



A defect management system for reinforced concrete work utilizing BIM, image-matching and augmented reality



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ARTICLE INFO

Article history:

Received 27 September 2013

Received in revised form 4 May 2014

Accepted 7 May 2014

Available online 22 May 2014

Keywords:

Construction defect management

Image-matching

Augmented reality

Mobile application

BIM

ABSTRACT

The repeated and inevitable occurrence of defects remains one of the primary causes of project schedule and cost overruns in construction. Currently, quality management on site is done by site managers through their visual senses. However, it is often challenging for a handful of site managers to perform quality management efficiently for an entire site based on inspected progress of construction works. As a consequence, inspections are often omitted, resulting in faulty construction and quality degradation which may necessitate rework. This may adversely affect project costs and schedule. This paper addresses these issues by utilizing BIM, image-matching, and augmented reality (AR) to develop two types of defect management systems including: 1) an image-matching system to enable quality inspection without visiting the real work site; and 2) a mobile DM-AR app which enables workers and managers to automatically detect dimension errors and omissions on the jobsite. The two systems are tested and evaluated by lab and site experiments for reinforcement concrete (RC) work to assess the benefits and limitations. Experimental results demonstrate the defect management system's effectiveness in automatic omission and error detection at real job sites. The study emphasizes the potential applicability of BIM, image-matching, and AR technologies that could be utilized to improve construction defect management.

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1. Introduction

Recently on construction sites, there are many efforts to improve the efficiency of numerous field tasks through modularization of construction materials, simplification of work processes and so on. More specifically, a number of studies are in progress for improvement of efficiency in terms of quality control work to minimize defects [2]. Higher building quality requirements from owners imply that more quality management will be required on site. However, the number of site managers is limited on existing construction sites, so there are challenges in performing process management to monitor project progress, labor management for worker control and effective quality management [8, 9]. Consequently, inspection which is one of the most important factors in quality management, is sometimes omitted. Such inspection omissions may cause construction errors and quality degradation, which negatively affect both the costs and the schedule aspects of entire construction projects. This may result in disputes between owners and construction companies regarding quality issues after construction is completed [16].

In order to solve these problems, several studies have been carried considering the development of defect management systems that would utilize state-of-the-art technology [6], such as BIM [18], AR

[17], RFID [7], PDA [11] and Laser Scanner [27]. These studies suggested ways to reduce the workload of site managers on construction sites. However, in the case of Korea, defects on RC works remain a significant issue which needs to be addressed. Therefore, the development of a defect management system utilizing digital technology will be necessary for RC work defect prevention in South Korea.

On construction sites, site managers carry out inspection work by recording information about defects on documents, such as shop drawing and checklist, while walking around the site. This information has to be re-entered at the site office, into companies' web systems such as PMIS (Project Management Information System) [11]. During these processes, site managers and inspectors may make mistakes and omit some content. This work process is inefficient and time consuming. It can be improved by recording defect information utilizing mobile-devices and by storing the information in the companies' defect database automatically [18].

This study aims to provide effective quality management, to reduce the workload of site managers, and to develop a defect management process, which can prevent defects that occur repeatedly on construction sites. In doing so, the following steps were carried out: 1) The present status of defect management in RC works was identified through interviews conducted on three construction sites that were operated by large construction companies in South Korea; 2) Existing problems were identified, and then a plan to improve the RC work defect management process was made; 3) A computing-based image-matching

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system and a mobile-based AR defect management application (DM-AR app) were developed; and 4) To review the applicability of the proposed systems on construction sites, a lab-experiment applying computing-based AR technology and an experiment utilizing the DM-AR app was carried out on a construction site with RC work in progress.

2. Defect management practices for RC work

2.1. Current status of defect management practices for RC Work in South Korea

Construction industry is a complicated environment where construction tasks often overlap causing serious schedule delays and cost overruns [12,14]. In South Korea, RC work makes up approximately 23% of the total construction cost, a very high proportion of the total cost. In addition, its construction period takes approximately 57% of the entire construction duration. Hence, delays in RC work would create a phenomenon of jammed processes for subsequent work. Additionally, defects in RC work often occur repeatedly, causing additional costs to be incurred [10]. Therefore, RC work defects should be prevented so that temporal and financial benefits could be gained.

In order to understand the current defect management process for RC work, three construction sites were analyzed. Construction sites were visited and site managers, inspectors and sub-contractors' managers were interviewed. Site managers were asked to describe the current defect management processes for RC work on site. It was mentioned that this work typically begins with the preparation of building materials such as cement and reinforced steel bars. Workers place reinforced steel bars and then, install formwork, pour concrete, allow concrete to cure, and finally they remove the formwork. The current defect management process requires inspectors and site managers to inspect these tasks. If construction errors are found, workers would be instructed to carry out rework as illustrated in Fig. 1 [1].

