Experimental Assessment of Wireless Construction Technologies

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Abstract: Wireless technology offers a first efficient avenue to communicate data within a construction site in real time. This paper presents the integrated wireless site (IWS) concept that is based on a meshed communication network that not only reaches almost every location of a site but is also connected to the World Wide Web. Lessons learned from installing and evaluating wireless mobile and fixed video devices during ongoing construction are shared. The relevance of this study to both practitioners and researchers are the experimental field data that assert technical feasibility as well as a series of benefits such as reduced non-value-added activities, quick response to safety hazards, and automatic as-it-was-built for documentation and training. Equally important was the finding that the success of this technology in the long run depends on trust, collaboration, and information sharing among participants. Expanding the IWS by incorporating a semantic network that integrates individual equipment, tools, specialty devices, and construction personnel promises to provide the necessary incentives for a revolutionary change in the way construction resources communicate.

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Introduction and Background

One key factor that contributes to low performance in construction is lack of effective communication. A survey given to 119 foremen on 11 different construction projects showed that the source of production delays cited most was "unanswered questions" (Elliot 2000). A variety of factors—fragmentation of the industry, temporary relationships between project participants, the adversarial relationships between parties founded on the lowest-bid or zero-sum game "culture" of the industry, and the constantly changing jobsite environment, weather, and other unforeseen conditions—has made the establishment of reliable site-based management information systems particularly challenging. However, recent advancements in information and communications technology (ICT) seem to be particularly promising for use in construction. Back in 1997 De la Garza and Hovitt already hypothesized that: "Because timely access to information is what keeps relevant information from becoming irrelevant, applications of wireless data communications technology have the potential of reaping more productivity benefits than the ones achieved already by applications of wireless voice communications technology, e.g., walkie-talkies" (De la Garza and Howitt 1997). Most especially, the shift from analogue to digital technology opened up an almost limitless field of opportunities. Now, data and information can be exchanged synchronously not only between humans but also between humans and machines or between machines themselves. For example, a crane working on a jobsite can be equipped with sensors, an interface device with a wireless transmitter to report autonomously its work status (e.g., safe handling), or it can be warned via a wireless weather-station when wind speeds are reaching a dangerous level. A delivery truck on the road equipped with GPS telematic devices allows both driver and site manager to effectively planning and control site logistics in real time.

While it is certainly interesting to suggest a long list of possible applications, the questions about is field worthiness, usability, and its "return-on-investment" can only be answered through experimental work in the real world of construction. This paper reports about an investigation to address those questions presenting several lessons learned of value to a contractor who plans to install a wireless system on his/her site. The following section introduces the underlying models developed to integrate the wireless site into the ever-growing world wide network.

Information Logistics in Construction

Traditionally, project teams rely on communication channels such as phone/radio, E-mail, letter, and face-to-face meeting to distribute/share information. However, none of the channels is sufficient to cover all their needs. The omnipresent phone/radio, while fast and convenient, is limited to one-to-one communication. The face-to-face meetings, on the other hand, provide an opportunity to communicate any kind of information to every party at the same time (one-to-many), but are asynchronous and expensive, especially when the team includes members that are located in different city or even countries. These communication channels are components of the overall information logistics (IL) model. Information logistics is considered an imperative part of logistics complementing physical logistics. Mellyn and Groeve (2000) defined the information logistics revolution as "the ability

