Methods for finding photos of parts of buildings in virtual space

Ishida Kosei[1]

[1]Associate Professor, Department of Architecture, Faculty of Creative Science and Engineering, Waseda University, Doctor of Engineering
k_ishida@waseda.jp

Abstract

We created a support system for inspecting the exterior appearance by loading a three-dimensional photogrammetric model into a virtual space. This system shows a photograph of what the observer sees in virtual space.

To realize this system, we devised a method to represent buildings as voxels, check whether the voxels are reflected from shooting points in virtual space, and register shooting points as voxels. The system allows the viewer to scan the voxel in front of their line of sight in virtual space and then displays a photo of the shooting point registered to the voxel.

We created software that implements this mechanism and confirmed that the necessary photos can be obtained promptly.

Keywords –

Photogrammetry; 3D model; Voxel; Inspection; VR

1 Introduction

The technology for creating three-dimensional (3D) models based on photographs is used in various situations in Japan. Many people use 3D maps, such as Google Maps daily. Three-dimensional models created using photogrammetry are essential for building inspections and patrols. Research is also being conducted on the technology to perform inspections in a virtual space.

Inspection using photographs confirms the disaster situation. Research has been conducted to predict earthquake damage using images and photometry [1]. In addition, to reduce the environmental impact, there are methods for checking the status of heat loss using photographs and thermography [2][3]. We considered the digitalization of buildings by combining UAV, photogrammetry, and BIM [4]. Photogrammetry and deep learning have been used to detect cracks and perform exterior inspections of buildings [5]. Similarly, this method has been applied to the external inspection of bridge piers [6]. Photogrammetry has been used to survey the occupancy status of buildings [7]. Furthermore, some studies have been conducted on visual inspection of tunnels [8] and remote inspection of wind power generators [9]. Photogrammetry has also been used for inspecting dam bodies [10].

However, as the surface texture of 3D models created using photogrammetry is rough, referring to an original photograph is often desirable. Because photogrammetry uses various photographs, it is often difficult to identify a desired photograph. Therefore, we aimed to develop a technology that would allow us to smoothly obtain detailed photographs of parts of 3D models.

2 Methods for finding photos of parts of buildings in virtual space

2.1 Procedure to search for photos that depict parts of buildings in virtual space

We plan to create a system to search for photographs of 3D models of buildings prepared in virtual spaces. Because this 3D model was created using photogrammetry, an original photograph exists. We devised a method to search for photos of a specific part of a building's surface while observing the exterior of the building in a virtual space. A conceptual diagram of this concept is shown in Figure 1.

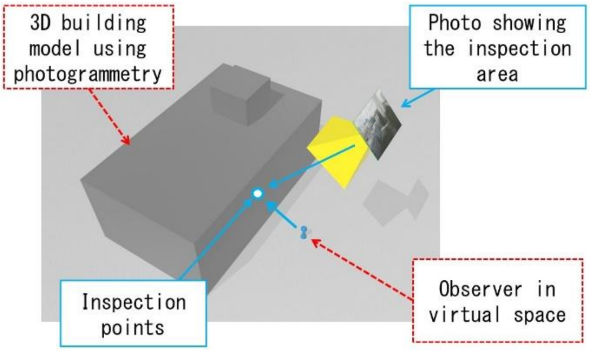


Fig 1 Conceptual diagram for finding a photo of a specific part of a building's surface in virtual space

The following procedure shows how to search for photographs depicting parts of buildings in a virtual space.

(1) Load the 3D model created using photogrammetry and photographic points.
(2) Replace the 3D model with voxels using photogrammetry
(3) Set up a camera at a shooting point in the virtual space and find all voxels within the range of the camera view.
(4) Record all shooting points on the voxel side.

2.2 Registration of shooting points to voxels indicating buildings

As described in Section 2.1, the buildings were made into voxels, and photographic points were registered for these voxels. When observing a structure in a virtual space and looking for a photograph of a part of a building, one can search based on the shooting points registered in the voxels.

Subsequently, we explain how to register shooting points for each voxel of this building.

This voxel registration method is straightforward: it reproduces the camera's shooting point and direction in the virtual space, captures a photo from the camera in the virtual space, and searches for voxels that can be observed from the camera. This approach is currently being implemented.

