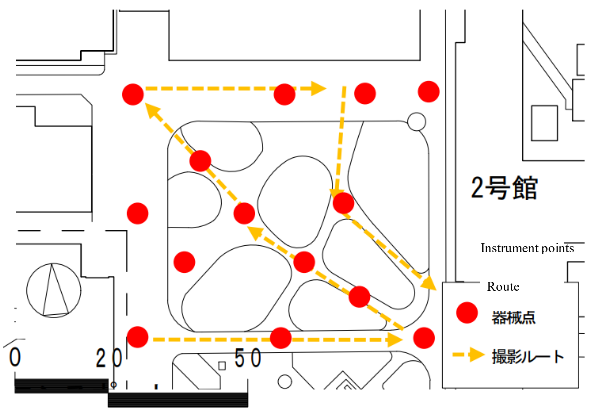

Figure 1. Details of the subject site

2.2 Data Processing

In this study, frame images were extracted from the video images taken, one per second, for a total of 96 images.
On the other hand, from the point cloud data acquired by the laser scanner, the angle of view of the point cloud data was manually adjusted so that the angle of view was the same as that of the above frame images, and 96 rendered images were output. The point cloud processing software RiSCAN PRO (64bit v2.9) (RIEGL,2017) was used for the rendering output. Fractal analysis and VQM were applied to the rendered images.

2.2.1 Processing by Fractal Analysis: Fractal analysis is a process to obtain fractal dimension, a numerical value that quantitatively expresses the complexity of the entire image, using fractal figures that have the characteristics of self-similarity and no length. The grayscale method was used for fractal analysis in this study. The grayscale method uses a grayscale image to obtain the fractal dimension of the entire image without specializing in a particular object. (O'Neill, R. V. et al. 1988)
The fractal dimension obtained by the grayscale method is expressed as a real number from 1 to 3, with higher numbers indicating greater complexity.
Note that, the effect of fractal analysis due to the presence or absence of shadows is also considered.

2.2.2 Processing by VQM: VQM is an algorithm proposed by Burley that classifies components in a landscape image and scores the landscape based on information such as the area and depth of each component, nineteen types of landscape components are included. These were extracted from sample images of many landscapes to determine the main landscape elements included in the images (Burley, J.B. 1997).
First, the landscape image is processed by dividing the entire image by a square grid of a certain size. In previous studies, 38 horizontal grids and 30 vertical grids were used to match the aspect ratio of film photographs. In this study, we assumed the aspect ratio of 4:3, which is one of the aspect ratios, and divide the image into 40 horizontal grids and 30 vertical grids, for a total of 1.200 grids. When scoring landscapes with VQM, landscape components such as trees, vegetation, pavement, buildings, and vehicles in the target landscape image are extracted, and variables are obtained from the number and edge length of the extracted grid. In this case, each variable related to vegetation requires depth information such as Immediate, Intermediate, and Distant. In other words, in VQM, there are variables that determine not only the landscape components however also the distance from the viewpoint to the components. In addition, VQM calculates the Environmental Quality Index (hereinafter referred to as EQI), which is an environmental evaluation index. Each EQI item is rated on a scale of +1, 0, or -1, and the sum of the ratings gives a such value of 1, 0, or -1, respectively. The range of values is an integer between +20 and -20.
The variables and EQI results obtained above can be multiplied by the coefficients obtained from the statistical analysis of previous studies, and the sum can be calculated to obtain the numerical value. The obtained values are generally real numbers ranging from 0 to 250, with lower values indicating a higher evaluation of the landscape. Figure 2 shows the indicators in the VQM, with the left table for landscape components and the right table for EQI (Burley, J.B. 1997).
In order to verify the usefulness of point cloud data in VQM, three patterns, Case A, B, and C, are shown below, which were processed by VQM for each acquired data.
Case A is the application of VQM to the frame image extracted from the video image using a previous research method, Case B is the application of VQM to the rendered image output from