On site 'A', the site manager had access to a defect information database for all construction trades. However, the sub-contractors could not access this database. Similar situations existed on both sites 'B' and 'C'. Furthermore, all three companies collected practical defect cases and listed them on their web systems. However, they did not possess any web system for defect management. It was observed that all three companies established their defect management databases only as mere formalities. Furthermore, according to site inspectors and sub-contractors' managers, the defect management databases for RC work were formally established on the Web, and when any defect occurred, it would be registered via the web system. However, they responded that such an

inefficient work process would just be formal, defects management would be processed based on project participants' practical experiences. Based on these responses, the RC work defect data was not captured and reused effectively for proactive defect prevention. Nowadays advanced technologies such as BIM and AR can enable the storage and retrieval of defect data visually [18]. These technologies offer great opportunities to enhance construction defect management for RC work. The following section will introduce of BIM, image-matching and AR technologies and review their potentials for defect management.

2.2. Potential of BIM, image-matching and AR for construction defect management

Among the recent advanced information and communication technologies, BIM, image-matching and AR that can append virtual information to the real world have been utilized as useful techniques for field work inspection. Image-matching has been employed as a technique for tracking and rapid object identification on the construction jobsite [4]. AR is a technology that combines virtual objects with the real world in real time. Numerous studies have utilized AR for design and construction [21,23–25]. A detailed review of the potentials of AR in Architecture Engineering and Construction can be found in [20].

In this study, marker-based AR and image-matching techniques are applied for defect management in the construction site. A BIM model is utilized for the creation of AR markers and virtual 2D images. Various BIM model information of a work element such as 3D drawing, materials and schedule are transformed to a marker which augments the information onto a real element on site. Also, virtual 2D image is extracted from 3D BIM models by using the camera function of BIM software to match with a real photo. Using these image-matching and AR techniques, managers and workers could automatically confirm the results of their tasks by augmenting virtual shapes and dimensions onto the real objects or actual photos. These marker-based AR and image-matching techniques would improve current manual inspection practices and be an innovative tool to control the work procedure proactively.

3. Image-matching system and DM AR app for defect management

3.1. Process of defect management using image-matching system for RC work

First, it is necessary to check the possibility of using image-matching system on construction sites. By comparing the image taken by BIM

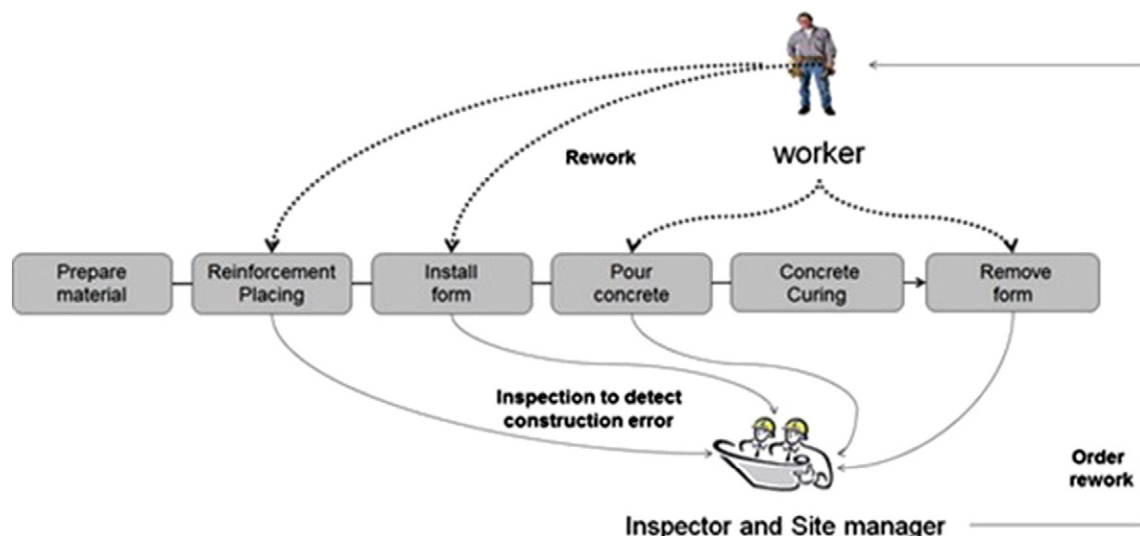


Fig. 1. Defect management process for RC work.

