ABSTRACT


Virtual Project Management (VPM) can be defined as the use of tele-presence and other modern technologies by virtual teams from remote locations to guide and manage construction projects such that the practical effects of an on-site individual are achieved without the physical presence of that person at the actual construction location. The main objectives of this research study are to:

1. Develop a centralized management system that can act as a communication tool to move around the construction site and assist experts in participating in virtual construction site visits and contributing from remote locations. It can be used to transmit live events at any place and any time.

2. Test the capabilities of this novel centralized management approach and demonstrate its abilities compared to the more conventional method currently used to manage construction projects.

In addition, the team of three graduate students from North Carolina State University was interested in evaluating the feasibility, reliability, and advantages of using this virtual management approach. For the team to accomplish this objective, Mungo Homes, which is a successful residential construction company, allowed us to use its construction sites in Raleigh, North Carolina to test the proposed concept. This innovative technique of centralized management enabled experts to participate in virtual construction site visits and make evaluations of the housing projects from remote locations. A Tele-Engineering and
Management (TEAM) Laboratory was developed at North Carolina State University to exchange information about on-site construction, maintenance, and repair activities. The idea included tele-presence and use of mobile video cameras for transmission of audio and video for real-time interaction and decision making from the TEAM Laboratory. Mobile cameras, as opposed to fixed cameras, provided the added advantage of bringing to light the intricacies of critical problems encountered while carrying out diverse operations at the construction site. A streamer™ provided by Mushroom Networks was used to expand the streaming bandwidth and to deliver a continuous high-quality video to the users. This novel approach was highly interactive and provided immediate feedback and solutions regarding a variety of issues, improved productivity, and reduced the cost of travel. It also proved successful in distance monitoring and inspection of activities, progress status, and percent complete without the need for actual attendance at the construction site. VPM made it easier to train new employees without experience in construction by providing them with help, support, and guidance from the remote expert whenever needed. Upper management was able to become more involved in the project and was able to validate the submitted schedules and reports without any filtered or censored information from lower management.

The team received much positive feedback from all participants in this research study. However, some complaints were encountered in regard to the average of 5 seconds of video delay, which resulted in audio overlap and some sound disturbance. The team developed its own technique to overcome this concern. Some future work in this area would be to 1) enable the physically challenged professionals to participate in virtual construction site visits and contribute from remote locations, 2) use the TEAM Laboratory for virtual status monitoring.
of construction projects, 3) virtual safety inspections on commercial, civil, and industrial construction projects, and 4) virtual monitoring of nonroutine activities in more challenging environments such as a disaster or crisis situation.
Real-Time Monitoring of Construction Operations Using Virtual Project Management Techniques

by
Ahmad Yousif

A thesis submitted to the Graduate Faculty of North Carolina State University in partial fulfillment of the requirements for the degree of Master of Science

Civil Engineering

Raleigh, North Carolina
2012

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DEDICATION

To my parents
BIOGRAPHY

Ahmad Yousif is a Kuwaiti civil engineer who has aspirations of becoming a university professor. He joined North Carolina State University (NCSU) in the spring of 2011 to pursue a Master of Science degree in civil engineering with a concentration in construction engineering & management. His master’s thesis addresses the use of virtual project management techniques to optimally manage construction projects and is being supervised by Dr. Edward J. Jaselskis. Ahmad has been a member of the American Society of Civil Engineers (ASCE) since 2008. He earned his Bachelor of Science (B.S.) from Temple University in August 2010 with a cumulative GPA of 3.93. Part of his senior design research project was accepted for the Geo-Frontiers 2011 conference and also for publication. After graduation in 2010, he had a three-month internship at Kuwait National Petroleum Company in the Projects Department, where most of his work was in construction engineering and management.
ACKNOWLEDGMENTS

I would like to thank my advisor, Dr. Edward J. Jaselskis, and my research partners, Arvind Sankar and Brett Clark, for their significant help and support. I also would like to thank Dr. Rene Cruz from Mushroom Networks for his immediate and substantial technical support throughout the research.
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CHAPTER 1: INTRODUCTION

Technologies are continuously developing and so should the construction industry. Other industries such as medical and manufacturing tend to be more flexible in terms of implementation of new technologies to enhance their efficiency and productivity. With the complicated nature of the construction process and its associated activities, the difficult environment in which operations are generally conducted (outdoors), and the lower educational level of the labor force as well as the culture of “If it’s not broke, don’t fix it,” the construction industry is hesitant to integrate new technologies. This has created the problem of reduced productivity, reduced interaction, increased miscommunication and misunderstanding between parties involved in a project, increased cost of travel for experts, slowed reactions concerning on-site issues, and reduced upper management involvement in the project, all resulting in inaccurate reports and schedules regarding the actual status and progress of the project.

The predominant method of tele-presence that is used extensively in the construction industry involves the use of fixed cameras. Some of the construction companies that use such cameras on their sites are PBS & J Construction, James G Davis Construction, Jarvis Downing Emch Construction, DPR Construction, BE&K Building Group, IMC Construction, and Brice Building Company. The use of fixed cameras may be advantageous for security purposes but has limitations in terms of its benefit for engineers, architects, owners, contractors, and site inspectors. Mobile cameras offer advantages over the customary, fixed method and should be relatively easy to adopt by firms in today’s technology-driven environment. This research
takes the technology a step further by experimenting with a new and exciting approach to bringing construction sites to experts in remote locations. One of the more promising approaches that the construction industry may consider concerns the use of Virtual Project Management (VPM). VPM can be defined as the use of tele-presence by virtual teams in remote locations to guide and manage construction projects. The practical effects of an individual being on-site are achieved without the physical presence of that person at the actual construction location. The main objectives of this research study are to:

1. Develop a centralized management system that can act as a communication tool to move around the construction site and assist experts in participating in virtual construction site visits and contributing from remote locations. It can be used to transmit live events at any place and any time.

2. Test the capabilities of this novel, centralized management approach and demonstrate its abilities compared to the more conventional method currently used to manage construction projects.

In addition, the team was interested in evaluating the feasibility, reliability, and advantages of using centralized management. For the team to accomplish this, Mungo Homes, a successful residential construction company, allowed us to use its construction sites in Raleigh, North Carolina to test the VPM concept. This innovative technique of centralized management enabled experts to participate in virtual construction site visits and contribute from remote locations. A Tele-Engineering and Management (TEAM) Laboratory was developed at North Carolina State University to exchange information about on-site construction, maintenance, and repair activities. The idea included tele-presence and use of mobile video cameras for
transmission of audio and video for real-time interaction and decision making from the TEAM Laboratory. Mobile cameras, as opposed to fixed cameras, provided the added advantage of bringing to light the intricacies of critical problems encountered while carrying out diverse operations at the construction site. A streamer™ provided by Mushroom Networks was used to increase the streaming bandwidth and to deliver a continuous high quality video to the users. This novel approach was highly interactive and provided immediate feedback and solutions for a diversity of issues, improved productivity, and reduced the cost of travel. The technology was tested using different scenarios on the construction site to determine its success in using the tele-presence of experts, including virtual site visits, virtual training, virtual site inspection, virtual monitoring of activities, and virtual punch lists. The technology work on a universal platform that can be accessed by clients, lending agencies, insurance companies, designers, and professional experts from any remote location.