Figure 2 shows a photograph of the registered camera shooting points on the voxels of the building.

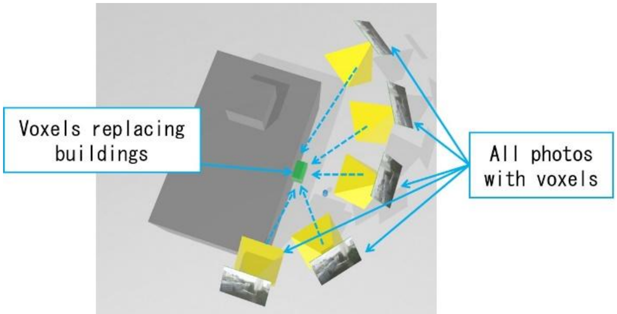


Fig 2 Image of registering camera shooting points to building voxels.

To register shooting points to voxels, the system reproduces the actual angle of view of each camera in the virtual space. We implemented a ray-casting approach where rays are emitted from the camera position with a sampling interval of 50 pixels in both horizontal and vertical directions across the image plane. This process identifies all visible voxels for each photograph and records the relationship in a pre-computed lookup table. By shifting the computational burden to this pre-processing stage, the system ensures high performance during real-time interaction.

2.3 Method for an observer in virtual space to search for photos of parts of a building

We explain how an observer can search for a photo that shows the observation point of a building in a virtual space using a 3D model in which photo points are registered in the voxels of the building.

When an observer in a virtual space observes a part of a building, the ray is irradiated in the direction of the center of their line of sight. Next, a list of photograph shooting points associated with the voxel hit by the ray is obtained. This list of photo points shows the parts of the building being observed so that one can efficiently search for photos used during photogrammetry.

Figure 3 shows how to search for the original photo when observing a building in a virtual space.

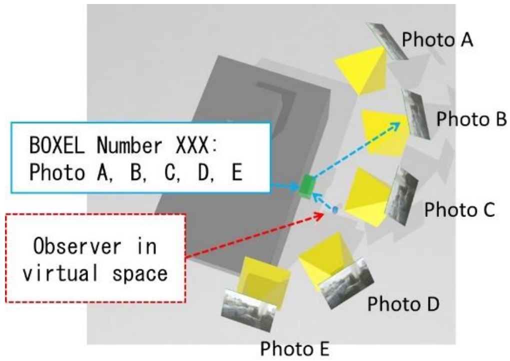


Fig 3 Searching for the original photo when observing a building in a virtual space.

3 Development of the finding system for photos of parts of buildings in virtual space

3.1 Creating a 3D model using photogrammetry

We create a system to search for photos in a virtual space, as described in Section 2. To achieve this, we created a 3D model using photogrammetry. The photograph used is shown in Figure 4. We cut the aerial videos captured using a drone into 960 still photographs.

Figure 5 shows the 3D model created using this photograph. Bentley context-capture photogrammetry software was used.

