Innovation in Construction Engineering Education Using Two Applications of Internet-Based Information Technology to Provide Real-Time Project Observations

Edward Jaselskis, M.ASCE[1]; Janaka Ruwanpura, M.ASCE[2]; Timothy Becker, S.M.ASCE[3]; Lahiru Silva, S.M.ASCE[4]; Paul Jewell[5]; and Eric Floyd[6]

Abstract: Improvements in construction engineering education result when innovative information technologies are incorporated into academic curricula. Through the use of internet-based communication technologies, no longer must students physically travel to a construction project site to observe and hear construction operations. This paper discusses two applications of internet-based, audio and video technologies currently being piloted at Iowa State University (ISU) and at the University of Calgary (UC) for the purpose of bringing live construction projects into the university classroom. *Virtual Project Tours* have been piloted at Iowa State University in which real-time video and audio are delivered from active construction projects to a remote classroom through the internet. The second application discussed in this paper, *Virtual Supervision*, is being piloted at the University of Calgary and consists of the monitoring and analysis of construction projects by using imagery gathered by web-enabled, digital cameras of fixed location transmitting video through the internet. This paper also presents a vision of a globally networked organization of engineering and construction education institutions each sharing the unique engineering and building techniques of their respective part of the globe with design and construction students located around the world. This exchange of construction project observations among the institutions will be enabled by the internet-based applications of virtual project tours and virtual supervision systems described in this paper. **DOI: 10.1061/(ASCE)CO.1943-7862.0000297.**

CE Database subject headings: Project management; Engineering education; Internet; Information technology (IT).

Author keywords: Virtual project tours; Virtual supervision; Engineering education; Construction education; Project management.

Introduction

Off-campus field trips are time consuming and often inefficient uses of students' limited time resources. Field trips may result in absenteeism in other classes and may also cause significant challenges for students with mobility disabilities. Furthermore, on-site field trips may expose students to safety hazards and also result in lessened communication and participation, and therefore reduced learning, by those students at the rear of a large tour group. Yet, visiting construction projects offers educational experiences for construction and engineering students unable to be taught with still photographs in textbooks or one-directional filmed media. It has been generally believed that only by walking a project could an individual judge the status of the project's schedule, evaluate conformance with safety requirements, or understand the unique physical characteristics of a particular construction site or building project. However, now with modern communication technologies, virtual visits and remote observations may be utilized to augment traditional on-site visits and to reduce the participation hurdles of time and cost.

In virtual project tours, handheld computers, cameras, and mobile phones are used to offer interactive project tours from locations hundreds or even thousands of miles away for students located in a remote classroom. In addition, systems of fixed, internet-enabled, video cameras (referred to as "webcams") allow students to view construction activities in real-time from remote locations. Virtual project field trips and virtual supervision through webcams address the previously noted disadvantages of traditional field trips yet maintain many of the most important learning aspects of real, live construction activity observations.

Literature Review

The most fundamental and widely used wireless communication device is the cellular phone. This common device offers advanced technology beyond simple voice transmission. For example, researchers at the Massachusetts Institute of Technology have collaborated with medical practitioners in the Philippines to transmit

[1]Jimmy D. Clark Distinguished Professor, Construction Engineering and Management, Dept. of Civil, Construction, and Environmental Engineering, North Carolina State Univ., 224 Mann Hall, Raleigh, NC 27695; formerly, Professor, Dept. of Civil, Construction, and Environmental Engineering, Iowa State Univ., Ames, IA. E-mail: ejjasels@ncsu.edu

[2]Professor, Director, and Canada Research Chair in Project Management Systems, Centre for Project Management Excellence, Schulich School of Engineering, Univ. of Calgary, Calgary, Alberta T2N 1N4, Canada. E-mail: janaka@ucalgary.ca

[3]Ph.D. Student, Dept. of Civil, Construction, and Environmental Engineering, Iowa State Univ., 451 Town Engineering Building, Ames, IA 50010 (corresponding author). E-mail: tcbecker@iastate.edu

[4]Ph.D. Candidate, Schulich School of Engineering, Univ. of Calgary, Calgary, Alberta, Canada. E-mail: silval@ucalgary.ca

[5]Program Coordinator II, Professional Education and Industry Relations, Iowa State Univ., 2273 Howe Hall, Suite 1364, Ames, IA 50011. E-mail: pjewell@iastate.edu

[6]Vice President, J. E. Dunn Construction Group, 1001 Locust, Kansas City, MO 64106. E-mail: eric.floyd@jedunn.com

Note. This manuscript was submitted on June 18, 2010; approved on September 20, 2010; published online on September 23, 2010. Discussion period open until March 1, 2012; separate discussions must be submitted for individual papers. This paper is part of the ***Journal of Construction Engineering and Management***, Vol. 137, No. 10, October 1, 2011. ©ASCE, ISSN 0733-9364/2011/10-829–835/$25.00.