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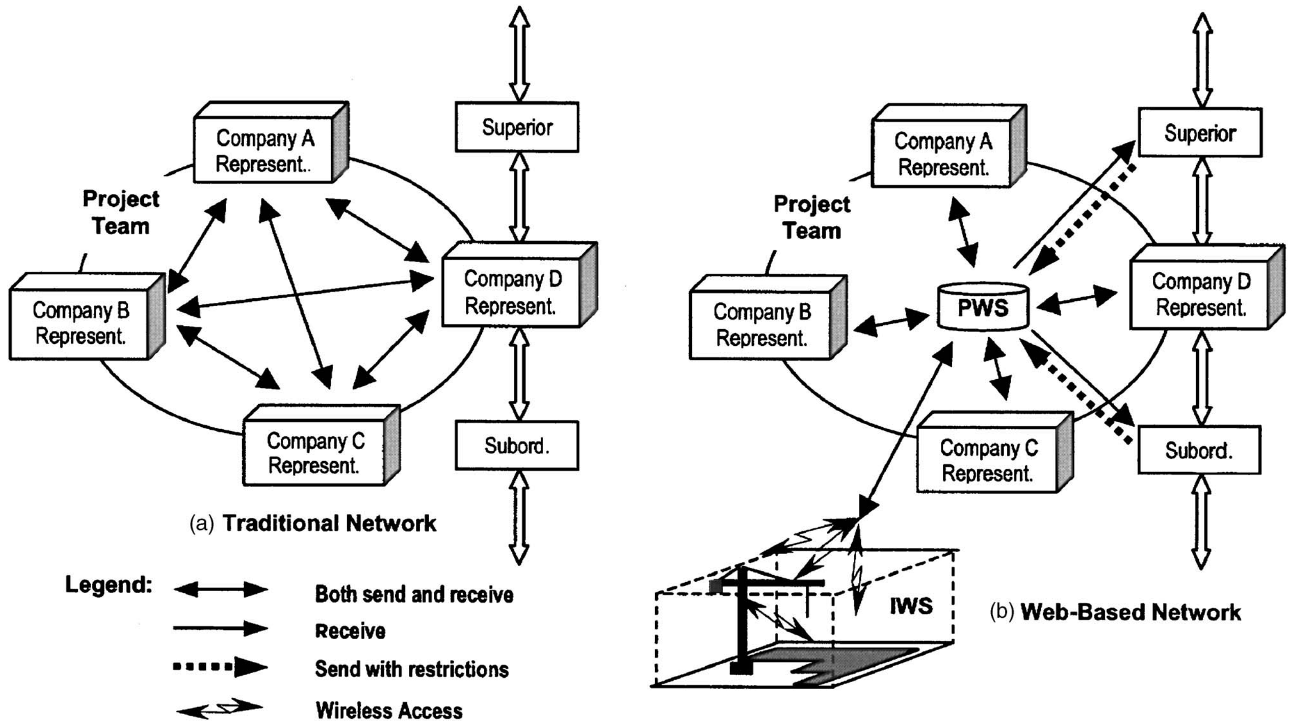

Fig. 1. Information flow structures in construction

to exchange and process ever-increasing volumes of information between economic actors at ever-decreasing cost to achieve just-in-time procurement manufacturing and distribution."

Fig. 1 compares two communication networks. Fig. 1(a) models the traditional structures found commonly in construction. Formal communication is following either horizontal or vertical paths. Informal communication between project members, of course, does not follow such strict channels, but fulfills an important role in complementing and speeding up the formal format (Attia 2002).

Fig. 1(b) on the other hand represents a situation in which a central hub links all the participants in away similar to an airline hub, which receives, swaps, and sends out airplanes with legitimate passengers. Dubbed the project-wide Web-site (PWS), this hub lets authorized "lines" submit, exchange, or access information. Another key difference between Figs. 1(a and b) is the link from the Web site to an access point within the construction site enabling wireless communication to and from transmitters/receivers within the envelope of the construction site. This wireless network covering the construction site, referred to as the integrated wireless site (IWS), constitutes the gateway to real-time information in the form of video images, environmental condition measurements at various locations, data received from radio-frequency identification (RFID) tags, equipment status, etc. On the other hand, wireless receivers will be able to access the PWS from anywhere on-site to request information such as drawings or specifications.

The digital format of wireless communication opens the possibilities to link sensors and devices that are mounted on equipment, machines, and tools to the IWS. One example is the intelligent crane safety monitoring system (Bernold et al. 1997). The simple architecture and the transportability of the sensors provide opportunities for utilizing the concept for many types of cranes or even for other machinery where unsafe conditions cannot be detected easily by an operator. Fig. 2 depicts how Black-Box Technology (BBT) provides the digital interface between the embedded "intelligence" that supervises the different sensors mounted on the crane and the IWS. Since the IWS is connected to the PWS or the World Wide Web, anybody, including remote data collection or a control system that meets the access requirements, will be able to interact either passively or actively with the crane's safety monitoring system.