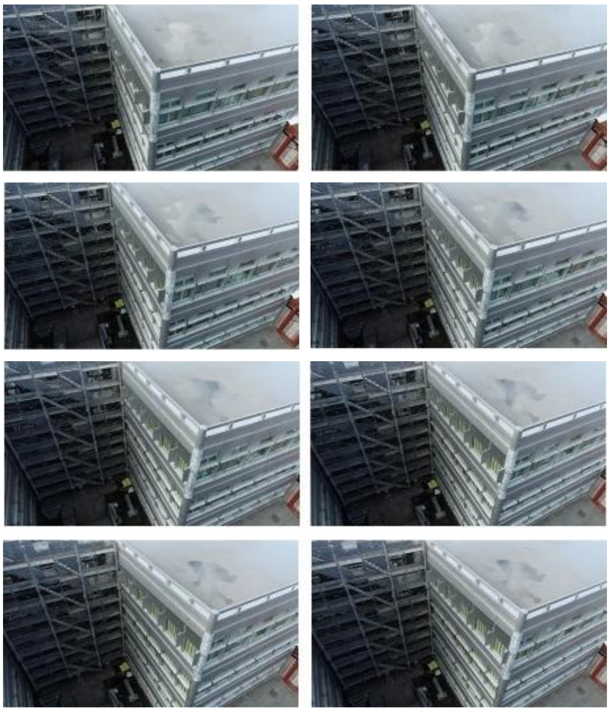


Fig 4 Examples of photos used to create 3D models

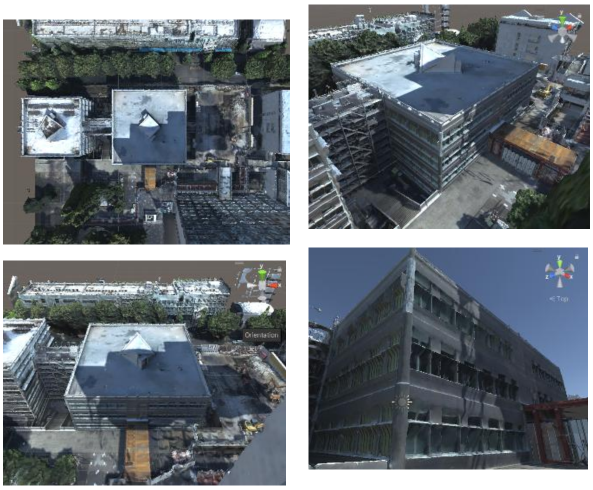


Fig 5 Three-dimensional model created using photogrammetry.

3.2 Replace the 3D model by photogrammetry with voxels

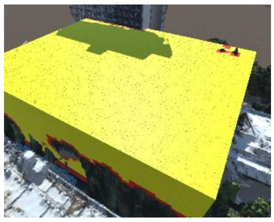
Subsequently, the 3D model created using photogrammetry was replaced with voxels. Using voxels with a side length of 1 m, the shape of the building and its surroundings was reproduced. We created a 3D model using voxels by the following steps:

(1) Place a 1 m-sized cube (voxel) at the location where the 3D model created using photogrammetry exists.

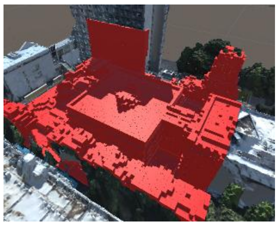
(2) If the 3D model and 1 m size voxel overlap, place the voxel.

Figure 6 illustrates the procedure used to replace the voxels. The system placed 1 m-sized cubes without gaps, as shown in Figure 6b, in a space containing the 3D model shown in Figure 6a. The yellow cubes represent space, and the red cubes represent voxels placed in the 3D model. Figures 6c and d show the results of replacing the 3D model with voxels.

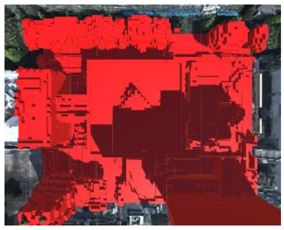
a. Three-dimensional model created using photogrammetry



b. Replacement by voxel



c. Three-dimensional model using voxels



d. Three-dimensional voxel model viewed from directly above

Fig 6 Results of replacing a 3D model of a building created using photogrammetry with voxels

3.3 Set up a camera at a shooting point in virtual space and find all voxels within the range that the camera can see

Next, our system searches for voxels of buildings that are visible from the point where the photo was captured. The procedure is as follows:

(1) Reproduce the photographing point and direction of a photograph in a virtual space

(2) A camera that reproduces the actual angle of view in the virtual space is created and installed at the shooting point.

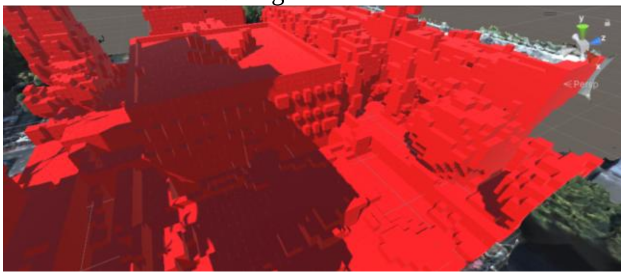
(3) The shooting range is irradiated with rays to clarify the range seen from the camera in the virtual space.

(4) The photo number in the voxel hit by the ray is recorded.

We used the data estimated using photogrammetry software for the camera shooting point and direction.