X-ray imagery by using a cellular phone platform (Denison 2009). This wireless technology (often referred to as "telemedicine") allows medical experts in distant metropolitan areas to review X rays taken in remote, rural areas.

The construction industry has wide application of cellular phone technology, most commonly for verbal communication. In addition to voice transmission, many construction researchers have proposed the use of wireless communication technologies, including digital cameras and wireless computers, to observe, review, and monitor construction projects. Digital camera technologies and wireless communication services have proven to increase the efficiency of completing many common project management processes.

Internet-enabled, remotely controlled cameras installed at project locations, also referred to as webcams and surveillance cameras, have become prevalent over the last 10 years (Hannon 2007). Digital video cameras are an increasingly common tool for observation, monitoring, and management of construction site operations. The ability to transmit live video images from fixed cameras at the project site to a construction company's central office was identified as an application of internet-based project management systems for the construction industry by Deng et al. (2001). Their research indicated that at the time of the research the limits of data transmission over the internet did not "generate videolike quality images" (Deng 2001). These researchers also identified the benefit of improving productivity through analysis of the images recorded by on-site video cameras.

Early research regarding the collection of field data obtained by digital cameras was also performed by Liu at the University of Illinois at Urbana-Campaign. Liu developed a prototype information collection device, termed a "digital hard hat" (Liu 1997). This innovative, information technology (IT) device included a standard hard hat outfitted with a digital camera mounted above the brim. This "hands-free" camera allowed for the transmission of real-time audio and video from the project site location to a remote office location. In this experimental model, Wi-Fi technology was employed to transmit data from the hard hat to a server located in the project site trailer. From the site trailer, data traveled off-site through a standard, cabled internet service.

Researchers at Carnegie Mellon University have also investigated the application of mobile technology on construction projects (Burgy and Garrett 2002). They studied certain mobile technologies termed "wearable computers," including laptop computers, personal digital assistants (PDAs), and pocket PCs, and proposed an application for these IT devices for the collection of construction project data by recording information relayed by embedded or attached sensors.

Applications of "active data collection" have been further explored through research by Trupp et al. at the University of Illinois (Trupp et al. 2004). Active data collection is performed when on-site construction personnel manually operate the recording devices. These researchers also envisioned automated data collection which would not require user interaction, including fixed digital cameras, 3-D laser scanners and radio frequency identification (RFID) tags.

Research by the National Cooperative Highway Research Program (NCHRP) in 2007 reported the advancement of fixed camera systems from either a single camera per project location or multiple independent cameras per project site to the development of "a networked robotic camera system" in which cameras have robotic features and improved image resolution capability (Hannon 2007).

Silva et al. (2009a) reported that declining construction productivity is resulting from inadequate supervision. This team researched improvement of project management with a "Virtual Supervision" model by using project information obtained by video cameras mounted on tower cranes. The fixed camera-based system allows project supervisors to watch construction activities remotely. The anticipated result of this convenient approach to providing construction supervision is improved operational efficiency, increased quality of communication, and enhanced construction worker satisfaction.

Researchers at Purdue University have connected the availability of communication technology with the need to provide engineering and construction students with observations of active construction projects (Shaurette 2009). With a handheld, digital video camera tethered to a mobile base station, Shaurette was able to transmit audio and video from project locations to remote classrooms over cable-based internet services. Shaurette's testing of "Wireless Webcam Field Trips" has validated the promise of such a remote tour but also has identified certain technological hurdles (specifically noting bandwidth limitations) and necessary and significant cost expenditures. These and numerous other research efforts strongly support the continued use of wireless and internet-based technologies to advance efficiency and convenience within the construction industry.

Virtual Project Tours (Iowa State University)

This paper will first provide details of the Virtual Project Tours application developed at Iowa State University. A *virtual* construction project tour as defined by this paper is a tour or presentation of a construction project of any type, including a land area undergoing civil works or a building under vertical construction, in which the practical effects of an on-site tour are achieved without requiring physical presence by those receiving the tour at the actual construction location. In the context of this research, a "virtual" tour refers to observing the actual, physical conditions of the project by using video and media communication technologies. This application is specifically differentiated with a virtual tour provided with a computer-generated model, e.g., Building Information Modeling (BIM). Such a project demonstration is also commonly referred to as a "virtual tour" in current literature.