In the next chapter, “Literature Review,” earlier studies, research, and applications related to VPM will be discussed. Chapter 3 will describe the research methodology and approach. Chapter 4 will provide more details on the technology proposed, the selected devices, the setup, and operation. Chapter 5 will illustrate the utilization of tele-engineering on several Mungo Homes construction sites, and Chapter 6 will discuss the results. This is followed by recommendations and future prospects in Chapter 7. Chapter 8 will include the summary and conclusions of this research.
CHAPTER 2: LITERATURE REVIEW

Some research has been conducted in the area of tele-presence and tele-engineering with positive outcomes. However, most of the previously conducted studies used only fixed cameras to remotely monitor and observe construction activities. The use of fixed cameras on a jobsite does not provide proactive, two-way communication and interaction capabilities between the office management and on-site personnel.

In 2007, for example, a research study by the National Cooperative Highway Research Program (NCHRP) reported the advancement of fixed camera systems from either a single camera per project location or independent multiple cameras per project site to the use of a networked robotic camera system (Hannon, 2007). In 2008 (Silva et al.), a research team studied the improvement of project management using a virtual supervision model. The project information was obtained by video cameras mounted on tower cranes. The model enabled project supervisors to watch construction activities remotely. This approach improved the operational efficiency, quality of communication, and construction worker satisfaction. In addition, the University of Calgary conducted pilot virtual supervision by using a fixed webcam on a five-story office building construction site. The camera assisted the construction management team in acting proactively, improving communication between site management and workers as well as improving safety (Jaselskis et al., 2010).

The U.S. Army Corps of Engineers (USACE) has pioneered research and development in the area of tele-engineering. It established the USACE Reachback Operations Center in Vicksburg, Mississippi. This center enables experts in the United States to provide immediate
solutions to the ground personnel through tele-presence. This is achieved by delivering real-time information using video conferencing, digital photos, and other mobile communication technologies (ERDC, 2011).

Jaselskis et al. (2011) has conducted successful research studies with promising outcomes using this approach. In the summer of 2010, for example, a team of multidisciplinary researchers traveled to Peru to reverse engineer the Inka Road with the objective of identifying sustainable engineering practices. Satellite-based audio and video communication equipment was used to test the functionality of tele-engineering by bringing the Inka location to an expert hydrology engineer located in Colorado. The researchers and expert were able to communicate in an interactive, two-way process (Jaselskis et al., 2011). Furthermore, Jaselskis, along with other researchers at Iowa State University, piloted virtual project tours via wireless technology, a micro PC, a digital camera, and a hands-free headset and microphone. Jobsite personnel transmitted real-time video and audio of construction activities to remotely located students seated in a high-technology classroom over 200 miles away. Students were able to observe and discuss the construction activities with the jobsite personnel (Jaselskis et al., 2010). Jaselskis and other researchers’ efforts support the continuous use of tele-presence to advance the construction industry.

In addition to the promising outcomes of tele-presence in the construction industry, tele-medicine has provided significant advantages to the medical industry. The University of Texas Medical Branch (UTMB) Health has a lot of experience in the area of tele-medicine and the use of tele-communications technologies and connectivity as well as the use of wireless and tele-monitoring technologies. It found that these approaches had improved the
patients’ access to specialists, increased patient satisfaction, improved clinical outcomes, reduced emergency room utilization, addressed patient problems before they required major intervention, and resulted in cost savings (Alexander Vo et al., 2011). In Dubai, there is a new center that will enable patients to receive virtual consultations from specialists all over the world (The National, 2011). In Bonsaaso, Ghana, information and communication technologies were used to overcome geographical barriers by reducing the patients’ need to travel long or unsafe distances to see medical experts (Novartis Foundation, 2012). Tele-presence has enhanced the efficiency of other industries, and therefore an effective implementation of such technology in the construction industry is reasonable to consider.
CHAPTER 3: METHODOLOGY

The research methodology used to determine the value of this innovative management approach is described in more detail in this chapter. The team of three graduate students from North Carolina State University has identified the following problems in construction:

- Low productivity.
- Weak interaction between upper and lower management.
- Low involvement of the upper management in the project.
- Miscommunications and misunderstandings between parties involved in the project.
- High cost of travel.
- Unreliable reports and schedules regarding the project.
- Slow reaction to on-site emergencies.

These complications have raised the importance of implementing tele-presence and VPM techniques in the construction industry. Therefore, the team had the objective of developing a VPM system that would enable a nonexpert (or even a drone) to send live, streamed video and audio feedback to remotely located experts. This approach essentially provides the same practical effects of an expert being on-site. Another objective was to test the capabilities of this novel centralized management approach and demonstrate its abilities compared to the more conventional methods for managing construction projects.

To satisfy these objectives, the team performed an extensive literature review in the area of tele-engineering, tele-presence, tele-communication, and VPM to understand these concepts and recognize what has been accomplished thus far in this area. It was found that most of the
research conducted in this area concerned the use of fixed cameras. The use of mobile cameras in VPM offers many advantages over the traditional fixed camera methods in terms of being highly interactive and providing immediate feedback and solutions for on-site issues.

Next, the team started to identify suitable technology to develop the capability to test out this novel approach. A Sony Handycam® (Sony DCR-HC62 MiniDV Handycam®) was selected due to its imaging quality, 2.7” LCD screen, manual focus, live-streaming capability, and its zooming abilities of 25x optical zoom and 2000x digital zoom (see Figure 1). Newer versions of this camera were not selected due to their lack of appropriate drivers for live streaming. A Sony VAIO® laptop (P Series Notebook) was chosen due to its built-in webcam as well as the accommodating dimensions of 4.8” (W) x 9.7” (D) x 0.8” (H), a screen size of 8”, and a light weight of 1.5 lb. It has an Intel® Atom™ processor of 1.60 GHz, a 2 GB DDR2 RAM, and a 60 GB hard drive (see Figure 2). A streamer™ provided by Mushroom Networks was also used to expand the streaming bandwidth by combining the bandwidth of three air-cards (AT&T®, T-Mobile®, and Sprint®) to deliver a continuous high-quality video to the users (see Figure 3). It has dimensions of 5.7” (W) x 3.9” (D) x 2.0” (H), weighs 1.32 lb, has four USB ports for cellular data cards, and has an external power supply and a rechargeable battery. The operating temperature range is 32–113°F (0–45°C), while the storage temperature range is 14–140°F (−10°C–60°C). In addition, a TEAM laboratory was created at North Carolina State University to assist with the testing and to serve as a command center for visualizing and guiding operations at the construction site. The TEAM Laboratory provided the opportunity to simultaneously view the live streaming from the site, the
construction schedule of the project, and the design specifications and plans related to the activity under inspection (see Figure 4 for views of the TEAM Laboratory). Site visits, site inspections, progress monitoring, and new employee training are expected to be accomplished more efficiently using this approach.