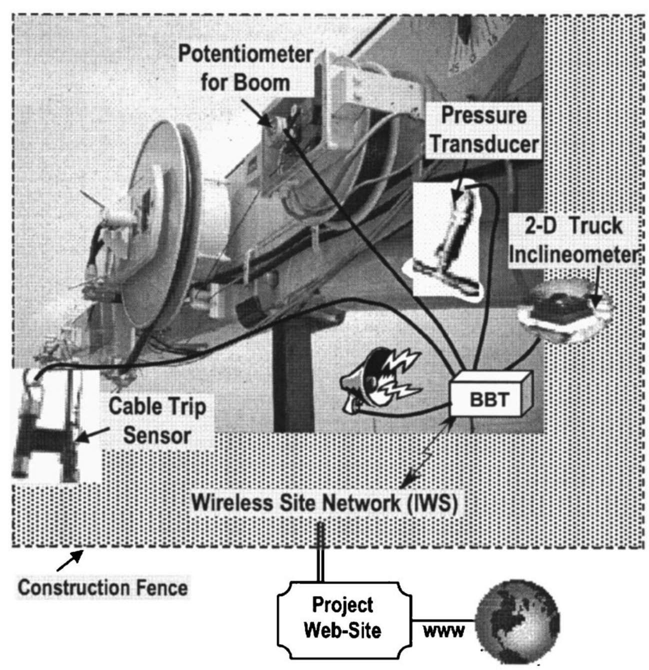

Fig. 2. Crane safety monitoring system linked to the World Wide Web

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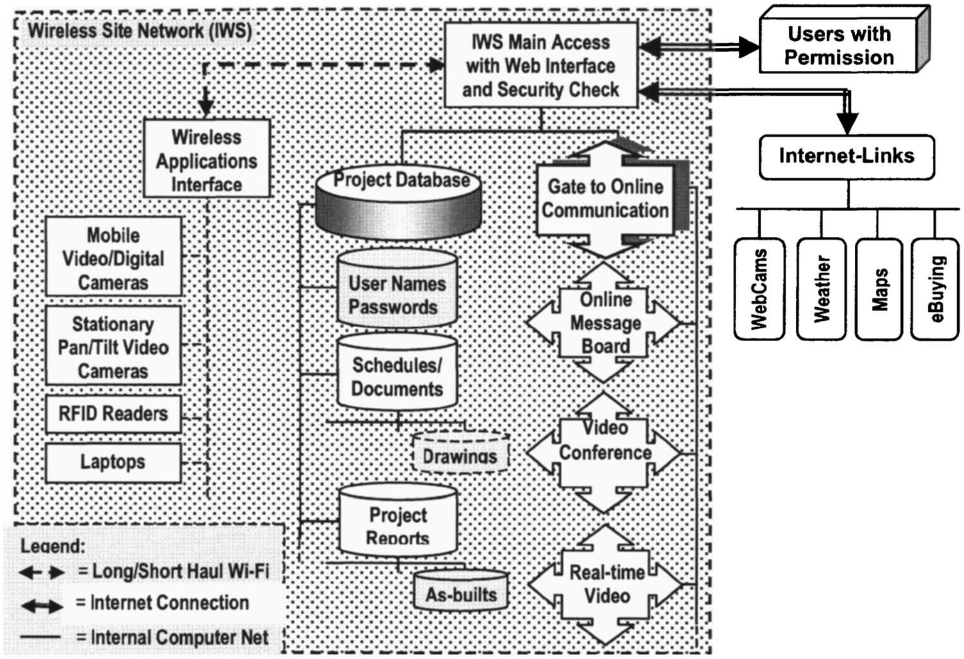

Fig. 3. Structure of project-wide communication network

In terms of planning and control function, IWS supports integrated planning and control both horizontally and vertically. Managers at any level have synchronous access to check progress status at any time. In fact, suppliers and specialty contractors are now able to verify the availability of space or the proper supply material on their own. In order to test the IWS model with presently available wireless hard- and software, focusing on long-haul communication and video/digital cameras, a prototype system was developed and installed on a real construction site.