Figure 7 shows a situation in which the range captured by the camera in the virtual space is confirmed. Figure 7b shows the range observed by the camera in the virtual space. Figure 7c shows a situation in which a ray is irradiated to investigate the range that the camera is viewing.

a. Original 3D model



b. Result after replacing the building with voxels

c. Situation where Ray is emitted from the camera

Fig 7: Range visible from a camera in virtual space is being investigated.

Figure 8 shows a situation in which the camera in the virtual space is moved to other shooting points, and the shooting range is investigated from each shooting point.

3.4 Record all the shooting points that you can see on the voxel

The number of photographs captured for each voxel was recorded by repeatedly searching for voxels within the visible range of the camera. In this section, we present the results of recording the shooting points in the voxels of buildings using the proposed system. Figure 9 shows the number of photographs captured for each voxel. The blue voxels indicate images captured at 50 or more locations. Figure 10 shows the number of photographs recorded for each voxel.

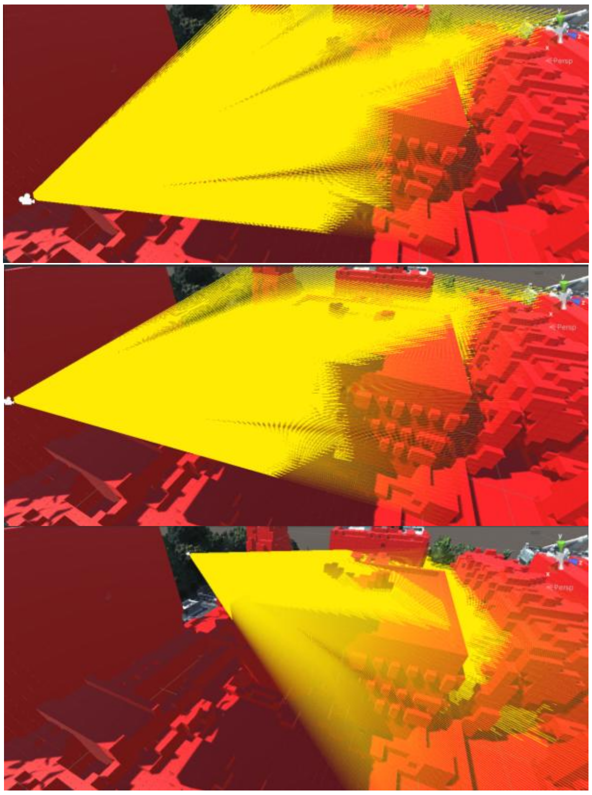


Fig 8 Situation where the shooting range is being investigated from each shooting point

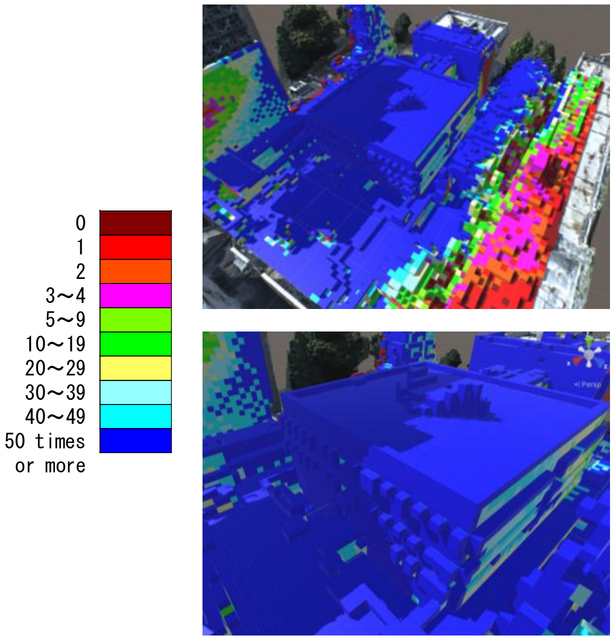
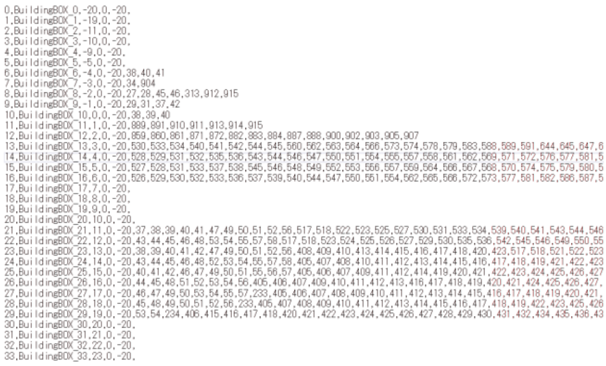


Fig 9 Number of times a voxel appeared in a photo.



