A Study on the Application of VR Technique to Building Construction
Comparisons of Site Photo and VR Image in Construction Progress

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Abstract: Photo taking at an actual job site provides a very useful tool for the record of construction progress and the inspection of built-up members. The photos are also utilized as essential data to carry out the control of construction progress in virtual space. Besides, the situation of construction progress at an actual site might well encounter a conflict with the construction plan that was prepared before the beginning of construction. This invokes the importance of use of site photos in VCS(Virtual Reality Construction Site) that enable the real time construction control by comparing themselves to the images from virtual reality.

In this study the comparison between the site photo taken at an actual job site and the virtual images corresponding to them was carried out to estimate validity of the proposed VCS. Particularly this paper demonstrates the possible troubles during development of a prototype system by acquisition of the site photos from an actual job site.

Keywords: *Virtual reality, 3D progress control, Site photo, Construction planning*

1. Introduction

Due to long-termed economical recession and lack of construction labors in Japan, recent construction activities require not only the improvement of its building skills but also the advanced product control using IT technology to enhance the safety in a job site and the quality of product and reduce the period of construction. To perform the product control properly, useful information such as site photos that provide a valuable means for investigation of ongoing process and quality control in a job site should be well collected and analyzed. This study aims to develop a product control system that is able to compare the VR(Virtual Reality) image simulated in VR space with the site photo taken from a actual job site using Virtual Reality Construction Site (hereinafter VCS), which allows for the time marching control of construction process in VR space prior to actual works in a job site. This paper addresses the comparison between the site photo taken at an actual job site and the virtual images corresponding to them was carried out to estimate validity of the proposed VCS.

2. Comparison of VR Images and Site Photos

2.1 Comparison of two images carrying identical 3-D Coordinate

The site photos taken at various locations at an actual job site are compared with the VR images created with the identical viewpoint and direction vector to the corresponding site photos in virtual space, thereby providing a measure of the control of construction progress and the inspection of built-up members.