Implementation of an Integrated Wireless Site

Fig. 3 presents a schematic of the tested wireless site network linked to the World Wide Web through a firewall. Authorized users from the project team were able to link to the network cameras via the Internet, thus allowing them to monitor the work from any place that provided fast Internet access. The wireless network included stationary and mobile cameras that were linked via a repeater and Long-Haul Wi-Fi to an off-site computer subsequently referred to as a visual-based integrated wireless site (V-IWS).

For the installation of Wi-Fi technology one is obligated to follow federal as well as local rules and regulations intended to minimize the interference between the users of radio equipment operated in unlicensed bands. In the United State, Wi-Fi is governed by Part 15 of Title 47 of the FCC Code. Security is also an essential consideration when implementing WLAN network. Without security protection such as firewall, anybody could access the system/Internet though the created "hotspot." In this experiment, the V-IWS had been set to allow only computers and network devices with authorized MAC address to access the wireless network.

Development of Test Facility

The V-IWS was implemented and tested at the Undergraduate Science Teaching Lab (USTL) construction project located on NC State University main campus in Raleigh, North Carolina. The project consisted of the construction of three-story building with basement of laboratories and classrooms for chemistry and physics and three greenhouses for horticultural sciences. R.N. Rouse, Inc. was the general contractor with single prime contract. A specialty subcontractor from Horse Shoe, approximately 418 km (260 mi) from Raleigh, built the greenhouses. As shown on the map presented in Fig. 4, the system consisted of one router connected to the IWS computer inside the Mann Hall Building which houses the department of Civil Engineering, two repeaters, two high-gain antennas, and three Web cameras. As indicated, the long-haul wireless communication covered approximately 440 m (1,400 ft), eliminating the need for an on-site access point (e.g., computer). The installations on the roof of the Garner Addition, serving as the "access point," consisted of a repeater and a high-gain antenna, which communicated with the antenna mounted on Mann Hall. Hardwired to the access point was a Web camera