0,BuildingBOX_0,-20,0,-20,
1,BuildingBOX_1,-19,0,-20,
2,BuildingBOX_2,-11,0,-20,
3,BuildingBOX_3,-10,0,-20,
4,BuildingBOX_4,-9,0,-20,
5,BuildingBOX_5,-5,0,-20,
6,BuildingBOX_6,-4,0,-20,38,40,41
7,BuildingBOX_7,-3,0,-20,34,904
8,BuildingBOX_8,-2,0,-20,27,28,45,46,313,912,915
9,BuildingBOX_9,-1,0,-20,29,31,37,42
10,BuildingBOX_10,0,0,-20,38,39,40
11,BuildingBOX_11,1,0,-20,889,891,910,911,913,914,915
12,BuildingBOX_12,2,0,-20,859,860,861,871,872,882,883,884,887,888,900,902,903,905,907
13,BuildingBOX_13,3,0,-20,530,533,534,540,541,542,544,545,560,562,563,564,566,573,574,578,579,583,588,589,591,644,645,647,6
14,BuildingBOX_14,4,0,-20,528,529,531,532,535,536,543,544,546,547,550,551,554,555,557,558,561,562,569,571,572,576,577,581,5
15,BuildingBOX_15,5,0,-20,527,528,531,533,537,538,545,546,548,549,552,553,556,557,559,564,566,567,568,570,574,575,579,580,5
16,BuildingBOX_16,6,0,-20,526,529,530,532,533,536,537,539,540,544,547,550,551,554,562,565,566,572,573,577,581,582,586,587,5
17,BuildingBOX_17,7,0,-20,
18,BuildingBOX_18,8,0,-20,
19,BuildingBOX_19,9,0,-20,
20,BuildingBOX_20,10,0,-20,
21,BuildingBOX_21,11,0,-20,37,38,39,40,41,47,49,50,51,52,56,517,518,522,523,525,527,530,531,533,534,539,540,541,543,544,546
22,BuildingBOX_22,12,0,-20,43,44,45,46,48,53,54,55,57,58,517,518,523,524,525,526,527,529,530,535,536,542,545,546,549,550,55
23,BuildingBOX_23,13,0,-20,38,39,40,41,42,47,49,50,51,52,56,408,409,410,413,414,415,416,417,418,420,423,517,518,521,522,523
24,BuildingBOX_24,14,0,-20,43,44,45,46,48,52,53,54,55,57,58,405,407,408,410,411,412,413,414,415,416,417,418,419,421,422,423
25,BuildingBOX_25,15,0,-20,40,41,42,46,47,49,50,51,55,56,57,405,406,407,409,411,412,414,419,420,421,422,423,424,425,426,427
26,BuildingBOX_26,16,0,-20,44,45,48,51,52,53,54,56,405,406,407,409,410,411,412,413,416,417,418,419,420,421,424,425,426,427,
27,BuildingBOX_27,17,0,-20,46,47,49,50,53,54,55,57,233,405,406,407,408,409,410,411,412,413,414,415,416,417,418,419,420,421,
28,BuildingBOX_28,18,0,-20,45,48,49,50,51,52,56,233,405,407,408,409,410,411,412,413,414,415,416,417,418,419,422,423,425,426
29,BuildingBOX_29,19,0,-20,53,54,234,406,415,416,417,418,420,421,422,423,424,425,426,427,428,429,430,431,432,434,435,436,43
30,BuildingBOX_30,20,0,-20,
31,BuildingBOX_31,21,0,-20,
32,BuildingBOX_32,22,0,-20,
33,BuildingBOX_33,23,0,-20,

Fig 10 Results of recording the number of photo shoots for each voxel

The proposed system was implemented as a Unity-based WebGL application. During the inspection in virtual space, when an observer's gaze hits a voxel, the system retrieves the associated photo list near-instantaneously. Since the spatial relationship is already indexed in a pre-built data structure, the retrieval complexity is $O(1)$, allowing for a seamless transition from the 3D model to original high-resolution photographs without any noticeable latency.