Figure 2.1 illustrates an example of VR image

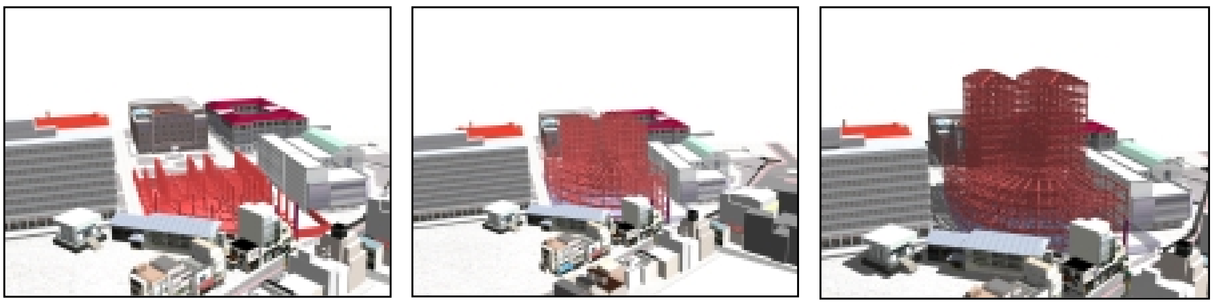


Figure 1.1. construction progress simulation in VCS

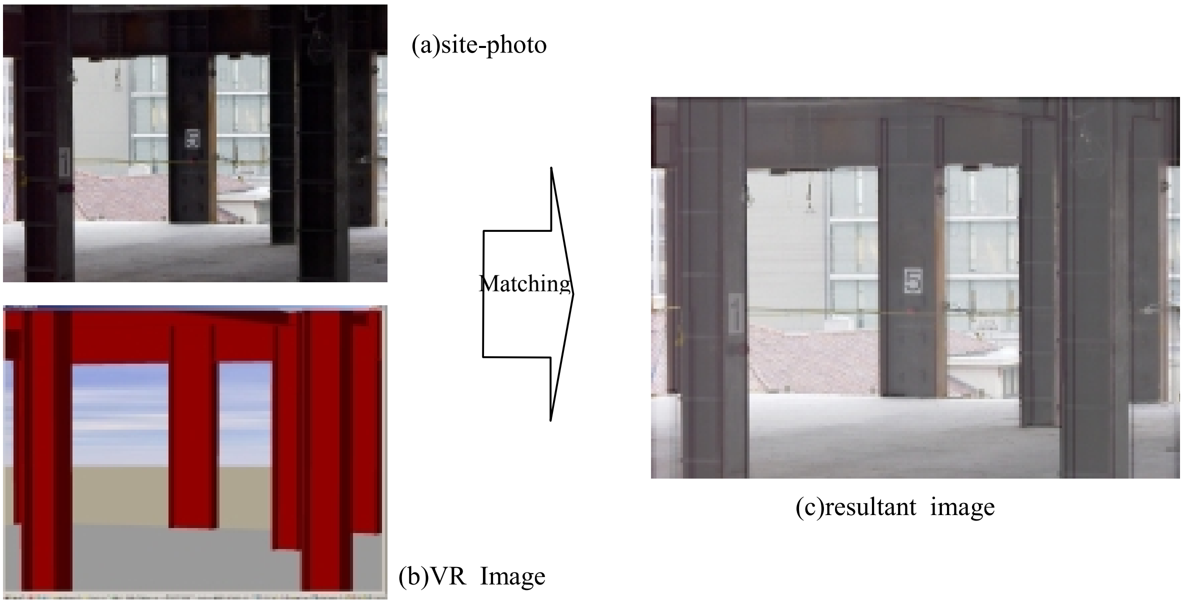


Figure 2.1. Comparison between the real picture and the corresponding virtual image from VCS

matching by the site photo that was taken with the identical viewpoint and direction vector. Besides, Figure 2.1 (c) exhibits a matching of outline from VR image and site photo.

2.2 Data Acquisition from Job Site

2.2.1 Acquisition of Site Photos

Photo taking at an actual job site provides a very useful tool for the record of construction progress and the inspection of built-up members. Besides, the situation of construction progress at an actual site might well encounter a conflict with the construction plan that was readily prepared before the beginning of construction. This invokes the importance of use of site photos for an actual job site that enable the real time construction control by comparing themselves to the images from virtual reality. The site photos for various activities in a job site are taken every day with an accurate coordinates for them which can be suggested by surveying machine. The acquisition of exact coordinate is strongly necessary to correctly match the photos with the images from VCS. Based on the coordinate, the site photos projecting from viewpoint to targeting point can be acquired.

2.2.2 Optical Devices for Acquisition of Site Photos

While taking the site photos at an actual job site, it is strongly required to survey the exact coordinates of selected target for photo taking to make the photos correctly coincide with the images from virtual reality. Non-prism level is used to measure the corresponding coordinates of targets precisely. Figure 2.2 illustrates a non-prism total station equipped with a camera that is able to provide the exact coordinate. The Total Station and camera are both designed to be manipulated by personal computer using remote sensors.

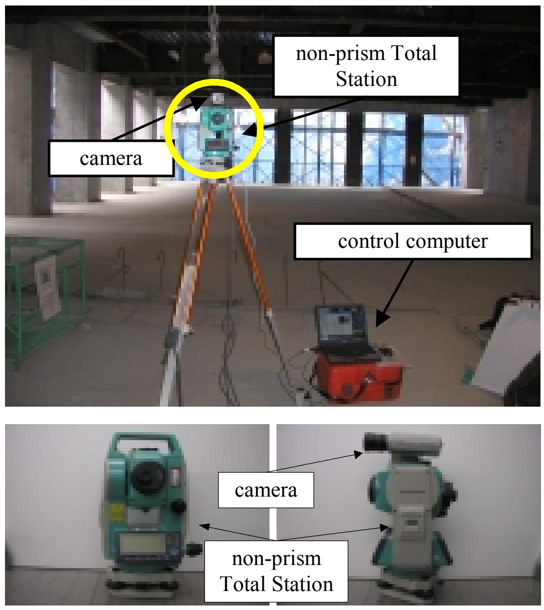
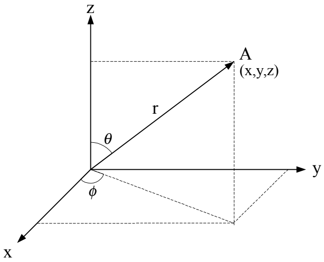


Figure 2.2. camera mounted on Non-prism Total Station

2.3 Correction of Target in Site Photo

While the total station aims a targeting point, the 3 dimensional coordinate of the point can be obtained based upon the angles with respect to the vertical and horizontal axes and the distance between the origin and the point in the rectangular coordinate as shown in Figure 2.3. The following equations can be used to calculate the exact coordinate of the point in the rectangular coordinate.