Execution of the virtual tour pilot program by Iowa State University has required the research, selection, and integration of several information technology devices including a digital camera, voice recorder/microphone, and wireless mobile computer. Second, software and communication services were researched and selected to allow voice and video information to be transmitted from each mobile device through the internet to multiple large television screens and speaker system in a remote, high-technology classroom. Furthermore, the tour delivery process was designed for two-way interaction, allowing students to ask questions of the project tour guide, thereby achieving real-time dialogue. The tour technology also provides digital recording, which allows for future asynchronous showings of the tours.

The experiment methodology for the virtual project tours included multiple pilot tours performed over more than two years so that "bugs" in the system could be worked out and emerging technologies could be tested. Following the completion of pilot tours, the tour guides and student participants were asked to provide feedback on the quality of educational experience, advantages, and disadvantages of virtual tours compared with typical on-site field trips and suggestions of improvements that could be made. This participant feedback was provided through both written survey instruments and oral feedback.

Technology Elaboration—Virtual Project Tours

By using a handheld digital video camera, minicomputer, and standard cellular phone, project personnel walk a designated job site, narrate, and transmit (or "beam") live action back to the classroom

J. Constr. Eng. Manage., 2011, 137(10): 829-835

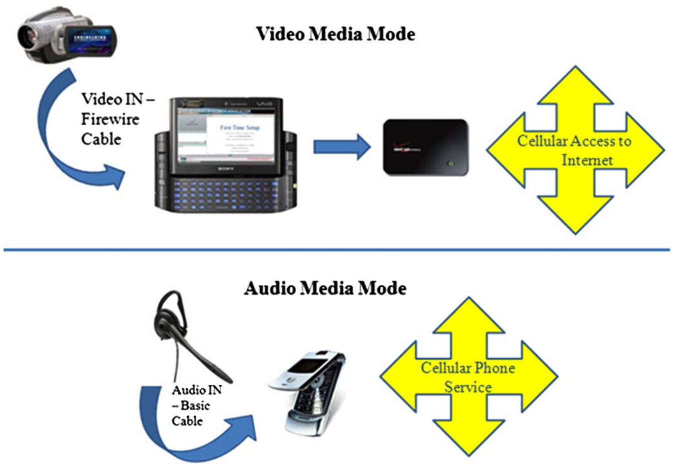

Fig. 1. Bimodal information flow and videography devices

in real-time through commonly available, cellular internet, and cellular voice/phone services. Students are able to view the project conditions and converse with job-site personnel as the action happens, experiencing project management situations as they occur. Fig. 1 depicts one of the two sets of devices used for this experiment.

All of the necessary devices to conduct a virtual tour are either handheld (e.g., video camera) or wearable (e.g., minicomputer and cellular phone are held in a satchel and headset type microphone/earphones are hands-free) which allows for mobility of the tour guide. To collect video imagery, the tour guide uses a Sony Vaio UX-390n computer that is similar in size to a portable DVD movie player and is designed to be mobile with built-in wireless and cellular broadband capabilities. Although this minicomputer has two built-in cameras for providing live video feeds of the narrator's face or a point-of-view shot of the construction site, researchers have connected a ubiquitous Sony Handycam camcorder by use of the minicomputer's USB port. The independent video camera adds zooming functionality and higher quality resolution not available with the computer's internal camera. The zooming feature is especially advantageous for long distance shots in which heavy equipment, treacherous topography, and other project-specific hazards prevent the tour giver from maneuvering to close proximity of the active construction work zone.

Two approaches to delivery of audio have been tested, one using voice over internet protocol (VOIP) and the other standard cellular, mobile phone. In each approach, a headset-style microphone is worn by the tour narrator under a hard hat. When using VOIP, the headset plugs into the minicomputer and enables the two-way audio communication with the remote location (the "unimodal approach"). In the second approach, the video remains to be transmitted through the minicomputers connection to the internet, but the headset/microphone is connected to a separate, independent cellular phone (the "bimodal approach"; Fig. 2).