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perimeter of immediate vegetation	V1	A Purifies Air
perimeter of intermediate non-vegetation	V2	B Purifies Water
perimeter of distant vegetation	V3	C Builds Soil Resources
area of intermediate vegetation	V4	D Promotes Human Cultural Diversity
area of water	V5	E Preserves Natural Resources
area of distant non-vegetation	V6	F Limits Use of Fossil Fuels
area of pavement	V7	G Minimizes Radioactive Contamination
area of building	V8	H Promotes Biological Diversity
area of vehicle	V9	I Provides Food
area of humans	V10	J Ameliorates Wind
area of smoke	V11	K Prevents Soil Erosion
area of wildflowers in foreground	V14	L Provides Shade
area of utilities	V15	M Presents Pleasant Smells
area of boats	V16	N Presents Pleasant Sounds
area of dead foreground vegetation	V17	O Does Not Contribute to Global Warming
area of esposed foreground substrate	V18	P Contributes to the World Economy
area of wildlife	V19	Q Accommodates Recycling
open landscapes V2 +V4 + (2*(V3+V6))	V30	R Accommodates Multiple Use
closed landscapes V2 +V4 + (2*(V1+V17))	V31	S Accommodates Low Maintenance
openness V30-V31	V32	T Visually Pleasing
mystery V30*V1*V7/1140	V34	
noosphericnessV7+V8+V9+V15+ V16	V52	

(a)Landscape components in VQM (b)EQI index

Figure 2. Indicators in VQM

the acquired point cloud data, and Case C is the application of VQM to the rendered image output from the acquired point cloud data by setting an arbitrary threshold value, considering the depth that can be grasped from the point cloud data. Case C is the case in which VQM is applied to the near, middle, and far views.

This section describes the threshold settings for the above-mentioned near, middle, and far views. In previous studies, the depth information in an image was visually classified by sensing the components in the image. Therefore, in this study, depth information was quantitatively obtained from the coordinate values of RiSCAN PRO's point cloud data. Figure 3 shows the threshold settings in this study.

Figure 4(a) shows the calculation of depth from the viewpoint to the target component. Figure 4(b) shows the distance from the viewpoint to all points within the angle of view, with darker colors indicating greater distance. The following is the rationale for applying the laser surveying depth to VQM in this study.

The conventional quantitative classification of near-, mid-, and far-field views is based on the assumption that the near-field is from 340m to 460m from the viewpoint. The mid-range is defined as the area from 340 to 460 meters to 2.1 to 2.8 km, and the far-range is defined as the area beyond the mid-range. However, since there are too many differences in scale among the sites in this study, we referred to Dreyfuss and set a threshold value based on the theory that the line of sight of a person in an upright posture is generally 10° lower than that of a person in an upright posture(Henry, D.1959).

The threshold was applied to the VQM by setting the line-of-sight height to 1.6 m, the near-view component to 9 m, the mid-view component to 9-18 m, and the far-view component to 18 m or more when the line-of-sight was lowered by 5° and setting the threshold at the VQM. The classification of landscape components by VQM and the calculation of distances were all done manually.

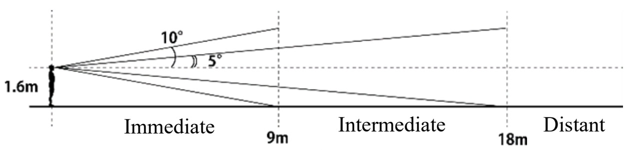

Figure 3. Threshold settings for immediate, medium, and distant views.

(a)Distance Calculation (b) Knowing the distance

Figure 4. Quantitative classification of immediate, intermediate, and distant views

2.2.3 Landscape Component Analysis: In the past, analysis of landscape components was conducted by categorizing each photograph taken. However, the advantage of using point cloud data is that once the data is acquired, any viewpoint in the target space can be reproduced at any time because the target space is represented by high-density three-dimensional coordinates. Using this, several basic components of the environment were categorized by color in the point cloud data stage and rendered according to the angle of view at the time of video acquisition. Specifically, from an arbitrary viewpoint, the sky, buildings, paved surfaces, trees (medium and tall), shrubs & ground cover, benches, and other facilities are considered utilities, and the percentage of each was calculated. Then, we examined the relationship with fractal analysis and VQM.

First, the point cloud processing software Cloudcompare (64bit, v2.11.0) was used to manually segment the components of the point cloud data. Data was output in .las format, the LIDAR data exchange format.