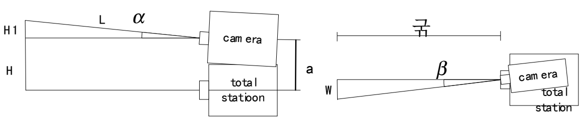


r : distance
θ : Angle with respect to vertical axis
ϕ : Angle with respect to horizontal axis

Figure 2.3.Cartesian coordinate

$$x = r\sin\theta\cos\phi$$
$$y = r\sin\theta\sin\phi$$
$$z = r\cos\theta \qquad (1)$$

To match the targeting point in the total station with that in the site photo, the coordinate of point aimed by the total station should be adjusted to exactly coincide with the coordinate at the center of site photo at camera. However, the current arrangement of camera and total station is not able to make a good agreement regarding the targeting direction, since the camera that is mounted on the top of the total station gives the photo with a deviation of coordinate up to 115 mm from that of the surveying machine in Z-axis as shown in Figure 2.4 a. Moreover, this kind of deviation is impossible to be cleared mechanically when the camera is mounted on the top of the surveying machine. Therefore, it is required that those deviations must be correctly measured when the site photos are taken at a job site. And the measured deviations should be corrected to obtain the exact 3-dimensional coordinate of site photo. The deviations can be expressed as α regarding vertical angle and β regarding horizontal angle.



(a)Deviation in vertical angle (b)Deviation in horizontal angle

α : Deviation in vertical angle,
β : Deviation in horizontal angle
a : Deviation due to the mounting location in the vertical axis

Figure 2.4.Deviation in a site photo

By adding the vertical and horizontal deviation to Eqn. (1), Eqn (1) can be rewritten as follows;

$$x' = r\sin(\theta - \alpha)\cos(\phi - \beta)$$
$$y' = r\sin(\theta - \alpha)\sin(\phi - \beta)$$
$$z' = r\cos(\theta - \alpha) + a \qquad (2)$$

3 Searching of Site Photos

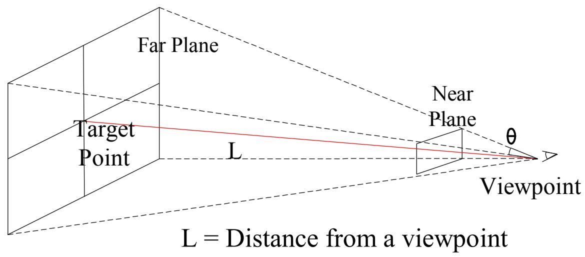
3.1 Necessity of Searching

Using the site photo holding the identical targeting and view point to the corresponding image in VCS facilitates estimation for the situation of site. For the sake of obtaining rather accurate information on the progress of the site, the site photos with a different viewpoint or in the vicinity of the site might be of use. This leads a supervisor to gain the site information more sufficiently. Furthermore, if the site photo with identical targeting point, view point and direction vector to a VR image is not available, these photos can be utilized as an alternative with an appropriate searching to grasp the current situation at the job site

3.2 Scope of Searching in 3-D Space

The view frustum indicates a space domain including all the observable objects in 3-dimensional space. It is like a pyramid of which vertex coincides with the location of camera. The projecting plane forms as a vertical plane with respect to the projecting direction of camera at a distance of L from the camera.

The assignment of a site as an object of monitoring using VCS enable the acquisition of 3-dimensional information on the coordinate and view point of the site. Similarly the 3-dimensional coordinate of a site photo can be also obtained. And each site photo is required to be searched in such a way that the 3-dimensional coordinate of the site assigned as a monitoring object in VCS is allowed to locate inside the 3-dimensional space of the site photo. In other words, the site photos should be searched to hold the target in VCS in the projecting plane.