*Figure 1: Sony Handycam® (Sony DCR-HC62 MiniDV Handycam®)*
Figure 2: Sony VAIO® Laptop (P Series Notebook)

Figure 3: Mushroom Networks Streamer™ With the Three Air-cards (T-Mobile®, AT&T™, and Sprint™)
Figure 4: Tele-Engineering and Management (TEAM) Laboratory in Mann 221
To test the effectiveness of the proposed VPM approach, Mungo Homes, a successful company in the area of residential construction, allowed the team to conduct pilot tests on several housing projects in Raleigh, North Carolina.

The team’s main goal was to test the technology’s capabilities and effectiveness in distance monitoring and inspection of activities, virtual checklists, and virtual training of new employees without experience in construction, and in the ability to increase the contractor’s upper management involvement in the project.

An evaluation for each pilot test was provided along with a discussion of the challenges and suggestions to improve subsequent tests. Feedback and recommendations from Mungo Home’s management and other participants were captured and used for consideration of future work in this area. The next chapter provides a more detailed description of the technology used to conduct this research.
CHAPTER 4: PROPOSED TECHNOLOGY

The proposed technology involves the use of portable cameras and Android-enabled hardware that is capable of streaming live audio and video data to off-site locations. A streamer™ provided by Mushroom Networks was also used to expand the streaming bandwidth by connecting three air-cards (AT&T™, T-Mobile®, and Sprint™) to the cloud (Amazon Web Services™ [AWS™]), and then delivering the continuous, high-quality video to the video server to which users have access for viewing the content. The advantage of this technique is the ability to provide close-up images anywhere on the construction site and to enable experts to participate in virtual construction site visits, thus contributing their knowledge and expertise from remote locations.

Figure 5 depicts a flow diagram of the process involving the technology used to provide high-quality video streaming from a jobsite to several remote locations. The streamer™ has a protocol, which is a system of digital message formats and rules for exchanging those messages between computing systems. When the live video goes through the video encoder, it prepares for streaming by encoding the digital video to meet the proper formats and specifications. Once the cloud (AWS™) reads the streamer™ protocol, the streamer™ then connects to the cloud and the air-cards start to link simultaneously. This expands the streaming bandwidth and delivers a continuous, high-quality video to the server from which users will be allowed to view the material. The estimated minimum duration of the video lag is 5 seconds for the air-cards to connect to the cloud and create the continuous video. Figure
6 shows a picture of the equipment setup in the TEAM Laboratory, and Figure 7 shows how this equipment is placed in a backpack while conducting the tests on-site.

Figure 5: Video Streaming Flowchart
Figure 6: Equipment Setup

- AC Power Adapter
- The Streamer™ with Three Air-cards
- Sony VAIO® Laptop
- Sony Hanycam®
The steps required for broadcasting a video through the cloud are shown in Table 1.

Figure 7: Equipment Packed in a Bag While Performing Tests

The streamer™ with 3 air-cards (AT&T™, T-Mobile®, and Sprint™), a Sony VAIO® laptop, and a rechargeable battery, all located in this backpack.
Table 1: Steps to Broadcast a Video Through the Cloud Using a Video Server and Streamer™

<table>
<thead>
<tr>
<th>Step 1</th>
<th>Use the AC power adapter to power the streamer™. There is a power button on the unit to turn it on and off.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Step 2</td>
<td>Plug the air-cards (AT&amp;T®, T-Mobile®, and Sprint™) directly into any of the four USB ports on the unit. There are two in the front and two in the back.</td>
</tr>
<tr>
<td>Step 3</td>
<td>Use an Ethernet cable to connect the streamer™ to a laptop (Sony VAIO®); use a USB cable to connect the Handycam.</td>
</tr>
<tr>
<td>Step 4</td>
<td>Wait about 3 minutes for the unit to boot up, and open the browser to <a href="http://192.168.249.99">http://192.168.249.99</a> to see the streamer™ GUI.</td>
</tr>
<tr>
<td>Step 5</td>
<td>Check the air-card’s connectivity, and then click on the Home tab on the GUI to see if the modems have reached a &quot;connected&quot; state.</td>
</tr>
<tr>
<td>Step 6</td>
<td>Log in to the AWS™ system at <a href="http://aws.amazon.com/">http://aws.amazon.com/</a>, set up the AWS™ cloud, and obtain an IP address (XX.XX.XXX.XXX). See the appendix for more details.</td>
</tr>
<tr>
<td>Step 7</td>
<td>To connect the streamer™ to the AWS™ cloud and manually set the video delay, click the Video tab on the streamer™ GUI, and then click the &quot;1&quot; in the leftmost column in the table at the top. In the pop-up window, enter the IP address obtained in Step 6 in the field “Peer IP,” and enter the desired playout delay in milliseconds (see Figure 8).</td>
</tr>
<tr>
<td>Step 8</td>
<td>Look for the &quot;Connected to BPA&quot; status indicator. If it shows &quot;YES,&quot; you are ready to start streaming from the same computer on which you are viewing the GUI.</td>
</tr>
<tr>
<td>Step 9</td>
<td>Open the video encoder, and then enter the IP address obtained in Step 6 in the “FMS URL” of the right table. Once this step is completed, video streaming and encoding can begin. Figure 9 is a picture of the video encoder.</td>
</tr>
<tr>
<td>Step 10</td>
<td>Use the video server at <a href="http://XX.XX.XXX.XXX/cgi-bin/streamer.cgi">http://XX.XX.XXX.XXX/cgi-bin/streamer.cgi</a> to deliver the video to the users (see Figure 10).</td>
</tr>
</tbody>
</table>
Figure 8: **Streamer™ GUI (Video Tab)** — http://192.168.249.99
Figure 9: Video Encoder (Adobe Flash Media Live Encoder)

Figure 10: Video Server (http://XX.XX.XXX.XXX/cgi-bin/streamer.cgi)
The streamer™ is capable of streaming the video and audio one-way only. This limitation generated the need to use conferencing software to achieve two-way communication and rich interaction between multiple participants. Since one of the main goals of using this technology was to produce high-quality, continuous live video, the research team decided to separate the video and audio received via the streamer™ from the audio received via the conferencing software. This way, the maximum available bandwidth was reserved for the streamer™ to create high-quality, continuous video. Hence, a Verizon Mobile Hotspot MiFi® used to access the web conferencing software (see Figure 11).