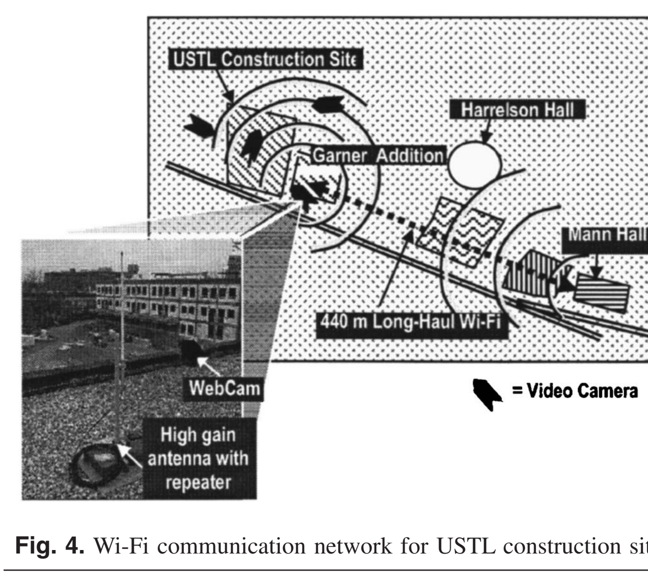

Fig. 4. Wi-Fi communication network for USTL construction site

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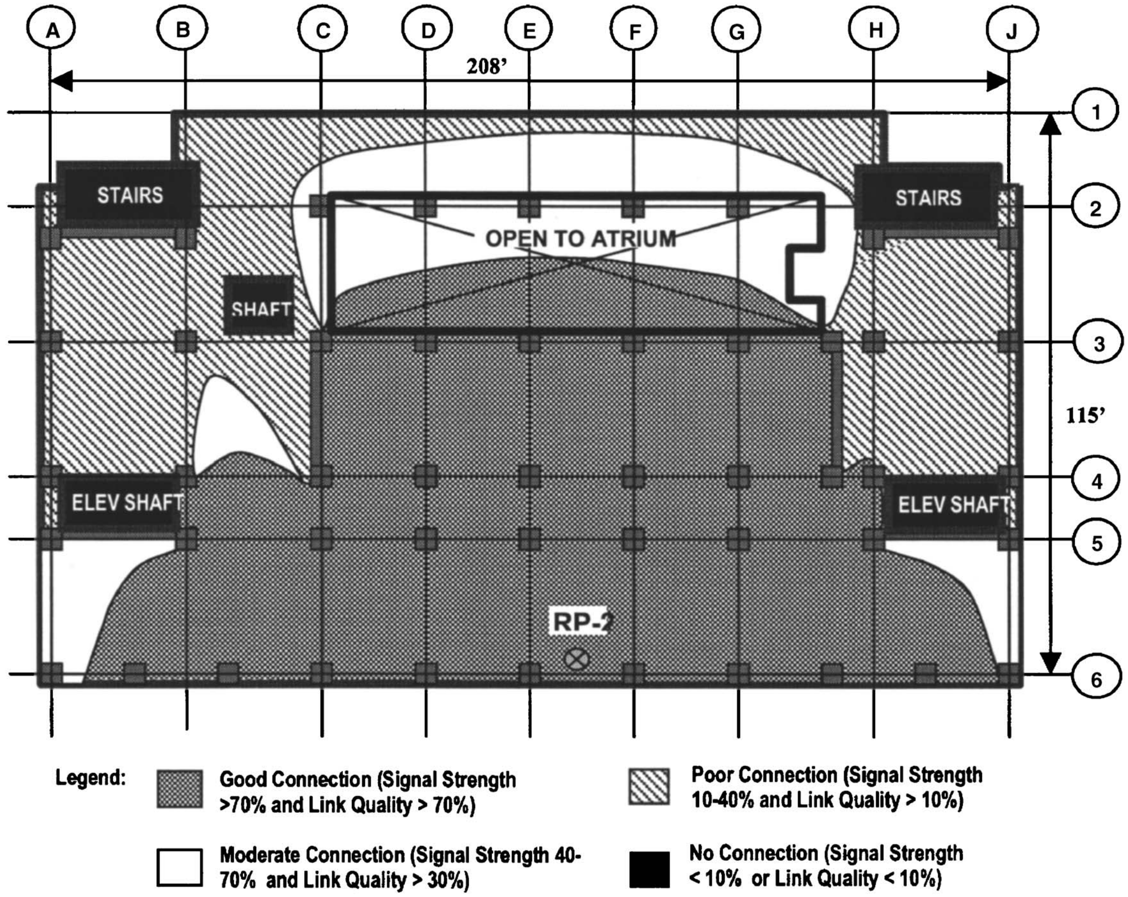

Fig. 5. Field intensity inside USTL building with second Repeater RP-2

overseeing the construction of the three greenhouses and the south facade as shown. A second wireless network camera was put stationary at two different places around the perimeter of the site while a second repeater and one network camera were used portably while walking around the building site.

Wireless systems were prone to experience interference by other wireless networks as was the case in this experiment. The longer the wireless ranges, the higher the interference. In this particular case, there was interference from up to five different wireless networks on the V-IWS that had coverage radius approximately 519 m (1,700 ft) from the Mann Hall Building. Most of these networks were implemented by NC State University. In order to reduce the interference, several measures, such as the use of directional antennas, should be considered and tested.

Establishment of the Attenuation Map

Wi-Fi networks use radio signals to transmit data between access point (e.g., router) and a client (e.g., repeater). Distance, obstacles obstructing line of sight, and background noise can cause attenuation, a reduction of signal strength during transmission. In order to establish a map that shows the signal strength inside and outside the facility under construction, the percentage of link quality and signal strength were measured on the jobsite and inside the building. There are no known standard of the percentage range indicating acceptable connection. Some manufactures only indicate signals as good, moderate, or poor connection.