4 System for an observer in virtual space to search for photos of parts of a building

4.1 Building a system to search for photos of building surfaces in virtual space

Using the method described in Section 3, we registered the shooting points within the voxels. Next, we created a system that smoothly searched for photos captured at the observation points while observing a 3D model in a virtual space.

First, a 3D model created using photogrammetry was loaded, and then the point at which the photo was captured was reproduced in the virtual space. Finally, the voxels described in Section 3 were placed. This voxel was placed in a transparent state—place voxel as shown in Figs. 11 and 12.

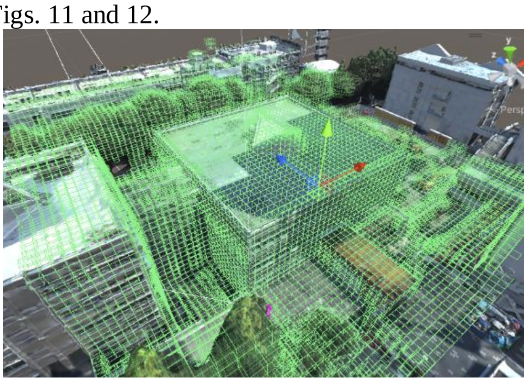


Fig 11 Result of placing transparent voxels

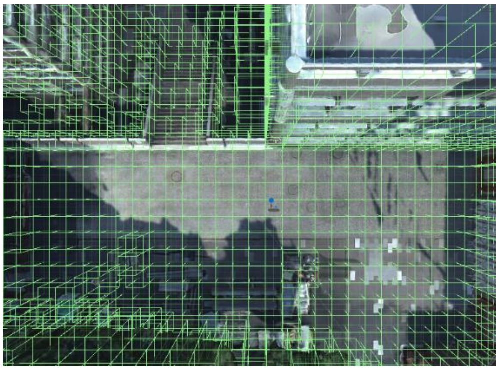


Fig 12 Close-up view of the result of placing transparent voxels

4.2 Search results for all photos depicting observation points

Based on the results obtained thus far, we created a system that shows all the photographs captured at the observation point when a building is observed in a virtual space.

Figure 13 shows the results of running the created system. In Figure 13, the voxel where the observer is looking in the virtual space is displayed, all shooting points registered to this voxel are shown, and a line is drawn between the voxel and the shooting point.

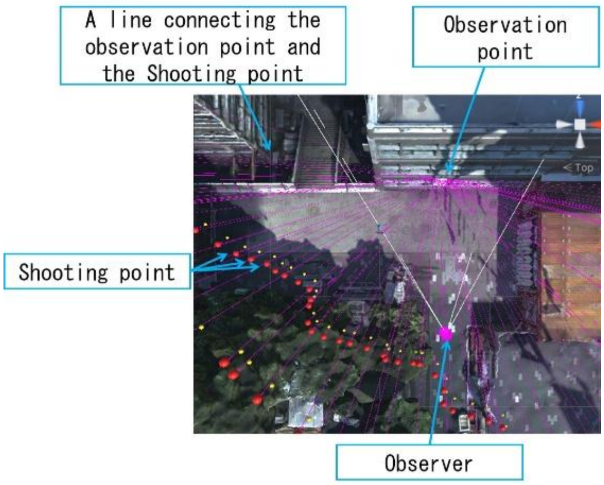


Fig 13 Result of the observation system execution

Figure 14 shows the viewpoint of the observer in the virtual space. In particular, voxels viewed by the observer are shown. The purple line extends to the shooting point that captures the voxel ahead of the line of sight.