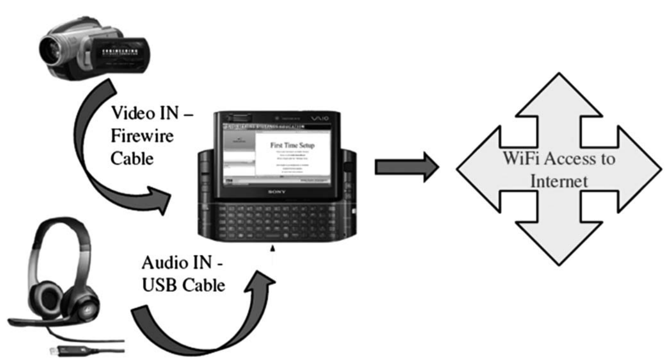

Fig. 2. Unimodal information flow and videography devices

Researchers have tested 3G cellular-based internet services offered by AT&T and Verizon and 4G cellular-based internet service offered by Sprint, obtaining essentially similar results with each. Pilot virtual tours have been completed by using both built-in cellular capability within the Sony Vaio and with external devices, such as Verizon's "Mi-Fi" and Sprint's "Over-drive." Each device is a small (ranging in size of 1–2 credit cards), external internet "hub" devices that can provide a localized "hot spot" of cellular service for numerous, proximate computers.

In 2008, Iowa State University performed numerous pilot virtual tours by using a wireless local area network (LAN) system from Trapeze Smart Mobile. This fixed equipment was deployed to blanket the work site with Wi-Fi coverage. In 2008, the 3G cellular services used in the 2010 pilot tours was unavailable. The media quality delivered by the fixed Wi-Fi setup is marginally better or equivalent compared with mobile cellular services, depending on the line of sight or other physical obstacles between the tour broadcast equipment and the Wi-Fi signal receiver. The significant cost and setup effort required to install a fixed Wi-Fi network makes such a method practically unfeasible for a single project tour. If the project location already has a Wi-Fi setup in place, this remains a viable solution to transmitting media from a project location. Iowa State University has focused on mobile cellular-based connections rather than Wi-Fi setups for its continuing experimentation with virtual project tours. It is believed that wireless internet services to be commercially launched over the next 2–3 years will provide the bandwidth necessary to achieve typical television-quality media transmissions.

During the 2008 pilot tour experiments, researchers tested the use of VOIP to transmit both the audio and video portions over the same Wi-Fi based connection to the internet (previously term as a unimodal approach). On the basis of the experiences of numerous pilot tours, it has been determined that separating the video and audio onto separate connections provides for a more robust delivery of media, in part because if one connection to the classroom fails (either the video or audio transmission), the other connection remains intact.

In addition to experimenting with different hardware devices and communication services, the researchers at Iowa State University have also tested the benefits of synchronous versus asynchronous delivery of media from the construction projects. Synchronous media is provided live, real-time with students or other remote participants viewing and hearing the tour presentation as it is given. With asynchronous delivery of media, the tour is prerecorded before presentation to the classroom, similar to a traditional film. An asynchronous tour of the Hach Hall construction project was provided to engineering students at Iowa State University on March 26, 2010. An asynchronous delivery offers benefits that are not available with synchronous delivery, such as editing, fast-forwarding, and pausing of the video for discussion and questions. Asynchronous tours could be enhanced by live, in-classroom presentation of the prerecorded tour video by the original tour guide, a *narrated asynchronous tour.* Although not fully virtual, this solution limits travel to one individual from the project site to the classroom in lieu of an entire classroom of students to the project site, allows for editing of the tour media, and eliminates the risk of communication failures during the class time.

J. Constr. Eng. Manage., 2011, 137(10): 829-835

Lessons Learned and Next Steps—Virtual Project Tours

The pilot virtual tours conducted in 2008 included 5–10 min segments of audio and video with gaps of similar amounts of time that occurred while the tour guide navigated around the job site in search of a location that both had Wi-Fi coverage and a construction operation that was of interest for the students. Positive feedback suggests that students will accept a certain amount of short interruptions in the audio and video feed and some harsh audio to have the opportunity of a remote construction tour.

Maintaining a Wi-Fi signal proved more difficult as the building enclosure became partially complete. Strategically placing Wi-Fi antennas to provide complete job-site coverage was challenging. This problem was mitigated when the antennas were moved to higher locations, such as attachment to the tower crane mast. Yet even when the antenna was placed in the best locations, constant vigilance was necessary to ensure that construction activity did not block the signal. The problems described can be avoided by use of cellular internet service.

The numerous pilot tours performed in 2010 with cellular service did not require installation of Wi-Fi antennas. The tours ranged from approximately 20–45 min, generally without interruption because of loss of internet connection. Furthermore, virtual tours using cellular-based internet services were performed of fully enclosed buildings, including basement areas. The quality of the video diminished when transmitted from the basement levels, but video was transmitted and students could nonetheless follow along with the tour guide. Such transmission is not possible with the original Wi-Fi setup, which required a "line of sight" between the Wi-Fi antenna and minicomputer.