Next, in order to verify the data in an environment close to the pedestrian space, the output data was loaded into Twinmotion (2022.1.2), a rendering software that can quickly and easily create high-quality images, videos, panoramas, and standard VR videos from point cloud data, and the images and panoramas were rendered 96 sheets each. The angle of view was adjusted to be the same as the moving image when outputting with Twinmotion. Shadows were turned off to facilitate segmentation. Figure 5 shows elemental division of point clouds. Figure 6 shows example of element-separated images of moving images and point clouds.

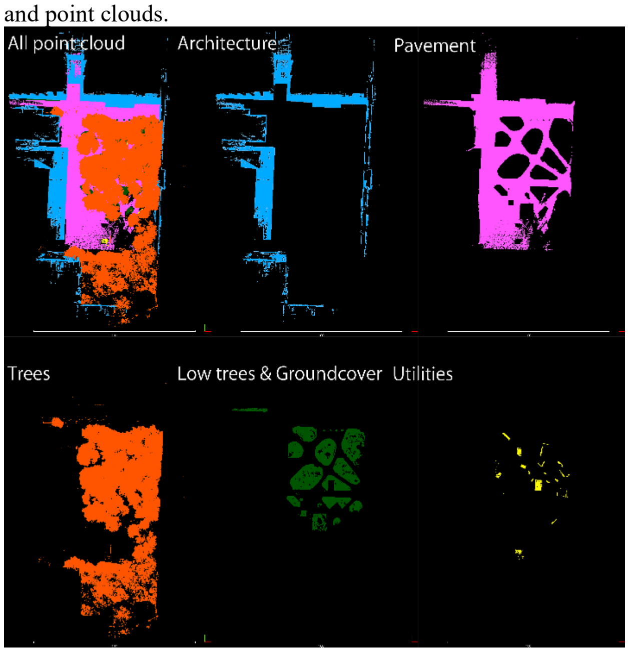

Figure .5 Elemental division of point clouds

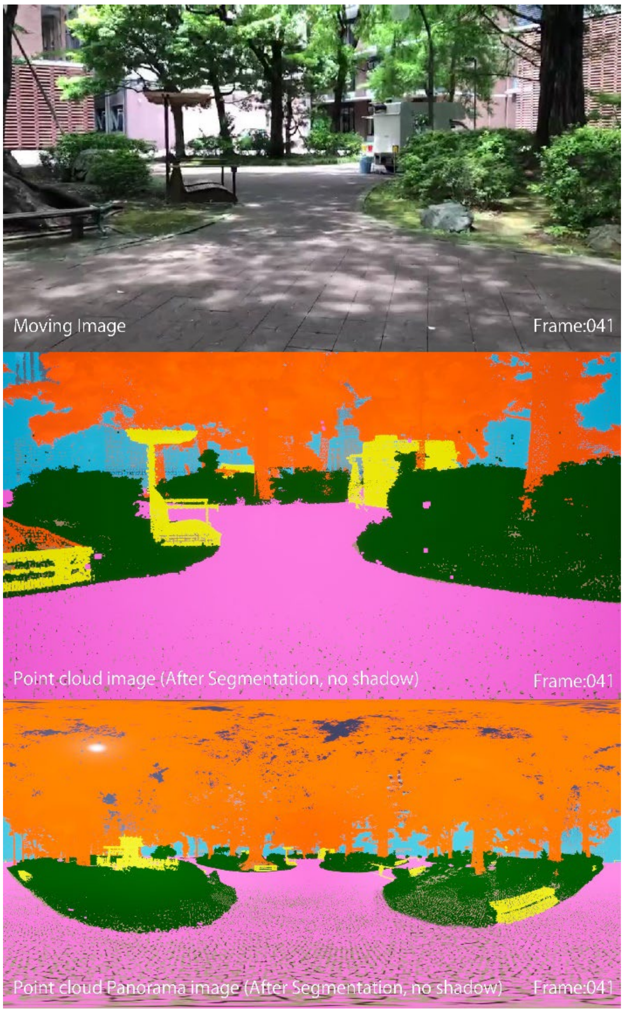

Figure 6. Example of element-separated images of moving images and point clouds

Ohno organized a parallel processing model between the physiological theory of environmental vision, which describes the concept of immediately grasping the situation in the surrounding environment and bringing effective information for one's localization and movement, and focal vision, which determines what the object of vision is by examining and scrutinizing a narrow area of the environment. (Ohno, R. 1993)
In Ohno's method of description, the surfaces that make up the environment are diverse and can be divided into countless segments, so he classifies them according to the way he perceives the most basic constituent surfaces for humans to act without hindrance in the environment. This classification is determined by Gibson's affordances, i.e., the information that enables and induces action. In describing environmental vision, previous studies have used a fisheye lens to record a 180° field of view. In this study, however, in order to describe environmental vision more precisely, panoramic images were rendered from point cloud data to provided a 360° description (Ohno, R. 1993).