Figure 11: Verizon Mobile Hotspot MiFi®

The two-way conferencing software Elluminate Live!™ and Skype™ were selected for this research study to determine their suitability not only for supporting the pilot studies
conducted as part of this research but also for any construction site location. Figures 12 and 13 represent screen images of the two different conferencing software. Camtasia® software was used to record and document all virtual testing results. Camtasia® is a simple screen recorder that provides the necessary tools to customize and edit videos so that viewers can watch anytime and on nearly any device.

Figure 12: Image of Web Elluminate® Conferencing Software
Figure 13: Image of Skype™ Web Conferencing Software
CHAPTER 5: USE OF TELE-ENGINEERING ON MUNGO HOMES' CONSTRUCTION SITE

Mungo Homes is a family-owned company that has been building new homes since 1954. It is currently ranked the 35th largest new-home builder in the country. Mungo Homes has a very strong purchasing power and financial stability compared to other local and national builders. In 2008, the company made annual revenues of $143 million. It is headquartered in Columbia, South Carolina and is building new homes in South Carolina, North Carolina, and Georgia. The company currently has several new-home projects throughout the Triangle Area (Raleigh–Durham–Chapel Hill), and the team was able to access some of its construction sites in Raleigh, North Carolina.

Before going to a Mungo Homes construction site to test the performance of the devices, the team developed a testing plan for the different applications of VPM (see Table 2). The team performed eight virtual tests in order to satisfy the research plan. Four tests were performed to investigate the technology for performing virtual site inspections, monitoring, and measurement of progress (percent complete). One test was conducted to evaluate the concept of performing a virtual punch list inspection. Another test was done to determine if this technology could provide jobsite training from a remote location. Yet another test was performed to experiment with different equipment setups (e.g., a different camera, computer, and operating camera in a Wi-Fi environment). The last test was reserved for any additional testing, if necessary. The main goal was to test the effectiveness and capabilities of this VPM system and compare its usefulness to the more conventional construction management methods.
Table 2: Virtual Project Management Test Plan

<table>
<thead>
<tr>
<th>Test No.</th>
<th>Date</th>
<th>Location</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test 1</td>
<td>Saturday, June 16, 2012</td>
<td>Downtown</td>
<td>Virtual Site Inspection, Monitoring, and Percent Complete</td>
</tr>
<tr>
<td>Test 2</td>
<td>Tuesday, June 19, 2012</td>
<td>Downtown</td>
<td>Virtual Site Inspection, Monitoring, and Percent Complete</td>
</tr>
<tr>
<td>Test 3</td>
<td>Thursday, June 21, 2012</td>
<td>Downtown</td>
<td>Virtual Site Inspection, Monitoring, and Percent Complete—Review Punch List Items</td>
</tr>
<tr>
<td>Test 4</td>
<td>Saturday, June 22, 2012</td>
<td>Downtown</td>
<td>Virtual Vs. Traditional Punch List</td>
</tr>
<tr>
<td>Test 5</td>
<td>Tuesday, June 26, 2012</td>
<td>Downtown</td>
<td>Virtual Training</td>
</tr>
<tr>
<td>Test 6</td>
<td>Saturday, June 30, 2012</td>
<td>Downtown</td>
<td>Virtual Site Inspection, Monitoring, and Percent Complete</td>
</tr>
<tr>
<td>Test 7</td>
<td>Tuesday, July 3, 2012</td>
<td>Downtown</td>
<td>Testing Different Setups of Equipment</td>
</tr>
<tr>
<td>Test 8</td>
<td>Thursday, July 5, 2012</td>
<td>NCSU</td>
<td>Other</td>
</tr>
</tbody>
</table>

24
To prepare for the site visits at Mungo Homes’ projects, the research team conducted daily training sessions for a period of one week at the Talley Student Center. The reason for this extra preparation was to overcome any future problems that could be encountered while broadcasting from the Mungo Homes construction sites. Camtasia® software was used to record and document those training sessions. During these pretests, some minor problems were identified pertaining to connecting to the AWS™ cloud that had to be resolved. After achieving a high confidence level with the use of the technology, the team started to broadcast from Mungo Homes.

At the end of each test, the team evaluated the video streaming, noted any challenges encountered, and provided some suggestions to improve the quality of the video streaming for the subsequent tests. The team had the opportunity to obtain feedback on this approach from Mungo’s upper management and others who saw the technology in operation. Details on each of the tests follow.

**Test 1: Saturday, June 16, 2012**
This was the first day at Mungo Homes construction site for testing the performance and efficiency of the devices. The team arrived at the site, set up the devices, connected to the cloud, and successfully started to stream. One team member was at the TEAM Laboratory recording the live video and asking questions, while the other two members were on-site broadcasting the video and explaining the activities. One of the two research members who was on the site is an employee of Mungo Homes and therefore explained the status of construction work, the progress, the completion percentage of each activity, and the problems
encountered and how they have been fixed as well as the activities that still needed to be completed.

It was easy for the person in the TEAM Laboratory to see the issues on the jobsite. An example was observing that the roofing on homes 1201–1205 was about 85% complete. The person was even able to identify that some parts over the garages had not been shingled and checked whether the units’ sidewalk pads were prepared and ready for pouring (see Figures 14 and 15). It was also possible to verify that the framing of the buildings was completed and ready for inspection. In addition, the person in the TEAM Laboratory was able to confirm that the electrical work of the units was about 90% complete. The research team member in the lab was informed that the workers on the site had some previous issues with the fireplace headers in some of the units. The size and location of the header were not according to the plans and thus needed to be resized and relocated. The person in the lab was able to clearly identify the problem and understood the proposed solution. Figure 16 is a photograph of the person on-site explaining the fireplace header issue to the person in the laboratory.
Figure 14: Virtual Inspection of the Roofing (Non-Shingled Parts)

Figure 15: Virtual Inspection of the Sidewalk Pad
During this test, the video was sent from the streamer™, while the audio was broadcast using Skype™ via a tablet connected to a stand-alone MiFi®. The bandwidth was selected to be 800 kbps, which increased the video quality but also increased the lag time to one minute due to the low signal strength. Video lag time is the delay between real-time actions by the person on-site and the actions delivered via the video server to the person in the lab. Therefore, to maintain a continuous video with a lower video delay, the bandwidth should be decreased from 800 kbps to 300 kbps. A volunteer was asked to use a tablet and a headset to watch the streaming from a different location on the site and provide the researchers with feedback. The volunteer told us that the video and audio quality was very good. The person complained only about the video delay of one minute. The clarity of the video in dark places was not good, and therefore a flashlight should be used in subsequent tests.
**Test 2: Tuesday, June 19, 2012**
The team visited the same units (1201–1205) to monitor some other activities and check on progress status. The person in the laboratory was able to see that the electricians were working on the units and trying to have their work completed and ready for inspection. It was also possible to monitor the workers’ preparation of the newer units’ (1206–1210) foundations so that they could be inspected the day before the concrete pour (see Figure 17).