The field intensity or attenuation map inside the USTL building showed quickly that the installed wall insulation prohibited a significant amount of radio frequency (RF) signals to reach a wireless camera inside. In order to overcome this obstacle, a second repeater, labeled RP-2 in Fig. 5 was installed close to the open window and with a line of sight to repeater on top of Garner Addition. The intensity map in Fig. 5 shows that with the additional repeater, the coverage area of Wi-Fi network was extended to cover more than half of the floor. Signal intensity is divided into four zones: (1) good-connection—both signal strength and link quality is higher than 70%; (2) moderate connection—signal strength between 40 and 70% and the link quality greater than 30%; (3) poor connection—signal strength between 10 and 40% and link quality greater than 10%; and (4) no connection—signal strength and link quality lower than 10%. From these results, it is clear that Wi-Fi networks work well in the construction environment. Fig. 5 indicates that concrete walls, as expected, severely cut the strength of RF but repeaters are able to extend area of coverage to almost everywhere, even in the basement or stair core if needed. After the establishment of the attenuation map the capability of V-IWS was ready to be tested.

Simultaneous Video "Broadcasting"

One important promise of installing multiple network cameras is to provide real-time video images of several areas simultaneously. Possible use of such a capability is material delivery and shakeout inside the building or supervision of multiple operations at different locations at the same time (e.g., for safety purposes). This capability was tested during the delivery of sheetrock that had to be distributed in different rooms inside the building. Fig. 6

