The Effectiveness of AR (Augmented Reality) Technology in Acquiring Information on Job-site Task

Prof. Yong-Woo Kim, University of Washington

Dr. Yong-Woo Kim is an associate professor and P.D.Koon endowed professor of construction management at the University of Washington. His research interests include supply chain management, lean construction, and integrated project delivery.

Mr. Wonil Lee, Department of Construction Management, University of Washington, Seattle, WA, USA

Mr. Lee is a Ph.D. Candidate in the Department of Construction Management, University of Washington, Seattle, WA, USA. Mr. Lee’s research interests include ICT Application in Construction, Occupational Safety and Health Management, Human Factors and Ergonomics, Serious Game, and Building Information Modeling.

Mr. Ryan J Eom, Legend High School

Ryan J. Eom participated as a student intern in the research activity at the lean construction lab of the College of Built Environments at the University of Washington. His interests include cognitive studies in engineering and education.
The Effectiveness of Augmented Reality (AR) Technology in Acquiring Information on a Job-site Task

Abstract

Acquiring information from drawings and specifications is one of the fundamental skills for construction laborers and students in a construction-related domain. The research assessed the users’ experiences in apprehending tasks, including interpreting drawing and specifications using an NFC-AR system. Three different surveys were designed and executed: a pre-test survey, a survey about AR usability, and one about the efficiency of delivering directives. The survey results were analyzed separately for comparison between groups using paper-based drawings and specifications, and those used AR groups. The findings from experiments suggest that the AR method was more effective in the students' apprehension of the tasks involving drawings and specifications when compared to the paper-based method. They also show that the level of students' understanding was consistent when the AR system was used, whereas students using the paper method had varied levels of understanding that depended upon the skills of the frontline manager.

Introduction

Acquiring information from drawing and specification is one of the fundamental skills for students in a construction-related domain. In many courses, such as estimating in construction-related education, the skill of apprehending information from drawing and specification is critical. This skill is useful not only in learning course works but also in communicating with field labor regarding directives. Front-line managers deliver the directives using specifications and drawings with verbal instruction. The efficiency of communication sometimes depends on the capability of interpreting materials.

Augmented Reality (AR) is recognized as an effective user interface technology to enhance a user's perception by inserting the computer-generated information into the user's real world experience. An AR-based prototype of task directives focused on drawing and specification review was created for improving communication with field labor.

Only a little research has been done to evaluate the effectiveness and usability of AR technology and industrial application in the construction domain. Thus, the purpose of the research is to test the usability and effectiveness of the prototype applied in a classroom setting. To this end, the prototype was applied in a classroom setting where graduate students learn about the task of pipe installation in a mechanical room. In this paper, the research assessed the user's experiences in apprehending tasks, including interpreting drawings and specifications. Three different surveys were designed and executed: a pre-test survey, AR usability, and the efficiency in delivering directives. The survey results were analyzed separately for comparison between groups using paper-based drawing and specification and those using AR group.
Benefits of NFC-AR Technology

One of the contributions of this research is implementing a Near Field Communication (NFC) marker in the AR system, since many of the previous AR researchers in the construction domain heavily relied on the Quick Response (QR) codes as the marker in the AR system. Therefore, the limited knowledge was investigated of the benefit of the NFC technology used in the AR system in the unique job-site environment and project communication method in the construction domain. The most noticeable advantage of NFC technology as an AR marker rather than using QR-codes is that it can be applied as a communication tool that can support cooperation among the enterprisers involved in the construction project because it allows for bidirectional communication between the tracker tag and the AR platform device that transmits information from the tablet PC to the NFC tag. Most other trackers, including QR codes, only enable unidirectional communication, through which 3D geometry or text information stored in the previous optical marker can be transferred. In other words, especially when the network signals of the construction site are not sound, instead of transmitting what needs to be corrected or complemented, or requesting information (i.e., RFI) to the central AR server, it is possible to deliver or store the data with the NFC technology within the tag present at the site after each cooperation between the project participants and the AR system’s user at the construction site. This information is delivered to the AR platform user in charge of the follow-up tasks (i.e., successor) so as to check if there are any additional pre-task constraints from the follower. Therefore, the NFC is a great mediator with which to implement an AR platform to improve communication on the concept of lean construction.