3. RESULT

3.1 Fractal analysis verification results

The results obtained by fractal analysis were used to verify the landscape complexity of the moving image data and point cloud data. Figure7 shows the results of fractal analysis for both data.

The fractal dimension ranges from 2.319 to 2.500 for the moving image data and from 2.390 to 2.541 for the point cloud data. Both the maximum and minimum values of the two groups were small, however the standard deviations were ±0.049 for the moving image data and ±0.032 for the point cloud data, indicating that the dispersion of the scores was larger for the moving image data. In addition, while the scores of moving images decreased around 26~31 images and 57~81 images, those of point cloud data showed an increasing trend. In the point cloud data, however, there was an increasing trend in the scores. In the 57-81 images, the fractal dimension of both the moving image and the point cloud changed as the number of man-made structures increased.
Next, the correlation coefficients between the fractal dimensions of the moving image data and the point cloud data were obtained, and an uncorrelation test was conducted on both data. The correlation coefficient between the fractal dimensions of both data was -0.258, and the coefficient was confirmed to meet the 1% significance level for the number of items (96). This indicates that there is a relationship between the two data. However, although this number satisfies the significance level, there was a difference between the scores of the two data sets when there is a large area composed of paved surfaces and buildings.
In other words, the laser scanner method may not reproduce the landscape as well when there are many paved surfaces and buildings. As shown in figure 8, the difference in fractal dimension due to the presence or absence of shade trees was correlated with the difference in fractal dimension, confirming that there is little influence on the fractal dimension. Figure 8 shows an example of the difference in fractal dimension between the moving image and the point cloud.

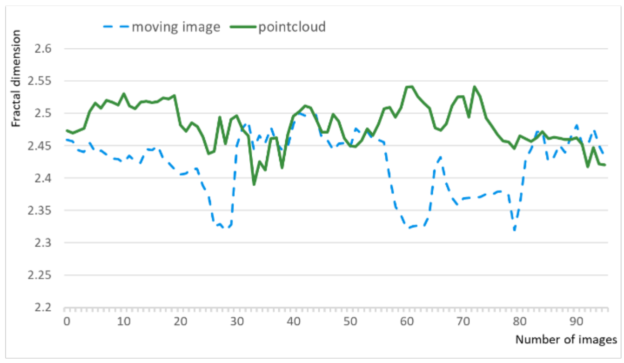

Figure 7. The results of fractal analysis for both data.

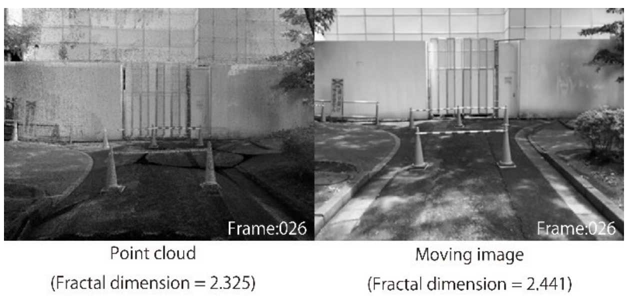

Figure 8. Example of a location where there is a difference in fractal dimension between the video image and the point cloud