software with the image taken at the assigned location on site, the image-matching system can confirm dimensions and check for omissions using image processing. The scenario of image-matching system (Fig. 2) would be described as follows:

- 1) A defect manager can create 2D virtual images from BIM models with the use of the screen shot function, in order to discover the RC work defect;
- 2) The defect manager saves the 2D virtual images into a folder in the image-matching system on the main server;
- 3) Next, the defect manager needs to see pictures of the assigned location on the real site. For this, the defect manager requires workers to take pictures, thus he/she sends workers detailed information on: (a) The shooting location; (b) The camera's position from the bottom; (c) The angle to shoot; and (4) The distance of the camera from the wall to be shot;
- 4) Worker or sub-contractors' manager finishes their work at assigned locations, and then, they take pictures of the completed work, which are to be used for image-matching system;
- 5) The pictures showing the completed work are then to be sent using a mobile devices' messaging function. They are then transferred and saved in a folder in the image-matching system;
- 6) The image-matching system then compares the 2D virtual image, which was saved by defect manager, with the photos of actual works, which were sent by construction site worker or sub-contractors' manager. Then, it checks for dimension errors and omission which could cause defects, and it automatically sends the results to a site manager or inspector;
- 7) The site manager or inspector confirms the reported result, and makes a decision on whether to proceed with work or to carry out

rework on the previous area. If it is decided that rework will be conducted, after rework the defect management process will be carried out again, as described in the steps above.

3.2. Process of defect management using DM-AR app for RC work

AR combines virtual objects and real world images in real time and inputs them through a camera to provide users with a new type of computing environment [3]. This can provide users an environment for computing visualization in an entirely new way in construction project [13,17,22,26]. The potential users at construction site, including site managers, workers, and sub-contractors' site managers, can use mobile devices like tablet PC to effectively manage defects with use of AR. Mobile-devices AR enables users to compare actual work areas to BIM models. Through this, workers can check the result of the work in advance, and they can prevent omissions and errors proactively. Furthermore, site managers or sub-contractors' managers can easily check for omissions in RC work, when they inspect the given work. The scenario of utilizing DM-AR app (Fig. 3) would be described as follows:

- 1) Using the BIM model, the defect manager checks the information required for RC work defect management, such as building geometry, materials and project schedule. Then, the defect manager converts the information that can be recognized in mobile device and saves it;
- 2) The defect manager transfers the BIM geometry information to an ARToolKit. The information is then registered to AR markers. Each marker is categorized based on its' work location;
- 3) During meetings, site managers can inform sub-contractors' managers and workers about the markers and their respective attachment locations;