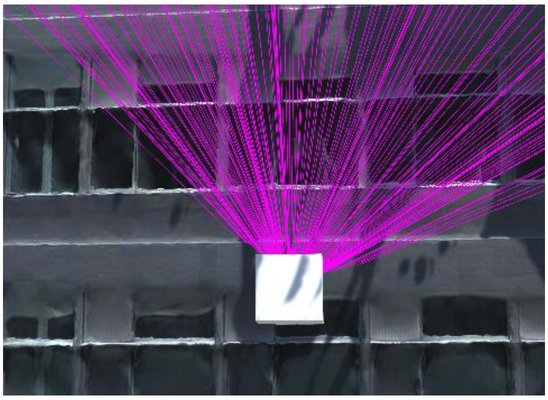


Fig 14 Observer's perspective

Figure 15 shows an example of acquiring voxel numbers on a building surface as observed by an observer. By accepting this voxel number, a list of photographs showing the voxels can be obtained, as shown in Figure 16. A photo number can be obtained by selecting any photo from the photo list. Next, as shown in Figure 17, the directory in which the photo was stored was obtained based on the photo number, and the photograph was displayed. The desired photograph is shown in Figure 18.

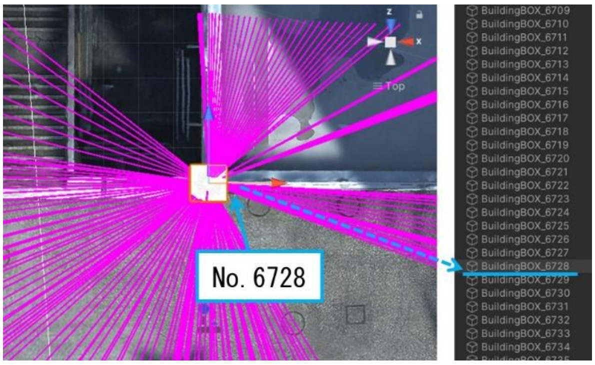


Fig 15 Example of obtaining the number of the voxel ahead of the line of sight

BuildingBOX_6728,
17,52,53,54,55,56,59,71,74,78,81,82,84,86,88,89,92,93,94,95,96,97,99,100,101,102,
103,104,105,142,143,144,145,146,147,148,149,150,153,154,155,156,157,158,159,1
60,161,162,163,164,165,166,167,168,169,170,171,172,173,174,175,176,177,178,17
9,180,181,182,183,184,185,186,187,188,189,190,191,192,193,194,195,196,197,198,
199,200,201,202,203,204,205,206,207,208,227,228,229,230,231,232,233,234,235,2
36,237,238,239,240,241,242,243,244,245,246,247,248,249,250,251,252,253,254,25
5,256,257,258,259,260,261,262,263,264,265,266,267,268,269,270,271,405,406,407,
408,409,410,411,412,413,414,415,416,417,418,421,422,423,424,425,426,427,428,4
29,430,431,432,433,434,435,436,437,438,439,440,441,442,443,444,445,446,447,44
9,450,537,540,543,546,550,551,554,561,562,564,565,566,568,569,571,572,574,575,
578,579,582,584,585,586,589,590,593,594,595,598,599,600,646,648,649,651,652,6
53,657,658,660,661,823,828,829,836,837,838,839,867,868,869,880,881,882,883,88
5,886,887,888,900,901,902,903,909,914,915,932,934,935,937,938,940,942,946,947

Fig 16 List of photo numbers that capture the voxel ahead of your line of sight

Fig 17 Situation to obtain photo storage directory from photo number

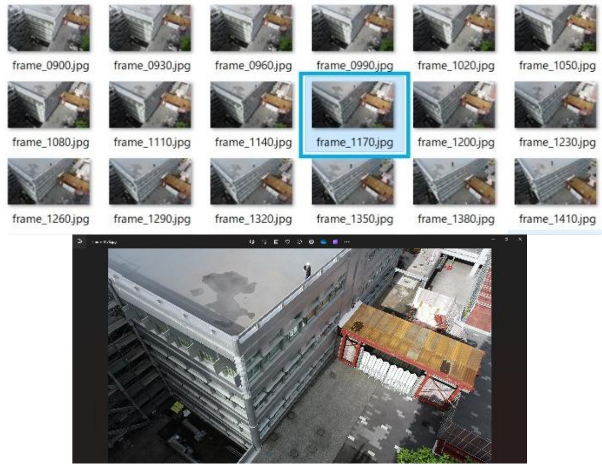


Fig 18 Example of displaying the desired photo

We selected a voxel size of 1 m for the building representation. This resolution is strategically determined based on the practical requirements of building exterior inspections, such as identifying cracks or concrete spalling. A 1 m grid provides a sufficient level of detail to localize defects on a building scale while ensuring that each voxel is covered by an adequate number of overlapping photographs from various drone shooting positions, which is essential for a reliable photogrammetric inspection.