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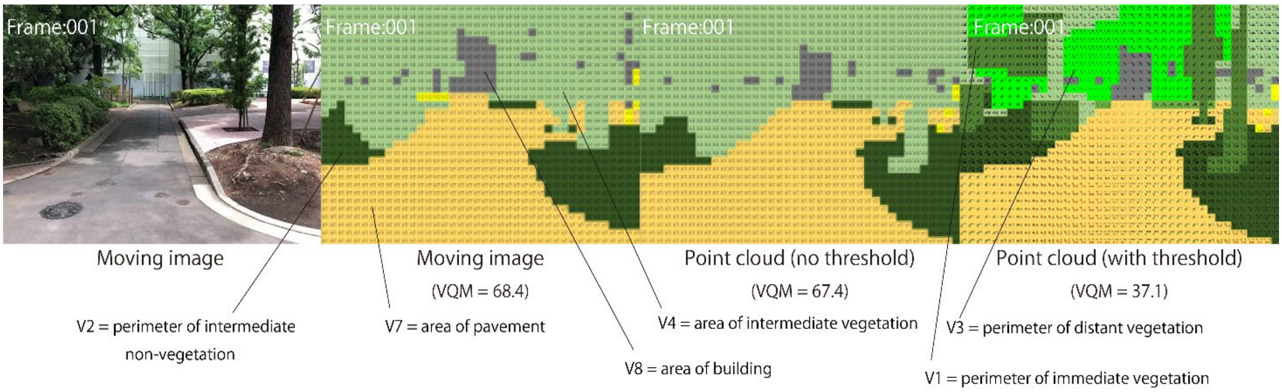

Figure 9. Variation of scores by immediate component.

3.2 Results of VQM verification

The results obtained from the VQM validated the usefulness of point cloud data for landscape evaluation.
While there was no significant difference in the scores between Case A and Case B, Case C showed lower scores for the first 6, 51-55, and 88-93 images. The tendency was that the difference in scores was larger when the near-view component was classified more frequently. This may be due to the fact that variables in the near-view component have a strong relationship with other components and affect the score. Figure 9 shows examples of images of areas where the difference in scores was large. It is confirmed from the image example that the score becomes lower when there are more near view components.
In addition, the highest for the moving image data, and the mean score was the lowest for the point cloud data with thresholding. In other words, it can be considered that the conventional VQM based on visual interpretation calculated higher values than the ideal values in areas with many near-view components, and that the accuracy of landscape evaluation was low.
Next, the correlation between the data was verified. Table 2 shows the statistics for each analysis value by VQM.
Focusing on the correlation matrix showing the correlation coefficient of each data, it was confirmed that the correlations were strong in all cases. The correlations of each data satisfy the 1% significance level for the number of items (96).
This confirms that VQM is a model applied to camera-captured landscape images, however it is also useful for point cloud data.

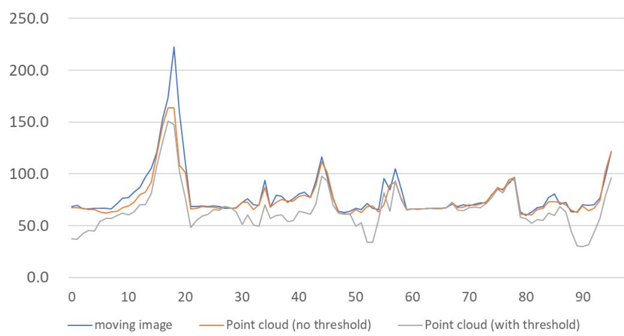

Figure 10. The statistics of the VQM model

	Mooving Images	Point cloud (no threshhold)	Point cloud (with threshhold)
Average	80.0	76.3	65.6
Maximum	222.6	163.7	151.1
Minimum	60.0	60.2	30.0
Standard deviation	24.8	19.5	20.7

Table 2. the statistics for each analysis value by VQM.

	Mooving Images	Point cloud (no threshhold)	Point cloud (with threshhold)
Mooving Images	1		
Point cloud (no threshhold)	0.951**	1	
Point cloud (with threshhold)	0.854**	0.878**	1

** p<01

Table 3. The correlation matrix for the scores by VQM

Figure 9 shows the statistics of the VQM model. Figure 10 shows the statistics of the VQM model. Table 3 shows the correlation matrix for the scores by VQM, and the uncorrelation test was conducted on the three types of data.