At times, a high volume of noise caused by background construction operations caused difficulty for the tour narrator to hear questions from the classroom and also reduced the clarity of audio delivered to the classroom. By the nature of construction projects being both outdoors and involving loud equipment, background construction noises can easily interfere and potentially even inhibit the comprehension of the tour guide's audio information by the classroom audience. Also, wind noise significantly detracted from audio quality of many of the experimental virtual tours. Efforts to protect the microphone from wind somewhat mitigated the problem but failed to provide a fully effective solution. Background noise reduction functionality is a technology with direct application to virtual tours of construction projects. Future research could include incorporation of "smart" noise reduction technology into the microphone apparatus used by the on-site tour guide. It is hypothesized that automatic elimination of background construction and wind noise will significantly improve the clarity of audio transmitted to the classroom and greatly improve the learning experience.

During certain experimental tours, a standard cellular phone was used as an alternate to the headset microphone and often provided considerable improvement in audio clarity. It also offered the benefit of an independent voice connection to the classroom, separated from the mobile computer's connection through the internet. At times when the Wi-Fi connection failed causing the video feed to drop, the use of an independent cellular phone allowed the tour to continue with audio-only until the digital feed could be reestablished with the classroom. Because of the experience gained from these test tours, it is recommended to have either an independent or backup audio connection that allows the tour guide to communicate with the audience at those times when the video connection is lost.

The selected camcorder required operation by hand. At times, however, the tour guide required use of hands to safely traverse the construction site and avoid construction hazards. A hands-free camera, such as hard-hat mounted, could offer some advantages in this regard. However, the narrator still requires an option to adjust camera settings, such as zooming in on the details of a specific construction activity or as-built condition. In the future, voice activated technologies may offer a solution to this human-equipment interface.

Numerous pilot and test tours have been executed by researchers at Iowa State University. Representatives of four construction companies, one architectural firm, and the Iowa Department of Transportation have participated in the virtual project tour experiments. More than 100 engineering students have witnessed a virtual project tour and one student served as the virtual tour guide. For three tours presented to students during spring 2010 semester, survey questionnaires were used to collect student feedback. The following paragraphs present details of these tours. Table 1 presents mean scores to various evaluation questions asked of the students. The student response demonstrated by the surveys indicates learning is accomplished through virtual project tours but can be enhanced with improved video quality. Perhaps the strongest point indicated by the surveys is that the students believe virtual project tours offer a valuable tool for the future of construction project management and engineering.

On April 6, 2010, 55 civil engineering students at Iowa State University participated in a synchronous, virtual project tour of completed road improvements located on South 16th Street in Ames, Iowa. These students had been learning how to interpret engineering drawings and specifications by using the for-construction documents of this particular project; therefore, touring the completed project offered an enjoyable and beneficial educational experience. Despite a poor, cellular-based internet connection, the majority of students indicated that they had learned from the tour.

On April 15, 2010, 34 construction engineering students at Iowa State University observed an asynchronous, virtual project tour of Hach Hall, a new chemistry research, teaching and administrative building under construction on Iowa State University's campus. This tour was originally recorded on March 26, 2010.

On April 22, 2010, 34 construction engineering students at Iowa State University observed a synchronous, virtual project tour of the Bio-Renewables Laboratory, a new biotechnology research and administrative facility under construction on Iowa State University's campus. This tour included an additional experimental component because it involved an architect who participated from his office in Des Moines, Iowa. The architect, like the students, viewed the tour remotely and participated in the conversation by using a conference call service. Through their survey responses, student participants indicated strongly that a synchronous versus an asynchronous tour is both a better learning tool and an overall more enjoyable experience (Table 2).

Virtual Supervision Application (University of Calgary)

Researchers of the University of Calgary recently launched a state-of-the-art Construction Monitoring and Visualization Centre (CMVC) for the purpose of remotely monitoring construction activities in real-time. In 1785, an English philosopher and social theorist named Jeremy Bentham initially developed remote monitoring. Bentham's concept is effectively amalgamated with the use of web-based, remotely accessible cameras to develop the CMVC. The system functionality includes zooming, changing direction, focusing on a certain object when required, and archiving images or video throughout the day in all working days (Silva et al. 2009b). Researchers can use this system to visually assess the construction

J. Constr. Eng. Manage., 2011, 137(10): 829-835

Table 1. Summary of Pilot Virtual Project Tours Performed by Iowa State University