Relevant Work

The development of AR technologies for the construction industry should go with research that adapts the features of the AR system to the different demands of management areas in which the technology can be used. Both effectiveness and usability need to be tested. Lertlakhanahulu and Han⁴ presented how the mobile AR technology can be used in the construction management domain. Dias et al.⁴ implemented a usability evaluation of AR. They conducted usability evaluations for simple manipulations using simple geometric transformations (translation, rotation, scaling). Paelke et al.⁵ developed an approach to make a systematic evaluation of AR information presentation and interaction techniques. Regenbrecht and Schubert⁶ developed an approach of developing a special questionnaire to psychologically measure the experienced presence of virtual objects in the real environment. Their approach was based on a theoretical model of presence in virtual environments that is easily generalizable to the presence of virtual objects in AR. Wang and Dunston⁷ investigated how users experienced virtual models in the AR system and assessed the users' experience and attitude towards the effectiveness of the AR tool for design review as compared to a 3D, paper-based method.

System description: NFC-AR System

Due to the enlarged scale of the construction site and the complexity of the process, plant projects can have some problems with communication among the project participants, the duplication of work, errors, rework, and so forth. These issues raise costs, delay the construction schedule, and reduce productivity and quality.
The system prototype was developed for pipe installation processes in industrial projects using NFC technology and AR technology with mobile devices for the plant construction site. As shown in Figure 1, the system allows field users (e.g. frontline managers) to retrieve daily tasks with associated drawing information from existing databases.

![Conceptual Diagram of the NFC-AR System](image)

Figure 1. Conceptual Diagram of the NFC-AR System

The system also uses an AR technology where users obtain graphic and textual information using markers attached to the object (e.g., pipes or walls). As for the reading marker, the team uses NFC technology, whereas other marker reading technology requires additional reading devices (e.g., RFID reader), the NFC reader is usually embedded in smart phones, which means that there are no additional costs for the reading devices. When a marker on site is scanned, a 3-D model is displayed on a smart phone or tablet PC device.

**NFC-AR System in Pipe Installation**

The pilot system used an Android-based Google Nexus 10, which has an embedded NFC reader and a rear camera, as well as an NFC tag marker. Figure 2 shows the procedures of how the system can be used in pipe installation tasks. Information on the pipes, such as their 3D models, installation instructions, and identification numbers, is stored in a server.

Once the NFC reader of the Google Nexus 10 scans the tag marker, which is usually attached to the building objects, information on the pipe installation is retrieved from the database and a 3D model is displayed as shown in Figure 2.
Operational Directives

Though the operational instruction works as a key bridge between a production plan and its successful execution (or no plan failure), it has not received much attention compared to
planning processes. Traditionally, frontline managers such as foremen use paper-based drawings and specifications to deliver the operational directives. Crews are also instructed on safety and quality issues so that they are fully aware of those issues prior to execution. Figure 3 shows a process map for operational directives that is made in a traditional way. As seen in Figure 3, a frontline manager needs to prepare a copy of updated drawings and specifications; he/she also needs to have the associated safety and quality instructions in hand prior to giving instructions to his/her crews. In addition, the effectiveness of the process relies heavily on the capability of the frontline manager, such as his/her experiences, articulation ability, and communication skills.

**Figure 3. Process Map: Operational Directives using Paper-based Drawing and Specs**

**NFC-AR System in Operational Directives**

With the NFC-AR system, a frontline manager does not have to spend his/her time in (1) locating updated drawings and specifications and (2) confirming that the drawings and specifications are the most up-to-date ones. The process map of operational directives, which involves the NFC-AR solution, is shown in Figure 4.

**Figure 4. Process Map: Operational Directives using NFC-AR Solution**
In addition to eliminating the processes of locating and confirming the drawings and specifications, the process of operational directive has merit in that the communication between a frontline manager and crew members becomes more efficient.