![Image](image.png)

*Figure 17: Virtual Monitoring of the Workers’ Preparation of Newer Units’ Foundations*

In this test, the research team reduced the video bandwidth from 800 kbps to 300 kbps due to the available internet signal. The video lag time was reduced from 1 minute to 12 seconds. However, the video quality of the 300 kbps bandwidth was lower due to the increased graininess compared to the 800 kbps bandwidth. During the first half of the broadcast, the video was from the streamer™, while the audio was from Skype™. This resulted in a 12-second delay between the audio and the live video. During the second half, the audio was
synchronized with the video; therefore, both the audio and video were recorded from the streamer™. In this approach, both the audio and video were arriving at the lab with a 12-second delay. Hence, Skype™ was used only when the person monitoring performance in the TEAM Lab had specific questions to ask. The drawback of such approach was the lack of two-way interaction between participants.

The microphone on the Handycam and tablet captured the noise of the activities on-site. This was noted while reviewing the recorded video in the TEAM Laboratory. Although, the video was treated for noise removal using Camtasia® software, one can still hear some mild noise disturbances in the open areas where the heavy construction equipment was being operated.

A headset with a built-in microphone can be used to eliminate this problem.

One of the project managers at Mungo Homes reviewed the recorded videos and was pleased with the technology and approach. However, the project manager preferred to sacrifice some of the video quality in order to minimize the video delay. Therefore, more tests were planned to resolve this issue.

**Test 3: Thursday, June 21, 2012**

In the first part of this test, units 1201–1205 were visited to check the progress on the electrical work, sidewalk, and roofing. Results using the VPM approach showed that the electrical work was 95% complete, the sidewalk was inspected, and the concrete was poured; however, there was no progress related to the roofing (see Figure 18). Units 1206–1210 were then visited to monitor the progress of the monolithic slab foundations. The concrete was recently poured and the person in the TEAM Laboratory was able to monitor the workers’ finishing of the surface. Those units would be soon ready for framing. Figure 19 shows
pictures of the on-site personnel remotely explaining the progress of the project to the person in the TEAM Laboratory.

Figure 18: Virtual Inspection Confirming That the Sidewalk Concrete Was Poured
During the second part of this test, the team visited a unit that was approaching completion and reviewed the punch list items. Figure 20 is a photograph of a person on-site reviewing the punch list items with the person in the TEAM Laboratory. Green tape was used to point out the location of any issue. The person in the laboratory was able to virtually evaluate the following punch list items:

1. Check if the pilot light in the fireplace is on.
2. Repair the drywall above an air vent on the second floor.
3. Check installation of ceiling fans in the second floor bedrooms.
4. Check installation of a towel bar in the master bathroom.

5. Repair the tub in the master bathroom.

6. Check installation of the cabinets in the laundry room.

7. Make sure that the trim around the dryer vent in the laundry room is installed.

8. Check installation of one extra shelf in the second floor bathroom.

![Virtual Review of the Punch List Items](image)

*Figure 20: Virtual Review of the Punch List Items*

It was noticed using the VPM approach that there were some paint imperfections on the walls such as discoloration and spots with extra paint, which needed to be refinished. In addition, there were some scratches on the floor that had to be appropriately marked with green tape for the flooring subcontractor to repair or replace.

With this test, the team was able to reduce the video delay from 12 seconds to 5 seconds. This is the estimated minimum duration it would take the air-cards to connect to the cloud and create the continuous video. This was achieved by manually setting the video delay in the streamer™ to 2 seconds and the video bandwidth to 300 kbps. The success of reaching
such a delay depends on the selected video bandwidth and the available signal strength. In future tests, the team attempted to further reduce the delay. During the first part of the test, both the video and audio were coming from the streamer™, while Skype™ was used to communicate back and forth between the people on-site and the TEAM Laboratory. This created an audio overlap and some random noise. Thus, during the second part of the test, the audio was received only from Skype™. This resulted in a few seconds delay between the audio and video, but the quality of the sound was significantly improved and therefore the communication.

**Test 4: Saturday, June 22, 2012**

During this test, the team wanted to compare the effectiveness of VPM with traditional project management. Thus, a scenario was created in which two members of the team were in the TEAM Laboratory as project manager and senior project engineer, while one team member was on-site as the project engineer. The project engineer went over the punch list in the traditional way without using the streaming technology. Afterward, the project engineer was asked to go over the same punch list again, but this time with the project manager and senior project engineer for them to see the progress virtually. Therefore, whenever the project manager or senior project engineer had a question about any item on the punch list, the project engineer had to show them the status of the work and explain to them what had been completed so far. The time it took the project engineer to complete the punch list in each case was recorded for comparison. The punch list items were noted as follows:

1. Fix the flipped shingles on the roof.

2. Plant the backdoor plants.
3. Paint the brick lintel above the front door.
4. Place a new filter in the first-floor air vent.
5. Check if the pilot light for the fireplace is on.
6. Paint the garage walls.
7. Install the garage keypad.
8. Install toilet paper handle in the first floor bathroom.
9. Install rubber sleeve in the kitchen sink.
10. Install the missing bracket under the handrail of the stairs.
11. Install ceiling fans in the second floor bedrooms.
12. Install a towel bar in the master bathroom.
13. Repair the tub in the master bathroom.
15. Put trim around the dryer vent in the laundry room.
16. Install one more extra shelf in the second floor bathroom.

In addition to the previously mentioned punch list items, the people in the TEAM Laboratory were able to identify the following additional items via their conversation with the person on-site:

1. Repair wall scratches or cracks (see Figure 21).
2. Repair floor scratches (see Figure 22).
3. Fix the crack on the edge of the mirror frame in the master bathroom (see Figure 23).
4. Paint the wall around the mirror in the smaller bathroom on the second floor.
Figure 21: Cut in a Wall Needs to Be Closed and Repainted

Figure 22: Scratched Floor Needs Repair
It took the project engineer 7 minutes to complete this punch list in the traditional way. On the other hand, it took about 14 minutes to complete the same punch list virtually. The first reason for the extra time was the video delay of 10 seconds, which was due to the available signal strength at that particular location and time of day. The selected video bandwidth was 300 kbps. In this test, the audio was received via Skype™, while the video was from the streamer™. As a result, the audio was received before the video. The people in the TEAM Laboratory had to wait a few seconds before being able to view the punch list items. Therefore, the project engineer used this time to explain the status of each punch list item, what had been completed, and what still needed to be completed. The second reason for the extra time for conducting the virtual punch list was the two-way conversation between the person on the site with the people in the TEAM Laboratory. The virtual visit allowed...
Mungo’s upper management to become more involved in the project. Therefore, more questions were raised while performing the punch list, and thus more time was spent to answer those questions. This is unlike the traditional way of performing the punch list in which the project engineers are doing work on their own without anyone monitoring their activities. Such involvement would increase the reliability of the on-site management reports and schedules as well as increase upper management awareness about the exact status of the project and what is happening on-site without any information being hidden or censored.