3.3 Relationship between environmental components and landscape quantitative analysis

The results of calculating the percentage of each landscape component and then examining the relationship with fractal analysis and VQM are described. Figure 11 shows Changes in landscape components. The first is with respect to the segmentation of the components within the moving image and point cloud, and the angle of view. In comparison with the fractal analysis, an increase in the capacity of buildings and pavement surfaces in the rendered image was observed around 20th-30th images and around 60th-70th images, as shown in the fractal analysis results. In other words, it was found that the fractal dimension of the moving image and the point cloud changed as the portion composed of paved surfaces and buildings increased and as the number of man-made structures increased. At the same time, the differences were larger in areas where the volume of trees, shrubs, and ground cover was small.
In the VQM, the scores varied depending on the number of near-landscape components, however when we focus on utilities, the graph is similar tendency to that obtained in the VQM, indicating that the presence or absence of utilities has a significant effect on the scores. The results show that Although benches and electric lights can be cited as components of utilities, they are not generally considered to have an impact on the landscape, and further study is needed. Figure 12 shows Changes in landscape components in panoramic images.
In panoramic images, there are differences in the proportions of spatial components compared to analyses with narrower angles of view, such as moving images, and values were obtained that could not be obtained in one-way analyses. For example, the

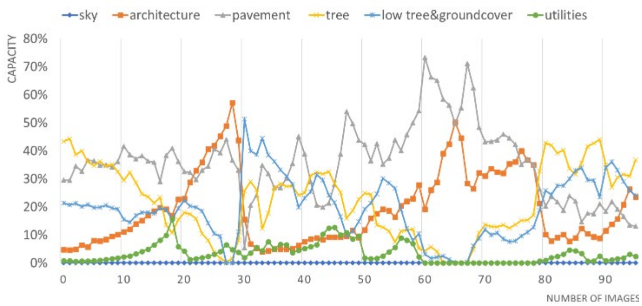

Figure 11. Changes in landscape components

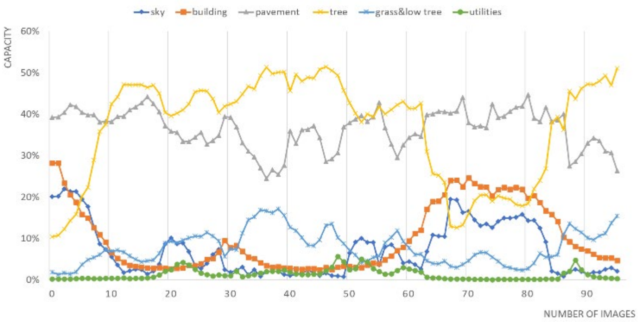

Figure 12. Changes in landscape components (Panorama images)

proportion of trees in a panoramic image increases while the proportion of trees in a normal image decrease. This indicates that the green and shaded space is increasing as the viewer moves around. Although this was not apparent from focal vision, it may be possible to analyze from an ambient vision, which provides the information necessary to grasp the situation of a large environment at a glance, to sense the atmosphere of the place, and to maintain one's own posture within the space. It is necessary to verify the relationship with the user's psychological situation in the future.

4. DISSCUSSION

In this study, using point cloud data acquired by a laser scanner, VQM was used as an index to quantify the overall characteristics of the landscape, in addition to fractal analysis, to quantify the overall characteristics of the landscape. As a result, it was confirmed that the fractal analysis showed a correlation with the existing research methods in understanding the landscape using the point cloud data, however there were differences depending on the degree of occupancy of pavements and buildings. In VQM, it was confirmed that there is a correlation between human subjective and point cloud distance perception, indicating that point cloud data can be used as a fair indicator of distance perception.

Unlike photographs, point cloud data can be used to extract views from arbitrary viewpoints over an arbitrary area. In contrast to previous studies in which the depth distance was determined subjectively by visual observation, the use of point cloud data enables accurate determination of the depth by calculating the distance to the object. In addition, the analysis of the landscape by segmenting the constituent elements in advance at the data processing stage was more efficient than the conventional analysis using photographs, and the usefulness of the landscape analysis from the data acquired by the laser scanner was demonstrated.

On the other hand, it currently takes about 1 hour to classify the components and about 2 hours to analyze the data, therefore if the processing of the data can be automated in this study, it is expected to further improve the efficiency of landscape understanding. In addition, although panoramic images were created and analyzed using point cloud data in this study, they may be useful for further understanding of space and landscape analysis if they are analyzed together with the psychological state of users. In addition, the range of visibility of the panoramic image is considered to be close to the human viewing angle, therefore it is assumed to have high reproducibility for the human senses.Based on the obtained data, it is necessary to verify the results in different landscaping spaces and with different samples in terms of threshold settings.

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