**Experiments to Test Effectiveness of NFC-AR Solution in Operational Directives**

**Purpose of Experiments**

The goal of the experiments is to test the effectiveness of the NFC-AR solutions when they are applied in operational directives in which a front-line manager delivers operational instruction with updated drawings and specifications. The specific objectives are two-fold:

1) Is the proposed system easy to use? (Usability test)
2) Does the proposed system improve the level of the crews' understanding on the operational directives? (Usefulness)

**Experiment Groups and Demographic**

Along with the agreement on the informed consent form, the researchers also collected the demographic information of the participants, including their levels of experience, most recently taken title in the company, and their ages. Twenty-one graduate students with industry experiences have been arranged into four paper groups and three AR groups for the experiment. Each group was assigned one foreman and two laborers roles. The foremen for each group were selected among these students due to their longer experience in the industry, while the laborers in each group were students who had relatively shorter industry experience. The purpose of the experiment group setup was to allow the experiment to be more similar to an actual construction environment in which foremen usually have more experience than the laborers.

Figure 5 (Left) shows the distribution of the students’ backgrounds in the paper groups. Of the students, 59%, including foremen and laborers, had backgrounds in construction management and 25% of the students had backgrounds in architecture. These distributions were similar to those of the AR group (Figure 5, Right). Nearly half of the students in the AR group had backgrounds in construction management while 22% of the students in the AR group were architecture professionals.

![Figure 5. Test Participants’ Background (N=21)](image-url)
Based on the information about the years of experience of each student that was collected, foremen in paper groups had an average of 8.25 years of experience in the industry and the foremen in AR groups had an average 7 years of experience in the industry. There was one architect, one civil engineer, one construction manager, and one consultant among the four foremen in the paper group, while there was one civil engineer, one architect, and one construction manager among the three foremen in the AR groups. All of the students in the labor roles had about one or less years of experience in the industry.

*Design of Experiments*

A task in the experiment is an installation of a pipe in a mechanical room. A 2D pipe drawing (Figure 6) and an identical pipe drawing in a 3D model generated using Autodesk Revit MEP (Figure 7) were developed to be used on the AR tablet platform for the experiment. The drawing showed a section of pipe in a heating, ventilating, and air conditioning (HVAC) system that consisted of five pipe segments and four connectors between each segment. The drawings also included the quality and safety requirements for the pipe installation. The 2D-paper drawings and the AR tablet were given correspondently to the foremen in the paper groups and the foremen in the AR groups for the purpose of giving instruction to their laborers. Information on quality and safety related to the task was also provided with 3D screen in AR groups while a paper-based specification page was provided in the paper groups.

![Figure 6. 2D Drawing used in paper groups](image1)

![Figure 7. AR image used in AR groups](image2)
In addition, each foreman was given text instructions about the steps of the pipe installation. Table 1 shows a task instruction used in this experiment. Furthermore, in order for the foremen to be more familiar with the safety/quality requirements, pipe installation, and experiment procedures, the foremen in both paper and AR groups were given a 10-minute instruction by the researcher before beginning the experiment.

Table 1. Task Instruction

<table>
<thead>
<tr>
<th>No.</th>
<th>Instruction</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>The plan shows one vertical and four horizontal duct components to be connected with four connectors</td>
</tr>
<tr>
<td>2</td>
<td>Install vertical ducts with support of riser clamps</td>
</tr>
<tr>
<td>3</td>
<td>Install horizontal ducts with support of hangers</td>
</tr>
<tr>
<td>4</td>
<td>Insert a connecting collar into the end of each length of duct, then slip a new length onto the opposite side of the collar</td>
</tr>
<tr>
<td>5</td>
<td>Affix components using duct tape</td>
</tr>
<tr>
<td>6</td>
<td>Wrap the length of the completed duct in insulation by rolling it in a spiral pattern</td>
</tr>
<tr>
<td>7</td>
<td>Connect ducts to storage units with flexible connectors</td>
</tr>
</tbody>
</table>

Before the start of the experiment, all of the students were required to finish a Pre-test Survey in order for the researcher to evaluate the students’ levels of knowledge of pipe installation before any instruction was given.