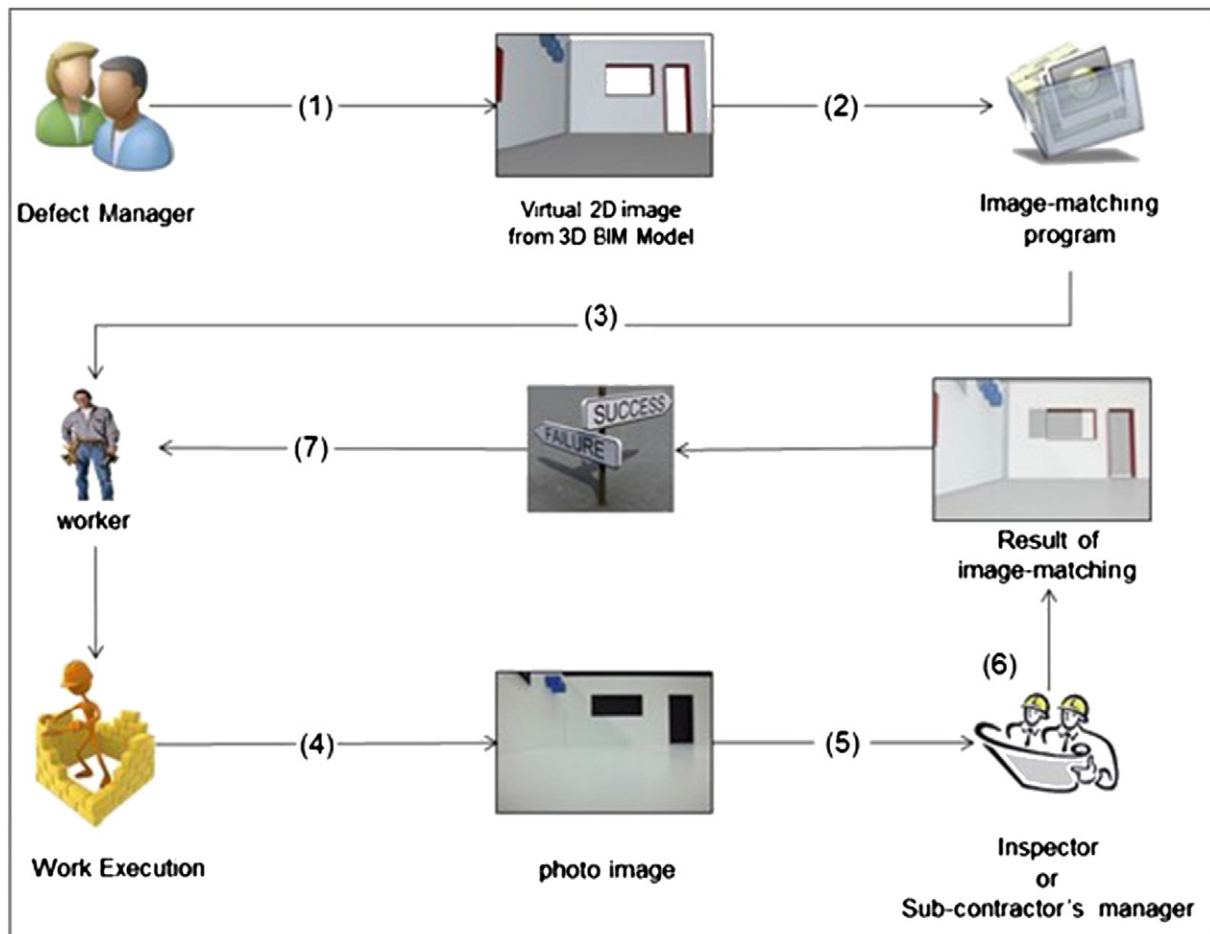


Fig. 2. Scenario of image-matching system for defect management.