5 Conclusion

We created a system that searches for all photographs captured from observation points when a 3D model created using photogrammetry is observed in the virtual space. Using the developed system, we obtained an original photograph of the location observed in virtual space. This results in more efficient inspections using building models in a virtual space.

References

[1] Ewelina Rupnik, Francesco Nex, Isabella Toschi and Fabio Remondino: Contextual classification

using photometry and elevation data for damage detection after an earthquake event, European Journal of Remote Sensing, 51(1), pp.543–557, 2018.5, https://doi.org/10.1080/22797254.2018.1458584

[2] M. Hasan Shariq and Ben Richard Hughes: Revolutionising building inspection techniques to meet large-scale energy demands: A review of the state-of-the-art, Renewable and Sustainable Energy Reviews, Volume 130, 2020, https://doi.org/10.1016/j.rser.2020.109979

[3] Mariluz Gil-Docampo, Juan Ortiz Sanz, Ignacio Cañas Guerrero and Manés Fernández Cabanas :UAS IR-Thermograms Processing and Photogrammetry of Thermal Images for the Inspection of Building Envelopes, Appl. Sci. 13(6), 3948, 2023, https://doi.org/10.3390/app13063948

[4] Didit Gunawan Prasetyo Jati: UAV-BASED PHOTOGRAMMETRY DATA TRANSFORMATION AS A BUILDING INSPECTION TOOL: APPLICABILITY IN MID-HIGH-RISE BUILDING, Jurnal TEKNIK SIPIL, 16(2), pp.113–121, 2021, https://doi.org/10.24002/jts.v16i2.4777

[5] P. Ko a, S. A. Prieto a, B. García de Soto :ABECIS: an Automated Building Exterior Crack Inspection System using UAVs, Open-Source Deep Learning and Photogrammetry, 38th International Symposium on Automation and Robotics in Construction, pp.637-644, 2021, https://doi.org/10.22260/ISARC2021/0086

[6] Sara Zollini, Maria Alicandro, Donatella Dominici, Raimondo Quaresima and Marco Giallonardo: UAV Photogrammetry for Concrete Bridge Inspection Using Object-Based Image Analysis (OBIA), Remote Sens., 12(19), 3180, 2020, https://doi.org/10.3390/rs12193180

[7] Seung Hyeon Lee, Seung Hak Woo, Jung Rim Ryu, and Seung Yeon Choo: Automated building occupancy authorization using BIM and UAV-based spatial information: photogrammetric reverse engineering, Journal of Asian Architecture and Building Engineering, Volume 18, Issue 2, Pages 151–158, 2019, https://doi.org/10.1080/13467581.2019.1631172

[8] F. Panella, N. Roecklinger, L. Vojnovic, Y. Loo, and J. Boehm: COST-BENEFIT ANALYSIS OF RAIL TUNNEL INSPECTION FOR PHOTOGRAMMETRY AND LASER SCANNING, The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume XLIII-B2-2020, 2020 XXIV ISPRS Congress (2020 edition), https://doi.org/10.5194/isprs-archives-XLIII-B2-2020-1137-2020

[9] Dayi Zhang, Robert Watson, Gordon Dobie, Charles MacLeod, Aamir Khan, Gareth Pierce: Quantifying impacts on remote photogrammetric inspection using unmanned aerial vehicles, Engineering Structures, Volume 209, 15 April 2020, 109940, https://doi.org/10.1016/j.engstruct.2019.109940

[10] Sizeng Zhao, Fei Kang, Junjie Li, Chuanbo Ma:Structural health monitoring and inspection of dams based on UAV photogrammetry with image 3D reconstruction, Automation in Construction, Volume 130, 2021, 103832, https://doi.org/10.1016/j.autcon.2021.103832