Date	Location	Attributes
2008 (numerous)	J.E. Dunn Headquarter Building (construction site), Kansas City, MO	Video was delivered from mobile Vaio CPU to fixed, project-based Wi-Fi internet service; audio was delivered in two ways: integral VOIP and separate cellular phone.
1/15/2010	Test location, Des Moines, IA	Video was delivered from mobile Vaio CPU through AT&T internal internet card (3G); audio was delivered through integral VOIP and separate cellular phone; synchronous delivery of media to research team.
2/26/2010	Wellmark Insurance Building (construction site), Des Moines, IA	Video was delivered from mobile Vaio CPU through AT&T internal internet card (3G); audio was delivered in two ways: integral VOIP and separate cellular phone; synchronous delivery of media to research team.
3/26/2010	Hach Hall Chemistry Building (construction site), Iowa State University, Ames, IA	Video was delivered from mobile Vaio CPU through Verizon Mi-Fi internet device (3G); synchronous delivery to research team members; asynchronous delivery to classroom of students.
4/6/2010	16th Street Bridge and street improvements, Ames, IA	Video was delivered from mobile Vaio CPU through Verizon Mi-Fi internet device (3G); external improvements rather than inside building; marginal weather conditions; synchronous delivery of media to classroom of students.
4/22/2010	Bio-Renewables Lab Building (construction site), Iowa State University, Ames, IA	Video was delivered from mobile Vaio CPU through Verizon Mi-Fi internet device (3G); synchronous delivery of media to classroom of students; incorporated synchronous involvement by project's architect at third location.
6/11/2010	Johnson County Juvenile Detention Center (construction site), Olathe, KS	Video was delivered from mobile Vaio CPU through both Verizon Mi-Fi cellular internet device (3G) and Sprint "Overdrive" cellular internet device (3G); synchronous delivery of media to classroom of engineering students; incorporated synchronous involvement by an architect at third location.
7/1/2010	State Gym renovation and addition (construction site), Iowa State University, Ames, IA	Video was delivered from mobile Vaio CPU through Verizon Mi-FI cellular internet device (3G); synchronous delivery of media to classroom of engineering students; incorporated synchronous involvement by senior project management at third location (Eagan, MN).
7/20/2010 and 7/21/2010	Numerous different transportation work zones located throughout northwest Iowa	Video and audio were collected both synchronously and asynchronously. Media was collected both in daytime and nighttime. All media was collected from within a moving vehicle. Synchronous delivery was achieved by using the Version Mi-Fi. Asynchronous delivery was recorded by typical laptop computer with Camtasia software. The media clips were asynchronously captured and shortly thereafter transmitted to FTP site through Mi-Fi cellular connection to internet for remote viewing.
8/13/2010	Kaufman Performing Arts Center (construction site), Kansas City, MO	This was the first virtual tour conducted by using 4G cellular service by Sprint. The connection was robust although not noticeably improved from 3G services. The video was synchronously delivered to remote student and faculty in Ames through the internet. Audio was transmitted by separate cellular connection to conference call system (audio was unintentionally not recorded).
8/13/2010	Todd Bolender Center for Dance and Creativity (renovation construction site) Kansas City, MO	This tour was synchronously delivered to a remote student and an industry representative (each in different locations) through 4G internet for video and standard cellular phones for audio. Video and audio were recorded. Given its renovation nature, this project had significant demolition background noise. The zooming feature of the camcorder was necessary to view high elevation and basement locations, which were infeasible to view close-up.

Table 2. Summary of Student Evaluations of Virtual Project Tours

Parameters	Hach Hall Chemistry Building	16th Street improvements	Bio-Renewables Laboratory
Date of Survey	3/26/2010	4/6/2010	4/22/2010
Sample Size	34	55	34
On a scale from 1 to 10 with 10 being the best, did you learn something from the virtual tour?[a]	7.5	6.1	8.0
On a scale from 1 to 10 with 10 being the best, rate the video quality of the virtual tour.[a]	6.7	5.5	6.1
On a scale from 1 to 10 with 10 being the best, rate the audio quality of the virtual tour.[a]	8.2	6.3	8.9
On a scale from 1 to 10 with 10 indicating a high quantity of applications, rank the quantity of construction management applications can you envision using virtual project tours in the future.[a]	8.4	7.4	8.6

[a]Mean values of the student responses are displayed in this table.

J. Constr. Eng. Manage., 2011, 137(10): 829-835

Fig. 3. Photograph of the Construction Monitoring and Visualization Centre (CMVC)

operations without interfering with the construction activities as identified by Hewage and Ruwanpura (2006).