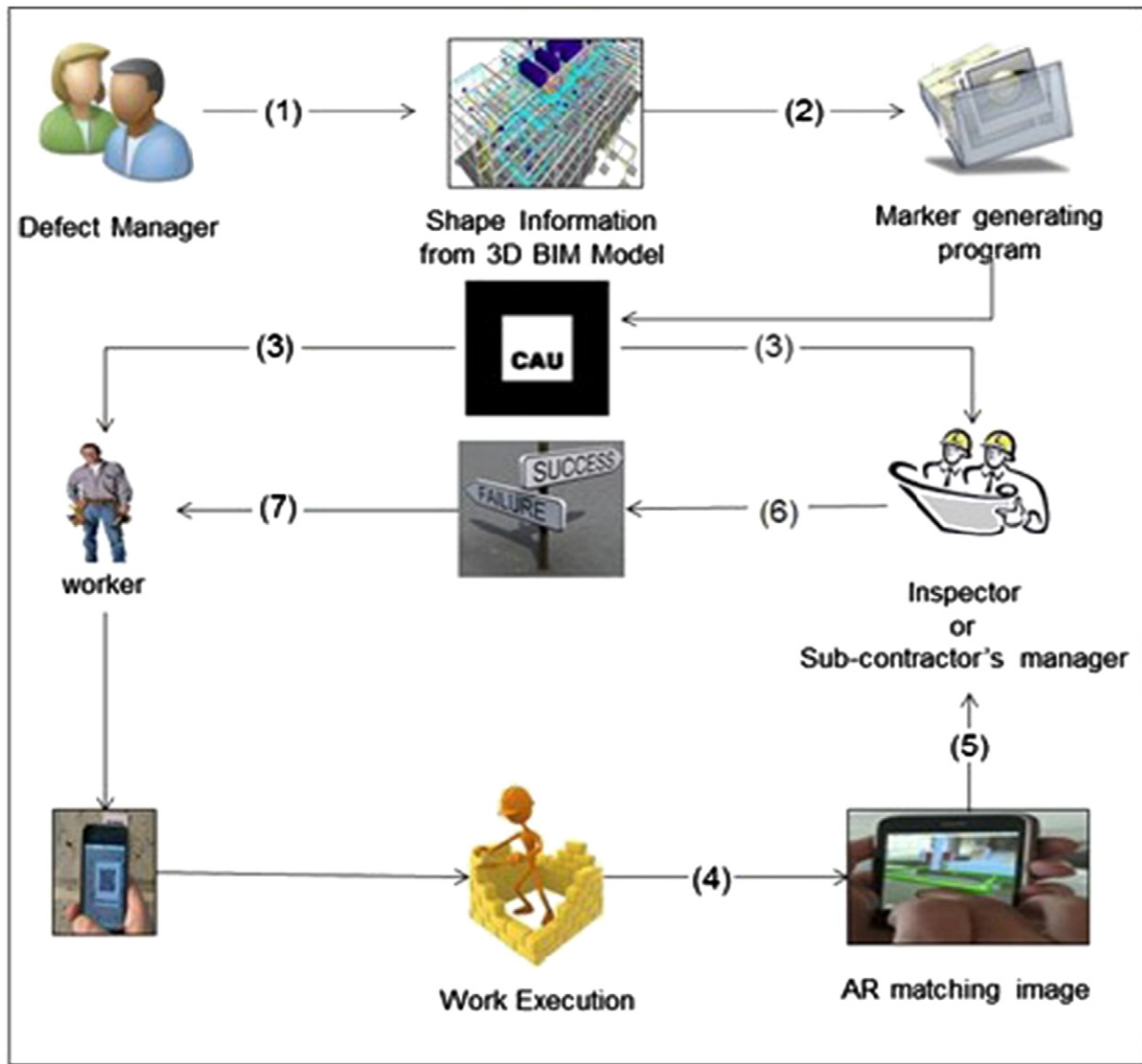


Fig. 3. Scenario of utilizing DM-AR app.

- 4) Next, the workers attach the markers to their assigned locations, and then use the DM-AR app on mobile devices to augment BIM geometry information. Then, they can view the augmented BIM geometry information superimposed on real site components. Through this, site managers and inspectors can check the status of RC work, and quickly detect any omissions;
- 5) Once work is completed in an area, the defect manager can ask workers to take a screenshot of the completed work. The DM-AR app would automatically send these images to the site managers and inspectors;
- 6) Using these images, site managers and inspectors can assess work results, and check for omissions which could cause defects;
- 7) If any omissions are found, workers would immediately be required to stop related work and an order to perform rework will be sent out through the work order alarm function in the DM-AR app. After workers finish rework, the defect management process described above will be performed again.

4. Applicability of the image-matching system and DM-AR app

The applicability of the image-matching system and DM-AR app was assessed based on three experiments: 1) a lab-experiment using the image-matching system based on camera images; 2) a computing-

based AR Lab-experiment and; 3) a DM-AR app experiment considering the systems applicability on construction sites. The three experiments focused on identifying major defects on RC work to demonstrate the potential of BIM, AR and image-matching in defect management. The applicability of the system can also be extended to other various trades and defects types.

As illustrated in Fig. 4, a lab-experiment was conducted, requiring the production of a mock-up model and BIM model in order to evaluate the defect management systems' performance. A BIM model was also created to enable accurate comparison with this mock up model. As such, the BIM model was designed with the identical dimensions, figuration, and interior form as the mock up model. Both the experiments (1) and (2) were processed using a computer that was equipped with CPU Intel Core i5, 2.8 Hz, and Ram 4 GB. The experiment considering the systems' applicability, which is described in (3), was conducted on a construction site, which was in the process of RC work.

4.1. Lab-experiment for the image-matching system

A previous study [18] included a lab experiment to test the image-matching method. Rather than using existing software, an image matching system was developed for this study. The experiment made use of a mock up model and BIM model which were created with

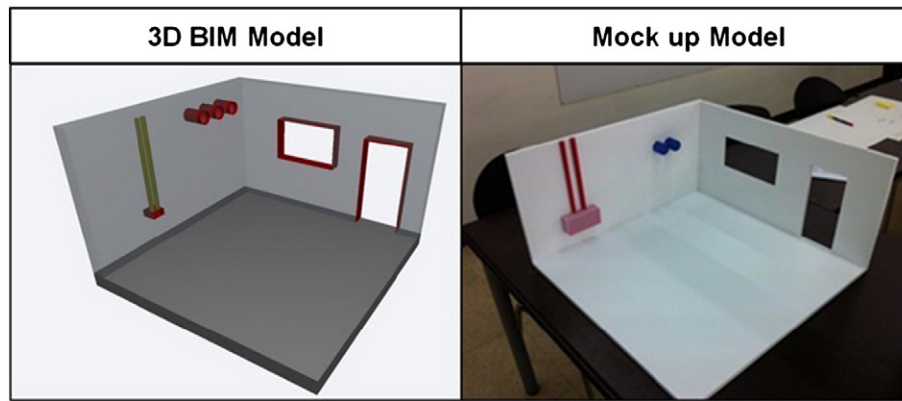


Fig. 4. BIM model and mock up model.

identical features as a real construction site. These models were used to acquire 2D images for the image-matching system. This lab-experiment aimed to check the applicability of image-matching system by checking dimensions and installation locations for windows and doors on the mock up model. As illustrated in Fig. 5, an experiment was conducted for the windows and doors in the models.