Test 5: Tuesday, June 26, 2012
On this date, the team tested the effectiveness of virtual training for newly employed engineers with no experience in construction. In addition, the team wanted to test the success of tele-presence of professional engineers in solving issues in remote locations virtually. It takes a lot of time and effort to introduce new engineers to construction sites and to help them to become familiar with them. They need to go through an intensive training course for them to gain the knowledge that would help them solve on-site issues by themselves (e.g., related to safety, quality, and progress). However, professional engineers are not always available to walk with every newly hired engineer to give them the appropriate assistance. Moreover, issues may come up on-site where no one has the knowledge to solve that particular problem properly, except for an engineer that is located in a different location. Therefore, in this test, we wanted to see how effective it would be to use this technology to connect the people on-site with experts located in a remote location to offer help, guidance, and support. To achieve that goal, one team member who was very familiar with the site was assigned to train and guide another member who had been to the same exact unit before.
The people in the TEAM Laboratory gave the person on-site clear directions to walk through the unit based on the received live video. The person on-site was guided to inspect the roof, ceiling, frames, thermal insulation, electrical work, water piping, windows, columns, and connections (see Figure 24).

Figure 24: Virtual Training to Inspect the Ceiling, Frames, Connections, and Columns
In this test, the video was received from the streamer™, while the audio came from Skype™ via an iPhone® that was connected to a MiFi®. The video bandwidth was selected to be 300 kbps. Although a delay of 12 seconds was found, the team had reached a confidence level using devices with which it was possible to work around that type of delay. The person on-site was instructed to move the camera and change its location only when asked by the people in the TEAM Laboratory. This was done to make sure that the people in the laboratory saw what the person at the site saw. This approach made communication very easy back and forth. The training went smoothly, without any problems, and the technology proved its effectiveness in such applications.

**Test 6: Saturday, June 30, 2012**

On this date, the research team visited units 1201 through 1210 to monitor their progress and inspect the completed work. However, this time, Elluminate Live!™ was used instead of Skype™ as the conferencing software. This software has several built-in features that best serve by improving communication among all participants during live sessions. To use Elluminate®, the session moderator needs to have an account (see [http://elluminate.wolfware.ncsu.edu for more information](http://elluminate.wolfware.ncsu.edu)), create a new live session, and send an e-mail to all of the invited users that includes a link to the session. Unlike Skype™, Elluminate Live!™ allows up to 25 participants at a time in a meeting with a maximum number of 6 simultaneous real-time participants sharing audio and video. The moderator and participants had the ability to chat, share pictures, desktops, videos, web pages, documents, drawings, and even write or draw on a white board. However, the moderator always had full control over what was shared during the session (see Figure 25).
The person in the laboratory was able to validate that the electrical tasks in units 1201-1205 had recently been completed and the work inspected. Nevertheless, minor changes still had to be made to fix some issues in the electrical and framing work. It was obvious for the person in the laboratory that all drywall had been delivered and stored in the units for installation. Surprisingly, the roofing on these units was still not completed, leading to an action item related to contacting the subcontractor to schedule a time to complete the work. Moreover, the person in the laboratory noticed a safety issue in the units where the framers had left boards on the floor with nails sticking out of them. Failure to properly dispose of these boards could have caused serious injury to workers at the site. The person in the laboratory
also asked the people on-site to prove that the foundations for units 1206 through 1210 had passed inspection, plumbing pipes had been installed, and the anchor bolts had been placed in the slabs (see Figure 26).

*Figure 26: Virtual Inspection of Foundation, Plumbing Pipes, and Anchor Bolts*
For this test, the team encountered a 5-second delay with the selected bandwidth of 300 kbps. The video was received from the streamer™, while the audio was from Elluminate Live!™ via a MacBook Pro® that was connected to a MiFi®. People on-site and in the TEAM Laboratory used a microphone, and therefore the voice quality was significantly improved. The signal was not as strong as it had been in previous tests, which slightly reduced the clarity of the video. The team found Elluminate Live!™ to be very effective and used some of its features to draw and write on the white board while explaining the status of some activities. It was easy to use, and it enhanced the communication capabilities between participants.

Test 7: Tuesday, July 3, 2012
During this test, the team experimented with a different equipment setup involving a larger number of participants using Elluminate®. A MacBook Pro® with a video encoder was connected to a Logitech® Cam instead of the Sony VAIO® Laptop with the Sony Handycam®. Figure 27 shows a picture of the new equipment setup. The team wanted to see if the latest updated versions of other operating systems, compared to the ones already used in the previous tests, would help to produce a better-quality video with a reduced delay. Since the team could not find any drivers for the Sony Handycam® that would work on the MacBook Pro®, the Logitech® Cam was tested.
In this live session, there were five participants—two at the site leading the tour, another two in the TEAM Laboratory, and another participant at Iowa State University. The off-site participants were able to go on a virtual tour to units 1201 through 1210. They were introduced to the site and provided with explanations on the status of each activity. This was the longest live video session due to the rich involvement of all participants as well as the number of questions asked.

The main challenge during this test was the lower Internet signal strength encountered, compared with the previous tests. The bandwidth therefore was selected to be 300 kbps, and
the streamer™ video delay was set for 6 seconds. However, the actual delay was 16 seconds. The video quality of the Logitech® Cam was poor compared with the Sony Handycam® and did not have any zooming capability. Thus, the team decided to return to the Sony Handycam® and not use the Logitech® Cam for future tests. The team decided to conduct one more test to see if the number of viewers on the web server would increase the video delay.

**Test 8: Thursday, July 5, 2012**

During this test, the team wanted to see if increasing the number of viewers on the web server would increase the video delay. Table 3 shows a summary of the results.