In the experiment, each group performed its tasks individually in a room separated from other students (Figure 8). The foremen gave instruction to their laborers by using either the paper drawing or the NFC-AR technology. Laborers were requested to understand the installation procedures, specifications, quality requirements, and safety requirements at the end of the instruction by following the foremen’s instructions, which were assisted by either the paper drawing or AR tablet. The experiment was not time-limited, though each group took an average of 6 minutes to finish the experiment. Students were then requested to finish a survey based on their roles in the experiment at the end of the experiment.

Figure 8. Photo of Experiments
Survey Design and Result Analysis

Survey Design

There were, in total, four different surveys designed and filled out by students who participated in the experiment. The first survey, “Pre-test Survey,” determined the students’ general understanding of pipe installation before they were given any instruction in the experiment. It provided a comparison between the level of knowledge of each student before and after the experiment. The second survey, “AR Usability,” was filled out by the foremen in the AR groups. This survey was to determine the overall user experience with the AR technology in assisting the foremen’s instructions on pipe installation. The 3rd survey was for the foremen in both the paper groups and AR groups to determine the degree of efficiency, including the level of understanding of the task from using the paper drawing or AR technology in giving instructions. Survey questionnaires are found in Appendix A to D. The survey results were analyzed separately for comparison between paper groups and AR groups. Each survey question uses a Likert scale, which provides the highest reliability and is the most widely used type of Likert-scale in the scale development literature. Accordingly, a 7-point scale was used with the degrees of ‘strongly disagree,’ ‘disagree,’ ‘neutral,’ ‘agree,’ and ‘strongly agree.’ The survey results were also analyzed separately for comparison between paper and AR group. The following sections show the survey results and the analysis of the data collected from the experiment.

The Pre-test Survey Analysis

The Pre-test Survey results show that the students in the paper group demonstrated a higher level of knowledge in pipe installation before any instructions were given (Figure 9). It corresponded with the demographic information that the foremen in the paper group had more industry experience on average (8.25 years) than the foremen in the AR group (7 years).

![Figure 9. Background Knowledge Comparison prior to Test](image-url)
**AR Foremen – AR Usability Survey Analysis**

The foremen in the AR groups were highly satisfied with the AR tablet for its ability to help them understand the pipe installation methods and for finishing the task correctly (Figure 10). It also showed that they considered AR technology to have helped them in understanding the drawings and specifications. However, the ability of AR in assisting safety and quality instruction was ranked low. During the experiment, students showed confusion when navigating the AR tablet to get the necessary information for the AR.

![AR Superintendents Usability Survey](image)

**Figure 10. Usability Survey Results**

**Laborer Survey Analysis**

The laborers’ feedback showed that the students in AR groups had a better understanding of the pipe installation than did the students in paper groups as shown in Figure 11. Given the facts that the foremen in the AR groups had less experience in the industry than the foremen in paper groups and that they showed less knowledge in pipe installation in the Pre-test Survey, the laborers in the AR group were able to get a better understanding of the pipe installation method, the drawing specifications, the safety requirements, and the quality requirements by using the AR technology. It also showed that the students believed that communication was improved by using AR technology.
The survey analysis suggests that the proposed NFC-AR solution is effective in both improving the communication among crew members and bettering the crew’s understanding of the operation, though the survey analysis does not provide statistically meaningful data due to its small sample size. For example, there were some differences in background knowledge, which was not standardized in the analysis. The pre-test survey results showed that the paper group had better background knowledge than the AR group. However, the post-test survey results showed that the AR group gained a better understanding of the task.

In addition to the survey results, the researchers received some feedback from the experiment participants on the effectiveness of the solution in operational directives, some of which included:

- The level of understanding does not depend on the capacity of a frontline manager in NFC-AR solution.
- The level of understanding depends heavily on the capacity of a frontline manager in paper-based directives.
- Time and efforts in preparing updated drawing and specification can be reduced if the NFC-AR solution is used.

Different from the research team’s expectation (i.e. reduced task completion time on the AR groups over the paper groups), the average task completion time was almost the same as the 6 minutes used by both the paper groups and AR groups. This is because the students in the AR groups spend more time and energy on learning the new NFC-AR technology that they haven’t used before, which is a factor to increase the learning curve to adopt new communication tools while the learning is curved to understand the operative directives were reduced. To rule out the effect of this learning curve to use a new technology for evaluating the effectiveness of the developed NFC-AR system, it needs to fully educate the students’ understanding to proceed from
recognizing NFC marker to snapshotting augmented images combining 3D modeling and a real world environment (Figure 2) to get familiar with the NFC-AR system.