The experiment process was as follows: First, using a mobile device, a picture was taken of the window and door of the mock up model. Then, the shooting location, camera viewing angle, shooting height, and distance between the wall and the camera were saved using the photographing function in Archi-CAD. This function was used for extracting virtual 2D images from BIM models. Lastly, the saved picture and virtual 2D image were saved in the developed image-matching program and their differences were compared. As illustrated in Fig. 5, based on the comparison it was found that the window position was incorrect.

This experiment confirmed that a defect management process utilizing image-matching could be implemented in actual site spaces for construction components. The suggested defect management system enables automatic dimension checking, without requiring site managers and inspectors to visit the job-site. Furthermore, this process would also reduce the time spent on inspection tasks, thus reducing site managers and inspectors' workloads. Also, the early detection of dimension errors would help prevent rework and rectification costs.

4.2. Computing-based AR lab-experiment

A previous study [18] conducted an experiment, where marker based AR was selected as the method to augment BIM models. There are many challenges involved in working indoors on construction sites and it is often very difficult for cameras to detect markers. Therefore, markers were attached to specific positions in order to augment 3D model. Furthermore, quite often, no lighting systems are installed indoors on construction sites. Thus, the recognition rate for markers is remarkably reduced under sunlight. To solve these problems, it is necessary to improve marker recognition through image preprocessing.

The experiment process was as follows: First, the 3D model, which was created in Archi-CAD, was converted to a virtual reality modeling language (WRL) file. The file format can be changed when the model is saved in BIM software. The WRL file in which the 3D model information was contained was registered in a marker using a marker-based software toolkit (ARToolKit). This marker was then attached at an appointed location on the mock up model, and the virtual 3D model was augmented through a web-cam. Since the augmented 3D model and the working place in the reality were matched with each other, the difference between them could be checked through the computer monitor. A virtual model was augmented through a marker which was placed in the left of the mock up model. As illustrated in Fig. 6, this experiment confirmed that there was an omission.

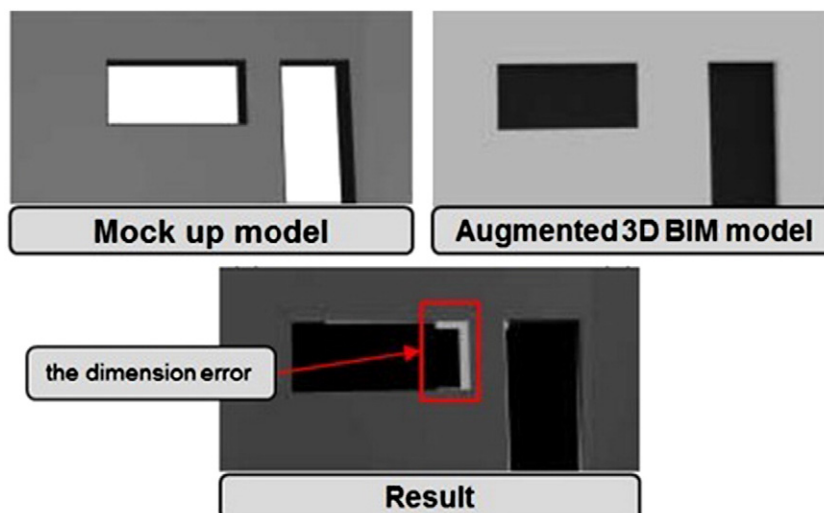


Fig. 5. Lab experiment using image-matching.

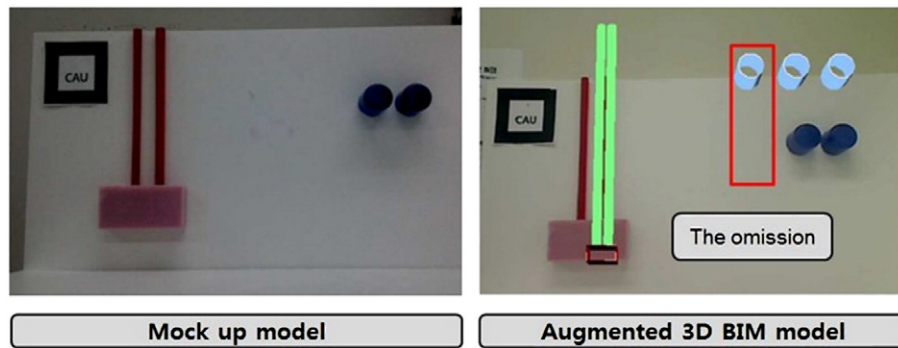


Fig. 6. AR lap-experiment result.