L = Distance from a viewpoint to targeting point
θ = horizontal angle

Figure 3.1.A view frustum of site photo

3.3 Methodology for Searching

Searching the appropriate site photos for investigation of the site situation out of great number of site photos can provide rather effective use of site photos. The method for searching can be categorized as three according to its purpose. The importance of validity is given to the searched site photos. The feature and purpose of each method are described as follow;

1) Close approach of targeting point in site photo to that in VCS;
provides rather accurate evidence for estimating

the surrounding situations by investigation into them near the targeting point of monitoring object assigned from VCS

2)Close approach of viewpoint in site photo to targeting point in VCS;
provides rather careful examination of targeting point as the distance from the viewpoint to it gets smaller even against the same object

3) Close approach of direction vector of viewpoint in site photo to that in VCS;
enables capture of the targeting point of monitoring object in more realistic sense by utilizing the site photos taken in various directions

4. Validity of Searching

4.1 Valid Range for Searching of Site Photos

It is required to identify the inside coordinate of view frustum to make use of 3-dimensional information from 2-dimensional photo data, which enable employment of multiple information from a photo data. For the sake of it, the distance from the viewpoint to the 3-dimensional coordinate of targeting point, L, and the angle of horizontal view of camera lens, θ, in Figure 3.1 can be utilized. The projection matrix is introduced to figure out the existence of homogeneous coordinate P (P_x, P_y, P_z, 1) [4)] within the inside of 3-dimensional space of site photo.

Figure 4.1 shows the distance from viewpoint of camera to targeting point, L, which essentially varies depending upon the type of lens in a camera. In this study, the distance, L, was set up as two times as long as the distance from targeting point.

4.2 Range According to Searching Method

4.2.1 Close approach of targeting point in site photo to that in VCS;

Where the targeting point in site photo approaches to that in VCS, the unit of range is L1, which means the distance from targeting point in site photo to that in VCS. And the validity becomes higher as it reaches to 0. The distance, L1, can be calculated using Eqn. (3). and both the coordinates (Xe,Ye,Ze) of targeting point in VCS and that (Xc,Yc,Zc) in site photo as shown in Figure 4.1.

$$L1 = |\vec{a}| = \sqrt{(Xe\text{-}Xc)^2 + (Ye\text{-}Yc)^2 + (Ze\text{-}Zc)^2} \qquad (3)$$

4.2.2 Close approach of viewpoint in site photo to targeting point in VCS

The perspective of a photo may differ depending upon the location of photo taking, in other words “viewpoint,” even it is taken against an identical targeting point. The site photo taken at near targeting point is searched based on the perspective regarding targeting point in VCS. In this case, the unit of range becomes L2, which means the distance from viewpoint in site photo to targeting point in VCS. Besides, D2 indicates range of validity. And the validity becomes higher as L2 reaches to 0. The distance, L2, can be calculated by substituting both the coordinates (Xp,Yp,Zp) of viewpoint in site photo and the coordinate (Xe,Ye,Ze) of targeting point in VCS for Eqn. (4).

$$L2 = |\vec{b}| = \sqrt{(Xe\text{-}Xp)^2 + (Ye\text{-}Yp)^2 + (Ze\text{-}Zp)^2} \qquad (4)$$

4.2.3 Close approach of direction vector of viewpoint in site photo to that in VCS

This kind of searching imposes investigation into the existence of coincidence between the directions of viewpoint in VCS and site photo. The smaller deviation between these two direction vectors indicates that they turn toward almost same direction. The unit of range becomes angle, A1, which usually falls within 90degree because the viewpoint is to turn toward the opposite direction when it overpass 90degree, Since A1 is the angle of reverse view, the smaller value of this can make the validity higher. The vector of reverse view can be calculated from targeting points in VCS and site photo using Eqn. (5), which yields the deviation of vectors carrying two different viewpoints in terms of angle.