Future directions may include (a) adopting an NFC-AR prototype in the process of planning, including look-ahead planning and schedule coordination meetings, and (b) applying and testing the technology in real construction projects. The benefit of an NFC-AR prototype is the bidirectional communication with the frontline manager and project manager in the field office. The future work will include testing the technical feasibility of the NFC-AR prototype swift update the RFI back to the AR database server from the site to office. This functionality of NFC-AR is expected to promote continuous improvement on the cycle of plan-do-act-check in the filed management by the frontline manager and laborer following the key theme of Lean construction.

Acknowledgement

This study has been funded by the Korea Ministry of Small and Medium Business Research Fund. Opinions, findings, conclusions, or recommendations presented in this paper are those of the authors and do not necessarily reflect the views of the Ministry of Small and Medium Business.

References


**Appendix**

**Appendix A.**

Augmented Reality Using NFC in Production Planning on Site
Survey Questionnaire to Measure the level of Usefulness and Ease of Use

Perceived Ease of Use (1 = strongly disagree, 7 = strongly agree)

<table>
<thead>
<tr>
<th>Compared to the case where you used a paper-based drawing and specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. It is easy to become skillful at how to use the AR system on tablet.</td>
</tr>
<tr>
<td>2. It is easy to perform the task using the AR system</td>
</tr>
<tr>
<td>3. I make less errors when using the AR system on tablet.</td>
</tr>
<tr>
<td>4. I find it easy to recover from errors encountered while using the AR system on tablet</td>
</tr>
<tr>
<td>5. The interaction with the AR system in accomplishing the task is clear and understandable</td>
</tr>
<tr>
<td>6. The AR system on tablet is intuitive and it is easy to get the system to do what I want it to do.</td>
</tr>
</tbody>
</table>

**Appendix B.**

Pre-Test: Background Knowledge

(1 = strongly disagree, 7 = strongly agree)

<p>| |</p>
<table>
<thead>
<tr>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Are you familiar with the construction process (method) which was addressed in the presentation and assigned drawing?</td>
</tr>
<tr>
<td>2. Are you familiar with the construction drawing and specification which was addressed in the presentation?</td>
</tr>
<tr>
<td>3. Are you familiar with job-related safety issues which were addressed in the presentation and assigned drawing?</td>
</tr>
<tr>
<td>4. Are you familiar with job-related quality issues which were addressed in the presentation and assigned drawing?</td>
</tr>
</tbody>
</table>

**Appendix C.**

Post-Test (Superintendent):
Perceived Usefulness (1 = strongly disagree, 7 = strongly agree)

<p>| |</p>
<table>
<thead>
<tr>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Using AR would enable me to understand the construction method of pipe installation.</td>
</tr>
<tr>
<td>2. Using AR would enable me to understand the construction drawing and specification.</td>
</tr>
<tr>
<td>3. Using AR helps me to understand the safety and quality requirements of pipe installation.</td>
</tr>
<tr>
<td>4. Using AR enables me to accomplish tasks correctly.</td>
</tr>
<tr>
<td>5. Using AR enables me to accomplish tasks quickly.</td>
</tr>
</tbody>
</table>
6. Over all, I find the system overall to be useful for me to complete the task.

Appendix D.

Post-Test (Labor)
Statements for soliciting the subjects' opinions on directives of assignments (Labor)

Questionnaire II (1 = strongly disagree, 7 = strongly agree)

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>I feel confident in my comprehension of the construction process (method).</td>
</tr>
<tr>
<td>2.</td>
<td>I feel confident in my comprehension of the construction drawing and specification.</td>
</tr>
<tr>
<td>3.</td>
<td>I feel confident in my comprehension of job-related safety issues.</td>
</tr>
<tr>
<td>4.</td>
<td>I feel confident in my comprehension of job-related quality issues.</td>
</tr>
<tr>
<td>5.</td>
<td>The paper-based job instruction better facilitated communication.</td>
</tr>
</tbody>
</table>