Through this experiment, it was found that a defect management system which applies AR can be implemented in actual spaces for construction components. As mentioned earlier, this system enables workers to check for omissions and errors by themselves, after completing work. Additionally, workers can use augmented 3D models to check their work contents and assess critical areas that could cause omissions and defects, prior to starting work. Accordingly, defects can be discovered at early stage, and both cost reductions and time savings will be possible. Also, proactive defect prevention will reduce rework.

4.3. Jobsite experiment for DM-AR app

As illustrated in Fig. 7, an experiment was conducted applying AR using a laptop. The previous experiment concluded that AR would be applicable to construction sites. However, due to poor portability on site, a laptop based defect management system would be inadequate. To address this, the mobile based DM-AR app was developed. In order to evaluate its applicability, an experiment was carried out on a site where RC work was in progress. The experiment used a Samsung Galaxy Tab 10.1, which is based on the Android OS.

In construction, cameras often encounter difficulties in detecting indoor objects because of dynamic on-site environment. As such, camera's locations and the 3D models to be augmented should be determined using marker in advance. With ARToolKit, when the 3D model to be augmented is determined, the shape embedded in the marker will be displayed. The way to use the marker is as follows. Various directions

and sizes are stored, and then, through template matching, the video coming from the camera and the video stored are to be compared with one another. Through this comparison, 3D model is to be determined. In this experiment, a system was created using frame marker. Frame markers are suitable for mobile environments, since they have more advantages than ARToolKit markers in data transfer. Additionally, frame markers are more robust in object detection and they can be detected faster. Furthermore, frame markers do not require the analysis of the format inside a marker. Instead, it uses the pattern of a marker borderline, so the desired image can be attached easily. This facilitates the insertion of images which can easily be recognized by humans.

To verify the system's applicability in actual construction, an experiment was carried out, focusing on a construction site where RC work was in progress. A BIM model was produced based on the architectural drawing of the site using Archi-CAD. The BIM model information was registered into a marker, and a field experiment was prepared. Also, the markers' location was specified in advance, in order to reduce errors related to marker recognition.

As illustrated in Fig. 8, a site experiment was conducted to inspect for window positioning errors. Through this process, workers can identify the location of windows in advance, and site managers and inspectors can check for errors more efficiently than with the current drawing based process. Furthermore, anyone involved on the project can attach marker, and use a mobile device to check for omissions. Workers can augment component position information prior to installation work; thus defects can be prevented proactively.

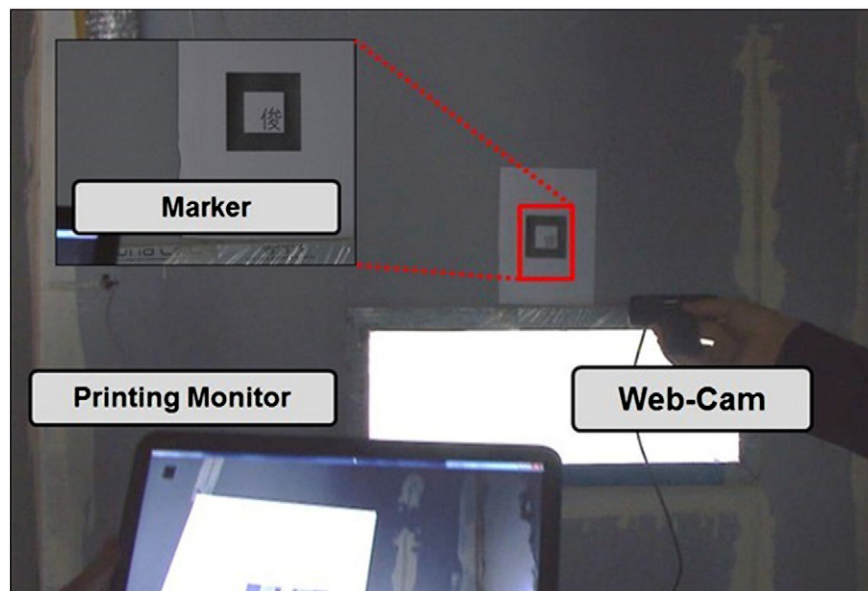


Fig. 7. AR experiment using laptop on construction site.