<table>
<thead>
<tr>
<th>Test No.</th>
<th>Bandwidth</th>
<th>Delay Time Set on Streamer</th>
<th>Actual Delay</th>
<th>Remarks</th>
<th>Signal Strength</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test 1</td>
<td>800 kbps</td>
<td>6000 ms</td>
<td>8 s</td>
<td>1 viewer</td>
<td>T-Mobile 45% AT&amp;T 90%</td>
<td>NCSU</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>9 s</td>
<td>2 &amp; 3 viewers</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>10 s</td>
<td>4 viewers</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>10 s</td>
<td>5 viewers</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Test 2</td>
<td>800 kbps</td>
<td>1500 ms</td>
<td>6 s</td>
<td>1 viewer</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>6 s</td>
<td>2 &amp; 3 viewers</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>6 s</td>
<td>4 viewers</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>6 s</td>
<td>5 viewers</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Test 3</td>
<td>300 kbps</td>
<td>3000 ms</td>
<td>6 s</td>
<td>1 viewer</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>6 s</td>
<td>2 &amp; 3 viewers</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>6 s</td>
<td>4 viewers</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>6 s</td>
<td>5 viewers</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Test 4</td>
<td>300 kbps</td>
<td>1500 ms</td>
<td>4 s</td>
<td>1 viewer</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>4 s</td>
<td>2 &amp; 3 viewers</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>4 s</td>
<td>4 viewers</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>4 s</td>
<td>5 viewers</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The internet signal was very strong, and therefore the video quality was high. The team selected multiple video bandwidths (300 kbps and 800 kbps) and set the streamer™ for different delay times (1500 ms, 3000 ms, and 6000 ms). As the number of web server
viewers increased, the corresponding actual delay was recorded. After reviewing the results from this test, it was obvious that the number of viewers did not have any significant effect on the video delay. For example, in tests 2, 3, and 4, regardless of the increasing number of web viewers from one to five, the video delay kept constant. In test 1, the change was insignificant.
CHAPTER 6: DISCUSSION OF RESULTS

Based on the tests that have been performed on the Mungo Homes construction sites, it was proven that the use of VPM techniques is promising in the following areas:

1. Virtual site visits and tele-presence of experts, architects, upper management, and other interested parties.
2. Virtual training.
3. Virtual site inspection, monitoring, and determination of percent complete.
4. Virtual checklists.

The team was able to create different scenarios on the site to test the effectiveness of the proposed technology in each area. Units 1201 through 1210 were used to conduct virtual site visits that helped to easily monitor, inspect, and verify the progress and percent complete of the activities in each unit from a remote location. Safety issues in each unit were pointed out whenever any were encountered. In addition, the proposed technology proved to be successful in the virtual training and support of newly hired engineers with limited construction experience. It would help them to become familiar with the site and be able to solve on-site issues. Similarly, this approach is very promising in using the tele-presence of professional engineers to employ their knowledge to help solve problems virtually and immediately, avoiding the extra cost of travel or lost productivity. More completed units on the site were used to compare a virtual punch list with a traditional one. The virtual punch list made upper management at Mungo Homes more involved and aware of the status of the project without any censored or misleading information.
One of the challenges encountered during the testing of the VPM concept was the fluctuating internet signals, which made it difficult for the team to control the quality or delay of the video. Internet signal strength was impossible to predict and therefore made it challenging to control the delay of the video. The team performed delay tests at different times of day with different video bandwidths and summarized the findings in Table 4.
Table 4: Summary of Multiple Delay Tests

<table>
<thead>
<tr>
<th>Test No.</th>
<th>Bandwidth</th>
<th>Delay Time Set on Streamer</th>
<th>Actual Delay</th>
<th>Remarks</th>
<th>Signal Strength</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>300 kbps</td>
<td>1000 ms</td>
<td>4 s</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>300 kbps</td>
<td>1500 ms</td>
<td>6 s</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>300 kbps</td>
<td>2000 ms</td>
<td>6 s</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>800 kbps</td>
<td>2000 ms</td>
<td>6 s</td>
<td></td>
<td>Video not Continuous</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>300 kbps</td>
<td>1500 ms</td>
<td>5 s</td>
<td></td>
<td>Continuous, Better—Quality Video</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>300 kbps</td>
<td>1000 ms</td>
<td>5 s</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>300 kbps</td>
<td>8000 ms</td>
<td>9 s</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>300 kbps</td>
<td>1500 ms</td>
<td>5 s</td>
<td></td>
<td>Continuous, Better—Quality Video</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>300 kbps</td>
<td>1500 ms</td>
<td>5 s</td>
<td></td>
<td>Fair Quality</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>300 kbps</td>
<td>1500 ms</td>
<td>5 s</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>800 kbps</td>
<td>1500 ms</td>
<td>8 s</td>
<td></td>
<td>Continuous, Better—Quality Video</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>800 kbps</td>
<td>6000 ms</td>
<td>9 s</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>800 kbps</td>
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<td>6 s</td>
<td></td>
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<tr>
<td>14</td>
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<tr>
<td>15</td>
<td>300 kbps</td>
<td>1500 ms</td>
<td>4 s</td>
<td></td>
<td></td>
<td>NCSU</td>
</tr>
</tbody>
</table>

It appeared that the streamer™ requires 5 seconds to initialize, which is the minimum duration for the air-cards to connect to the cloud. The streamer™ is designed such that the minimum delay time could be set for 1000 ms. If the streamer™ was manually set for anything below that number, the streamer™ would not be able to connect to the AWS™ Cloud. The third column from the left in this table shows the streamer™ video delay that was manually set by the team, while the fourth column indicates the actual video delay encountered. The bandwidth column represents the selected bandwidth in the video encoder, while the signal
strength column gives an idea of the actual available bandwidth due to the signal’s strength (%) at that particular time and location. This table shows that the streamer™ could be manually set for a lower delay, but the actual delay might still be higher due to buffering. In streaming, buffering refers to bringing in an extra amount of data before playing an audio or video. The team evaluation of the video quality can be seen in the remarks column.

The inferences from Table 4 are as follows:

- The minimum expected video delay is about 5 seconds.
- The signal strength (%) is an important factor that determines the delay to be set on the streamer™ and the quality of the video obtained.
- A better-quality continuous video could be produced if a better internet signal were available. However, when signal strength (%) decreases, the video quality also decreases and noncontinuous, or buffered, video may be encountered.
- To reduce the video delay, the selected video bandwidth in the encoder should be decreased.
- The people on-site should first check the available signal strength to decide what video bandwidth and streamer™ delay should be selected.

The team encountered another challenge when using the streamer™ for both video and audio. First of all, the streamer™ could only stream the video and audio one way. This means that two-way video and audio transmission could not be performed. This generated a need for video conferencing software like Elluminate Live!™ or Skype™ for the two-way communication. Since the main goal of using this technology was to produce high-quality, continuous live video, the team decided to separate the video and audio received via the
streamer™ from the audio received via the conferencing software. The reason for that was to reserve the maximum available bandwidth for the streamer™ to create high-quality, continuous video. At the same time, a MiFi® was used to access the conferencing software. The 5-second delay on the streamer™ created an overlap between the audio received from the streamer™ with the conferencing software. The audio via the conferencing software arrived before the audio and video via the streamer™. To work around this problem and prevent any audio overlap or sound disturbance, the following could be done:

1. Set the audio to be received only through the conferencing software, while the video is received only through the streamer™.
2. The person on the site should use the few seconds of video delay to prepare the participants using the conferencing software to what they are about to see.
3. Avoid unnecessary movement of the camera and wait for the participants’ approval before moving the camera to a different location.