By using the technological infrastructure in the CMVC, researchers can monitor different construction activities concurrently and provide an uninterrupted delivery of real-time video imagery to remote researchers and other stakeholders (Fig. 3).

The CMVC consists of two identical, high performance video servers and an array of hot plug hard drives. The redundancy of the system is achieved through the two video servers. In case of a breakdown by one of the two servers, the standby server will continue an uninterrupted service. The disk array connected to the servers has the capacity to store 10 terabytes (TB) of data. The CMVC consists of multiple large video screens for observers to view and monitor construction activities (Fig. 4).

A few researchers have the capability for simultaneous monitoring and sufficient capacity is available for an increased number of viewers. The infrastructure of the facility was designed for easy upgrade in the future. CMVC enables the researchers to virtually observe a project from any part of the world. This opportunity will improve the quality of the research work and the productivity of the research teams. Further, the Centre enhances the capability of graduate students to gain real construction management experience.

The remotely accessible camera systems connected to the CMVC offer many useful features such as full 360° rotation, −170° to 170°

Fig. 4. Screen shot of the interface for the camera control

panning, 25 times optical zooming, 300 times digital zooming, and 736 × 480 resolution capabilities. The enclosures of the cameras are designed according to C-4150J military standard (EverySpec 2009), which is able to withstand temperatures ranging from −45 to +50°C. The system has the flexibility to change the frame rate from 1–30 frames per second, depending on the data rate and the available bandwidth.

The archival facility installed in the video server has the capacity to store video data for 3 years from 20 cameras if the cameras are operated for 10 h per day. Selecting from a wide variety of existing video archiving software available, the University of Calgary research team selected a system that is capable of handling multiple cameras and archiving video images simultaneously [Mattern et al., U.S. Patent Application No. 20060174302 A1 (2005)]. The digital video cameras are programmable for 20 different preset locations with different viewing settings.

The software creates time-lapse videos by taking snapshots of the preset locations based on any of the preferred settings specified by the research team or the contractor. The software also offers administrative functionality with a user login protocol and the ability of the research team to regulate differing privilege levels for research team members, research partners and guests to the system. The system administrator has a full setup control and access to all the cameras in the system. The research team has the ability to create user accounts with limited access for research partners depending on their requirements. Furthermore, temporary user accounts may be created upon the requirements of the partners for events such as site meetings held in virtual space. For these meetings, temporary accessibility is given to the client's and consultant's staff to remotely view the imagery from the cameras.

The first pilot study conducted by installing a camera to test "Virtual Supervision" was very successful. This camera was tested at a five-story office building construction site at the University of Calgary. The access of the camera was given to the contractor's site management team, which included a construction manager, project superintendent, concrete superintendent, safety officer, and project field engineer. After using this camera for more than five months, the researchers conducted a workshop with the project team to solicit and document their experiences. The most common purposes reported were construction monitoring from a bird's eye view, evaluating safety conditions, and remotely auditing the project progress. The team expressed that the camera assisted them on a daily basis to act proactively. This included the opportunity to monitor the site from any place, improve communication between the site management and the workers, ability to view archives (if required), assist project coordination, and improve project safety. Two specific examples are: the safety officer stated that the camera was used to enhance the safety of the workers, and the safety officer shared video with the workers of certain unacceptable safety practices observed through the cameras. The project superintendent too, emphasized how the camera was used to monitor a concrete operation and to reduce the truck turnaround times and to reduce the nontool time of the construction workers.

Captured digital images can be incorporated into training and capacity building exercises for construction personnel, whereas recorded videos may be used for the orientation of new recruitments. As identified by Silva et al. (2009a), the secondary-level benefits (subject to the approval of the Conjoint Faculties Research Ethics Board at the University of Calgary) include the following:

1. Usage of video recordings as a learning tool;
2. Productivity enhancement through off-site monitoring;
3. Review of the completed construction work and use of the videos as a backup to demonstrate progress; and

J. Constr. Eng. Manage., 2011, 137(10): 829-835

4. An educational tool for undergraduate teaching and the potential to develop teaching materials to support undergraduate/graduate level courses (e.g., Construction 101).

Construction 101 through Remotely Accessed Cameras

Typically, when an instructor teaches a construction-related undergraduate or graduate course, real life examples are introduced to explain construction methods and processes. The instructor could use diagrams, photos, slides, or videos to illustrate these concepts. However, students may have difficulty in understanding these concepts unless they can visualize them. Videos are the best way to illustrate these concepts. The systems developed at ISU and UC offer students the opportunity for visualization and interaction with remote projects.