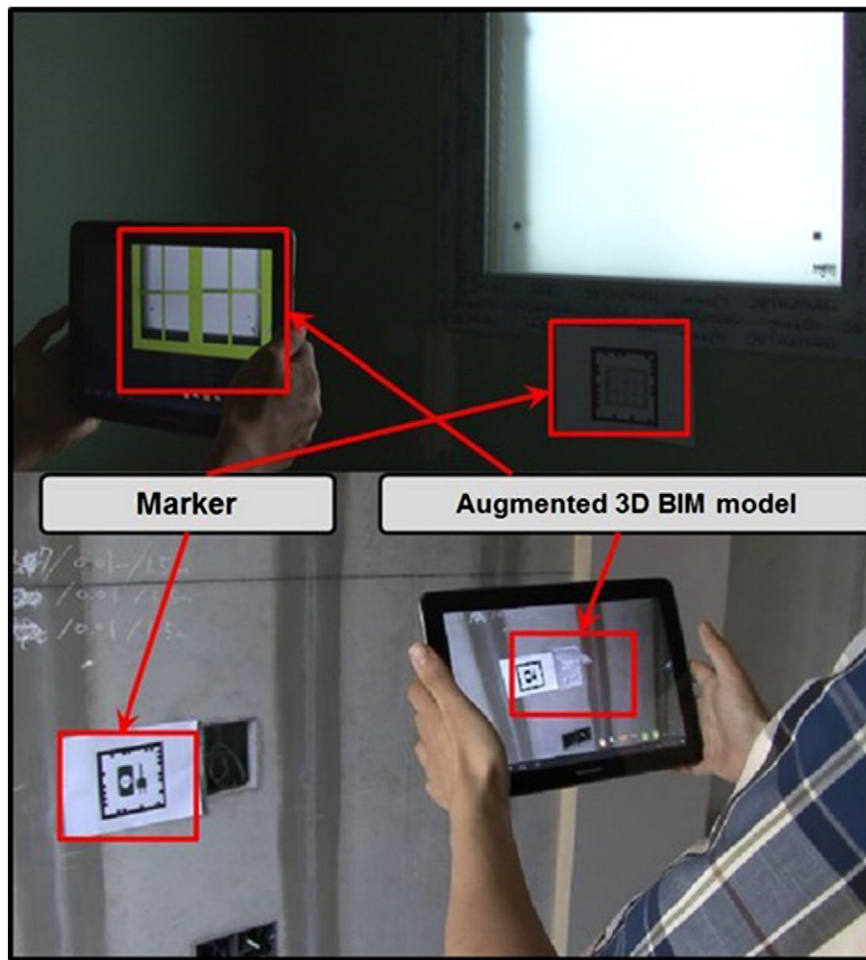


Fig. 8. AR site-experiment using mobile device.

4.4. Experiment limitations

The lab experiment for the image-matching system utilized markers, thus matching real pictures with BIM screenshots required a perfect angle when taking real photos. Workers had to take real picture from the exact same angle for image processing. This process can be problematic due to the large numbers of markers required and time consuming angle calibration. However, existing advanced technologies can be adapted to address these issues. In order to reduce the effort required in this process, the full scale system will adopt markerless tracking which enables convenient extraction of scenes' features and identification of the relationship between the camera and real world coordination system. Local detection and scale-invariant key-point algorithms would be incorporated to facilitate the matching process, making it possible to easily capture and match pictures from different angles [15].

Furthermore, in the DM-AR app setting up markers in the job site was very time consuming. Therefore, real-time fiducial marker and markerless tracking for AR would be better for the further development of the DM-AR app [5,19]. This method enables faster and more convenient target detection. By calculating the pose between the camera and the objects, AR contents can then be projected onto the site target. This technique has the potential to improve the efficiency and effectiveness of traditional RC work defect inspection process.

5. Conclusion

This research aims to enhance the current manual-based defect management, to reduce site managers' workloads, and prevent RC

work defects proactively by utilizing BIM, image-matching and AR technologies. Two types of defect management systems are developed: 1) an image-matching system to enable quality inspection without visiting the real work site; and 2) a mobile DM-AR app which enables workers and managers to automatically detect dimension errors and omissions on the jobsite. Lab and site experiments were conducted for the verification of the image-matching system and DM-AR mobile application. The experiments proved the effectiveness of the image-matching system and the usefulness of the DM-AR app for automatic error and omission detection and demonstrated the usability at real job sites. The proposed system would greatly improve the current manual based defect management process by allowing site quality managers and trade managers to inspect construction works at the office without visiting the real site. It would help not only save time, but also reduce rework-related costs at construction sites. However, the current system has limitations regarding the time consuming marker-based system operation. Therefore, future efforts would be directed towards the development of real-time markerless AR for the enhancement of the system. Additionally, the application of the system will also be extended to various defect types.

Acknowledgments

This research was partially supported by Chung-Ang University Excellent Student Scholarship and the National Research Foundation of Korea (NRF) grant funded by the Korea Government (MEST) (No. 2012-0005662 and No. 2013R1A1A2062181).

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