$$A1 = c \cdot d = |\vec{c}|\,|\vec{d}|\,\cos\theta \qquad (5)$$

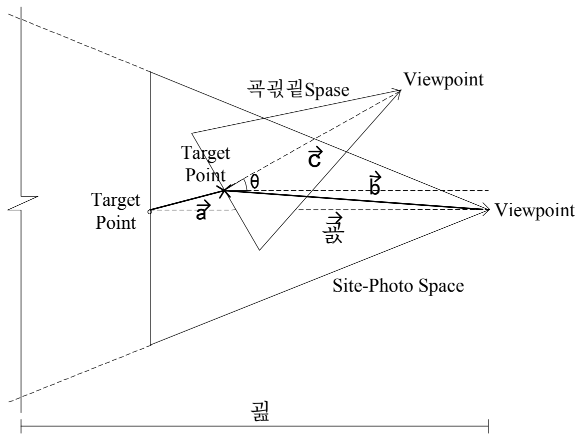


Figure 4.1. 3DS of the VCS and the site-photo which were seen from the top

4.3 Weighted Validity with respect to Searching

In order to perform more efficient searching out of a number of site photos, weight value could be given. Provided that the 3-dimensional coordinate of site selected as a monitoring object in VCS falls within the 3-dimensional space of site photo, namely the subject in a site photo well matches with the monitoring object in VCS, the distance L1, L2 and the angle, A1 calculated for the site photo provide the validity by which weight value is specified. The weight value ranges between 0~1 for each searching method, so that the maximum weight value for a site photo results in up to 3. Figure 4.1 summarizes the weight values according to each searching method.

Table 4.1. Weight value according to searching method

The searching method	Weight
Distance L1 by the searching method 1	W_1=1-L1/3400mm
	W_1=0 -> L1>3400mm
Distance L2 by the searching method 2	W_2=1-L2/15000mm
	W_2=0 -> L2>15000mm
Angle A1 by the searching method 3	W_3=1-A1/90°
	W_3=0 -> A1>90°
W_0	$W_0=W_1+W_2+W_3$

4.3 Searching Flow

The 3-dimensional coordinate of site selected as a monitoring object is specified in VCS. The viewpoint on the screen of VCS is also defined in terms of 3-dimensional coordinates. Then the appropriate site photos corresponding to selected site in VCS can be searched using those two coordinates. Figure 4.2 illustrates the flow proposed to search the appropriate site photos in this study.

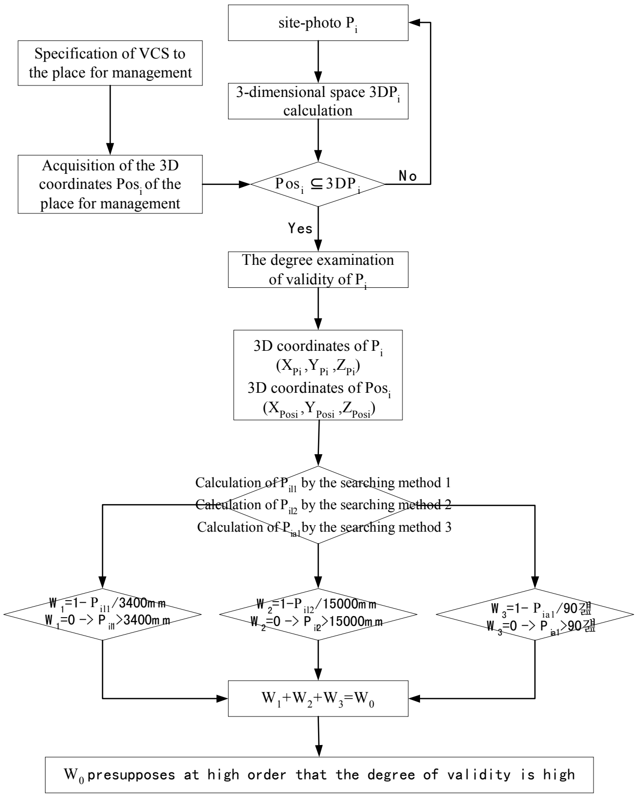


Figure 4.2. searching flow

5. Case Studies

5.1 Adopted Model

Sufficient number of site photos has been taken at 7th floor of new building currently under construction in Nishi Campus of WASEDA University for which 3D modeling of construction process has been established in virtual reality as far as precision is allowed. Comparison between the site photos and the images from virtual space has been also carried out in this study. The precision of modeling has been improved using 3D CAD Micro Station.

5.2 Target for Searching

The site photos were obtained by photo taking at 7th floor of the building under newly construction in Waseda University. At the same time the position of camera and the direction vector for each photo were stored as a set of data in 3-dimensional coordinates. In addition the date and time at the moment of photo taking were also added to the data automatically. Figure 5.1 shows the monitoring objects in this paper that locate within red line in the figure, namely column X8 and YH. And their targeting points has a