Such approaches would not only help to prevent the audio overlap and improve the audio quality, but would also advance the communication efficiency between the participants regardless of the video delay. In addition, using microphones by all participants, especially the ones at the site, has significantly improved the quality of the audio and minimized any capture of the on-site noise activity. Since, the previously mentioned challenges were somewhat difficult to totally eliminate, these techniques would substantially help to mitigate them.

The team is still in the process of testing the latest updated versions of different devices and operation systems to see if they would reduce the video delay and improve the video and
communication quality. Overall, this approach seems very promising in virtual site inspections, monitoring, percent complete assessments, training, and punch lists, all without the need for the expert’s physical presence at the construction site. The team believes that the research objectives were achieved and are currently planning to experiment with different applications of the technology.
CHAPTER 7: RECOMMENDATIONS AND FUTURE WORK

The fluctuating internet signals appeared to be the team’s main challenge throughout the field tests and made it difficult to control the video quality and delay. Therefore, more collaborative work is currently being done between the Mushroom Networks company and the research team at North Carolina State University to resolve this issue and improve future broadcasts.

Furthermore, it is necessary to point out that the VPM applications are not limited to what has been tested. There are other approaches that would help to achieve the desired advancement in the construction industry. Some of the other applications that the team should consider investigating are as follows:

1. Use the proposed technology to assist and create job opportunities for a large number of unemployed disabled, retired, or senior citizens in the United States. This approach will enable the physically challenged to participate in virtual construction site visits and contribute from remote locations. The department could also provide online training courses and certificates for those who do not have any background in construction to prepare them for the industry.

2. Use of the Tele-Engineering and Management (TEAM) Laboratory for virtual status monitoring of construction projects. The person in the laboratory would be able manage any unforeseen risks and perform a cost/benefit analysis by monitoring the project’s cost and schedule. Furthermore, this person could virtually attend the site
at any time to confirm the submitted documents and reports from the on-site management and verify the actual status of each activity.

3. Use the proposed methodology to perform virtual safety inspections. The team is currently contacting the project managers of Talley’s student center and the new student housing construction sites at North Carolina State University to access those sites to test the efficiency of such an application. Safety is one of the most important factors in construction. Virtual safety inspections can provide immediate feedback and solutions to diverse safety issues at the site. Being able to enforce safety and increase site monitoring and inspections, as well as perform safety inspections and investigations from a distance at any time, would be a significant advantage to the industry.

4. Examine the proposed approach effectiveness in more challenging environments such as a disaster or crisis situation with more of the nonroutine activities that need to be monitored (ex. monitoring bridge bearing that is failing).
CHAPTER 8: CONCLUSIONS

The research team believes this innovative, centralized management approach involving the use of virtual technology has accomplished its goal of investigating how this approach can revolutionize the way the construction industry manages and controls projects. The innovative technique proved its success qualitatively in remote site inspections, monitoring, percent complete assessments, training, and punch lists without the need for an expert’s physical presence on the construction site. In the pilot tests involving Mungo Homes, this contractor’s upper management became more involved in the project and more aware of the actual status of the project. Although the technology, in this research project, was only tested in a residential construction setting, the team believes that the same positive outcomes would be achieved in other types of construction as well. In fact, the proposed technology seems to be valuable for large-size construction companies with many projects in different remote locations in an international context.

The research team received a substantial amount of positive feedback from all participants in this research study. However, some complaints were encountered with regard to the few seconds of video delay. The team introduced some temporary solutions and is currently conducting more tests on the latest versions of different devices and operation systems to provide better solutions. In addition, the team would like to test the technology’s effectiveness in: 1) enabling physically challenged professionals to participate in virtual construction site visits and to contribute from remote locations, 2) virtual status monitoring of construction projects, 3) virtual safety inspections on commercial, civil, and industrial
construction projects, and 4) virtual monitoring of nonroutine activities in more challenging environments such as a disaster or crisis situation.
REFERENCES


APPENDIX A

Dr. Rene Cruz, Chief Science Officer at Mushroom Networks, has developed the following instructions for creating and terminating machine instances:

CREATING:

2. Click "My Account/Console" and select AWS Management Console. After you enter the system, click "EC2" to go to the EC2 console.
3. Click the Instances link in the left frame. Make sure you are in the desired region—US East Coast, in your case.
4. Click the "Launch Instance" button. Select Classic Wizard and click Continue.
5. Select Community AMI tab; in search box enter "streamer" and hit return. After a delay, an entry for the available AMI(s) should appear in window. If there is more than one, select the one with the latest date in the manifest date listed. At the current time, in the US East Coast region, this is the AMI with ID "ami-da2f89b3" and has a name that begins with mushroomnetworks-east-devpayimages/streamer052612B. Click "Select" in the right column.
6. For instance, select Small if it is not already selected. You can leave everything else at default values, and then click Continue.
7. On the next screen, leave default settings (after they have finished loading) and click Continue again.
8. On the next screen, you can type some text below "Value" for a name for the instance (e.g., "Streamer BPA"), so you can identify it in the list of active instances later. Then click Continue.

9. On the next screen, select "Proceed without a keypair," and then click Continue.

10. On the next screen, select the "streamer" security group that was created for you, and then click Continue.

11. Review all settings on the next screen (you can hit the Back button to go to past screens to correct any mistakes). If everything looks OK, click Launch at bottom. You will see a confirmation message in a pop-up window that you can click to close. At this point, you will start to be charged at the associated rate until the Instance is terminated.

12. If you click Instances in the left frame, you will see an entry for a new AMI. Wait for the dot to turn green—this means the AMI is ready. In the "Public DNS" column, you will see a random DNS name assigned to the instance—this has an embedded random IP address, which is the external IP address of the instance, unless you bind it to a fixed "elastic IP address."

13. To bind it to an Elastic IP address (optional—see below), click the "Elastic IPs" link in the left frame. Select the free Elastic IP address created earlier by clicking the check box next to it, and then click on the "Associate Address" link. You will then see a pop-up menu where you can select which of your active instances you want to associate with the Elastic IP address. Choose the instance you created earlier and click "Yes, Associate."
14. After a couple of minutes, your BPA instance should be ready.

TERMINATING:
To terminate a virtual machine instance, go to the AWS console and click the Instances link in the left frame. (Make sure you are in the correct region.) Select the Instance you wish to terminate by clicking on the check box in the leftmost column in the table of instances. **MAKE SURE NO OTHER INSTANCES ARE SELECTED.** Then click the "Instance Actions" button and select "Terminate."