By using the ISU and UC-developed systems, students have the opportunity to visualize the construction operations in two ways: (1) students can view and/or hear live construction operations from any construction site anywhere during their class time; and (2) students can view the archives of the construction videos and may use them for assignments.

Technically, a new course can be designed by dividing the course into various modules of construction processes and then teach them by using the archived video or real-time virtual tours of actual construction projects. With access to video originated through ISU and UC, the students at both locations will get the benefit of visualizing the construction operations in the United States and Canada. This will also provide some unique learning experiences for students. For example, the students at Iowa State University will be able to see the winter construction under harsh conditions common to Calgary and will be able to view the regionalized methods required to construct buildings under these conditions. ISU and UC are planning to go beyond North America with collaboration among several universities in Asia and South America. Although most Asian countries do not have relatively cold temperatures, the students in these countries could observe the uniqueness of winter construction. Similarly, students in North America could witness specialized facets of construction operations with severely hot temperatures. The media filmed in countries around the globe and distributed through a globally networked organization of engineering education institutions could provide access to international construction projects otherwise unavailable to engineering students.

Conclusion

Experimentation and testing of the virtual project tours and virtual supervision as described in this paper have validated the potential for these innovative teaching methods to benefit construction education. Through these technologies, students who were previously unable to view live construction operations because of geographic, time, cost, or other constraints are now enabled to easily participate. These experiments have proven that modern video equipment and internet communication technologies allow, in concept, for on-site construction professionals to conduct real-time, virtual construction project tours and to remotely supervise construction activities. These results provide the basis to explore further applications of these internet-based technologies, not only for construction education around the globe but also for use in commercial and industrial applications.

Acknowledgments

The researchers at Iowa State University are deeply grateful for the foresight of Jack Taylor, construction engineering alumnus, who provided educational funds for development of new and innovative methods for educating construction engineering students at Iowa State University.

The researchers from University of Calgary wish to acknowledge the support and funding for this research project by Canada Research Chair Program, Canada Foundation for Innovation, CANA, PCL, EllisDon, Graham, Ledcor, Stuart Olson, Revay & Associates, Canadian Construction Research Board, and Calgary Construction Association and Natural Sciences Engineering Research Council (NSERC) for their commitment for the research through the CRD Grant No. CRDPJ 341047-06.

References

Burgy, C., and Garrett, J. H., Jr. (2002). *Wearable computers: An interface between humans and smart infrastructure systems*, Bauen mit Computern, Bonn, Germany.

Deng, Z. M., Li, H., Tam, C. M., Shen, Q. P., and Love, P. E. D. (2001). "An application of the internet-based project management system." *Autom. Constr.*, 10(2), 239–246.

Denison, D. C. (2009). "MIT project leads to programs that help heath workers, farmers in developing countries." *Boston Globe*, Oct. 14.

EverySpec. (2009). "MIL-C-4150." ⟨http://www.everyspec.com/MIL-SPECS/MIL+SPECS+(MIL-C)/MIL-C-4150J_6264/⟩ (Feb. 14, 2009).

Hannon, J. J. (2007). "Emerging technologies for construction delivery." *NCHRP Synthesis 371*, National Cooperative Highway Research Program of the Transportation Research Board, Washington, DC.

Hewage, K. N., and Ruwanpura, J. Y. (2006). "Carpentry worker issues and efficiencies related to construction productivity in Alberta's commercial construction projects." *Can. J. Civ. Eng.*, 33(8), 1075–1089.

Liu, L. Y. (1997). "Construction field data collection using the 'digital hardhat'." *Proc., ASCE 1997 Construction Research Congress V*, ASCE, Reston, VA, 399–404.

Shaurette, M. (2009). "Wireless webcam field trips." VDM Verlag Dr. Müller Aktiengesellschaft and Co., Saarbrücken, Germany.

Silva, L. P., Ruwanpura, J. Y., and Hewage, K. N. (2009a). "Virtual supervision in construction projects." *Proc., ASCE 2009 Construction Research Congress*, ASCE, Reston, VA, 487–496.

Silva, L., Ruwanpura, J., Wickramaratne, S., and Hewage, K. N. (2009b). "Construction Visualization and Monitoring Centre." *Proc., 2nd Int. Construction Specialty Conf.*, CSCE, Montreal.

Trupp, T., Soibelmann, L., Hashash, M., and Liu, L. (2004). "Novel technologies for construction field data collection." *Int. Conf. on Computing in Civil and Building Engineering, ICCCBE, 10*, Bauhaus-Universität, Weimar, Germany.

J. Constr. Eng. Manage., 2011, 137(10): 829-835