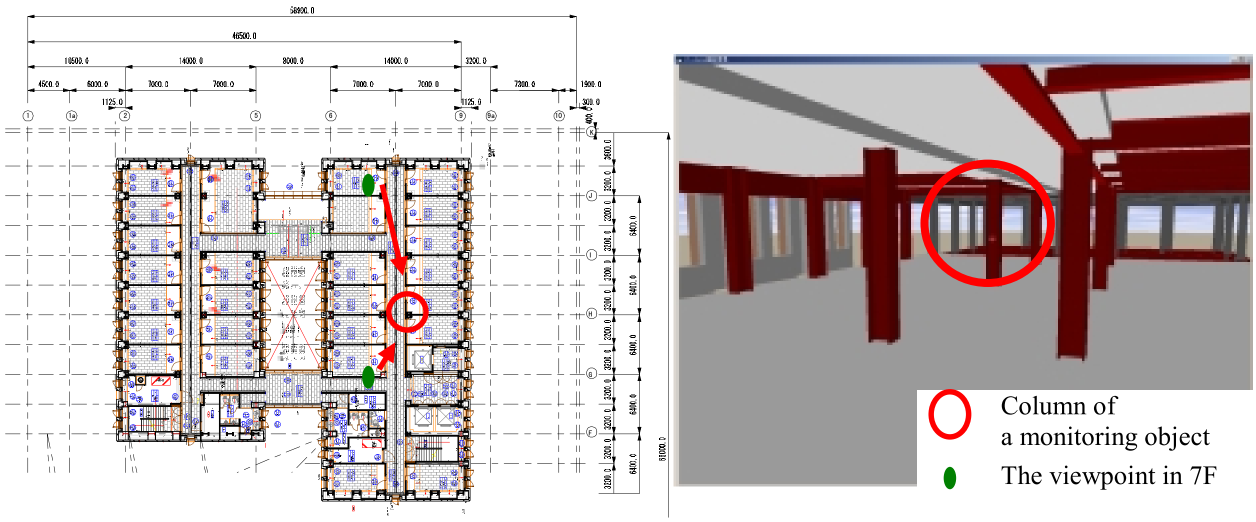


Figure 5.1. Plane view of 7th floor and, VR image for column as a monitoring object

coordinate of x,y,z(40945, 48411, 27546) as summarized in Table 5.1. Figure 5.1 exhibits the 3D VR images of this column corresponding to monitoring object that is acquired from VCS.

Table5.1. 3-D coordinates for monitoring object

monitoring object	7F、Column :X8YH		
	Target Point	Viewpoint	Direction Vector
x	40945	37439	0.31137
y	48411	61384	-0.94198
z	27546	28188	-0.12534

5.3 Results of Searching

4 site photos have been finally searched out from whole 91 site photos. Figure 5.2 shows the coordinates of targeting point, viewpoint and direction vector and resultant weight value for each selected photo simultaneously. Using three kinds of searching methods proposed in this study, the distance, L1, L2 and the angle, A1 corresponding to the site exhibited in Figure 5.2 (a) were calculated as follows; 443mm, 12348mm and 1.5degree respectively. These values yielded the following weight values according to the searching method; for searching method 1, 0.9259, for searching method 2, 0.1784, for searching method 3, 0.9549. The resultant weight value thus came with 2.0617, which is the largest among the values for 4 selected site photos as shown in Figure 5.2. As mentioned above, the most appropriate site photo corresponding to a monitoring object in VCS could be determined automatically in this study. On the other hand, the red circle in Figure 5.2 indicates the column that mainly treated as a monitoring object in this study.

Table 5.2. Final Result of Searching

weight \ photo		(a)	(b)	(c)	(d)
W_1		0.9259	0.7023	0	0
W_2		0.1784	0.1784	0.1784	0.1784
W_3		0.9574	0.9462	0.916	0.9138
W_0		2.0617	1.8269	1.0944	1.0922
Target Point	x	40858	40964	40869	40801
	y	48387	48404	41987	42005
	z	27781	26534	27678	26463
View point	x	34226	34226	34226	34226
	y	38655	38655	38655	38655
	z	27959	27959	27959	27959
D-Vector	x	0.39711	0.39427	0.42551	0.35802
	y	0.59538	0.57902	0.52170	0.61973
	z	-0.00751	0.02670	-0.05280	0.02225

6. Conclusion

This paper presents the method of construction planning system using a virtual reality technique which enables the real time construction planning by collecting the information about the actual progress of the job site in the format of photo files and comparing them with the virtual images from VCS. It is successfully proved in this research that comparison between site photos and VR images is valid for the assessment of construction progress in a job site.

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(a) (b) (c) (d)

Figure 5.2. Final Result of Searching