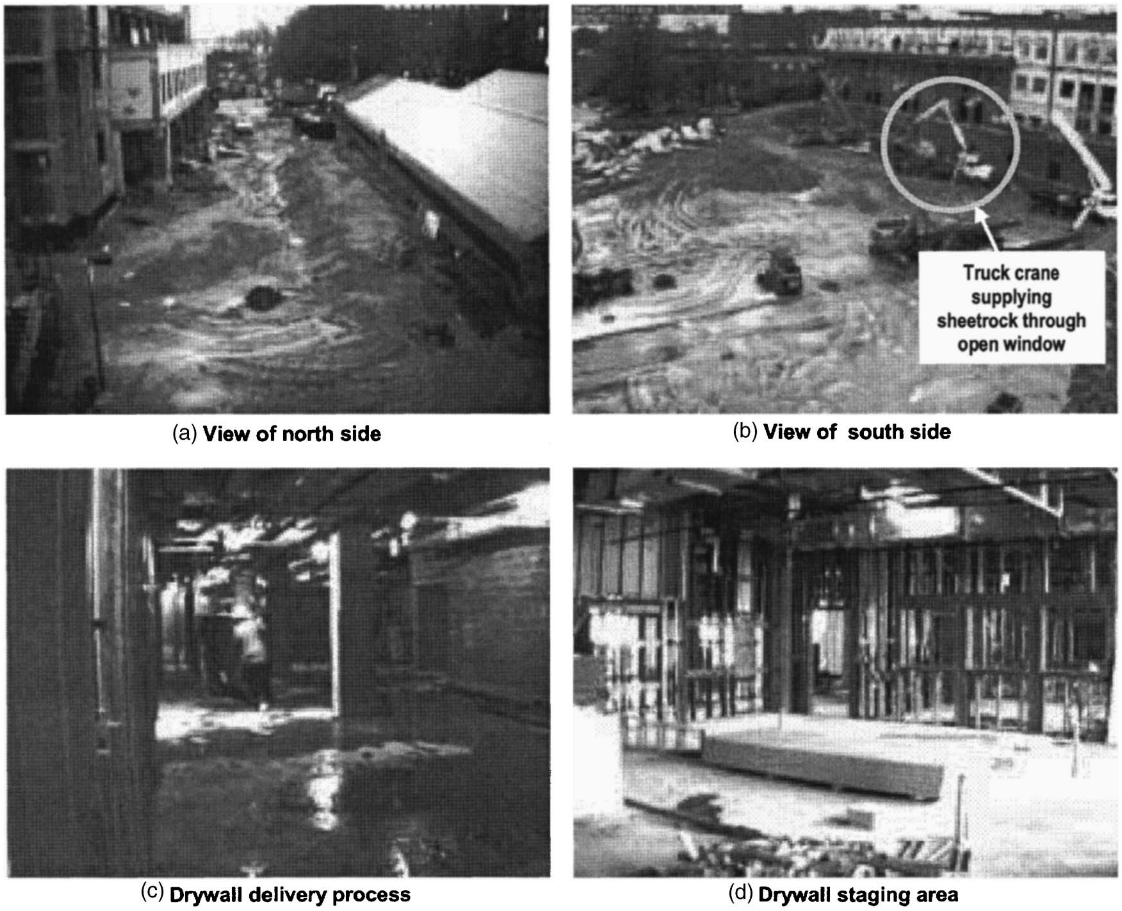

Fig. 6. Example of simultaneous video broadcast

shows video images from three network cameras during sheetrock delivery process. Fig. 6(a) illustrates that, on this wet morning, nothing is happening on the north side of the USTL building. This was a surprise since we were told that the sheetrock be delivered here. Fig. 6(b), however, shows that in fact the sheetrock is being "craned" by the white delivery truck through windows on the south side of the building. Figs. 6(c and d) were taken by the mobile camera inside the building showing the distribution process and one staging area. The cameras capture and upload pictures to the Web server in Mann Hall. The maximum transfer rate is 10 frames/s. In this experiment, the interval time between pictures was set at 30 s and was found sufficient for the intended purpose. However, it was no problem to switch to live motion video by using streaming features supported by the cameras.

Automatic capturing and storing of simultaneous video broadcast involves a considerable amount of storage space. Setting one picture per minute for 14 h will require approximately 50 MB per camera. It is apparent that storing images from multiple cameras will require a strategy that tailors managerial objectives to storage space that has to be made available. For instance, the total number of pictures captured should be set (by adjusting interval time) according to the process to be studied. If the process last for a couple hours, one picture per minute would be appropriate. If the process takes a week or month, the interval time should be set to one picture per hour or more. With modern photo management software and the price of storage steeply declining this issue may become less important.

System Evaluation

During the construction of the three new greenhouses on the south side of the building, the V-IWS was made available to several project participants in order to assess usage and impact it might have. The USTL project includes three greenhouses for which Van Wingerden Greenhouse Company from Asheville, N.C., was the subcontractor. Right away, problems due to the spatial separation between architect, engineer, general contractor, and Van Wingerden became apparent. One example was the approval process for detail drawings, which relied on mailing hardcopies, a very slow process. The greenhouse structural elements were prefabricated at the subcontractor's yard 418 km (260 mi) from Raleigh and shipped to the USTL site for erection. However, the general contractor was responsible for the foundation of the greenhouses, which needed to be very precise. The processes of building the foundation and prefabrication were done in parallel. During the months preceding the first delivery, the subcontractor had no direct access to the jobsite and relied on phone calls with the general contractor to confirm progress.

Remote Monitoring of Material Delivery

According to Stukhart (1995), approximately 80% of the project schedule is controlled by material from acquisition to the delivery of the last item. Earlier reports published by the Construction Industry Institute (CII) concluded that implementing a basic ma-

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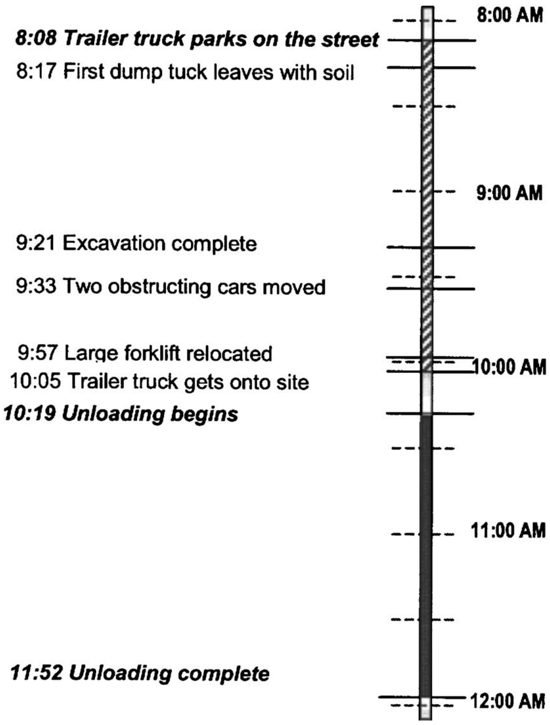

Fig. 7. Event line created from V-IWS during material delivery

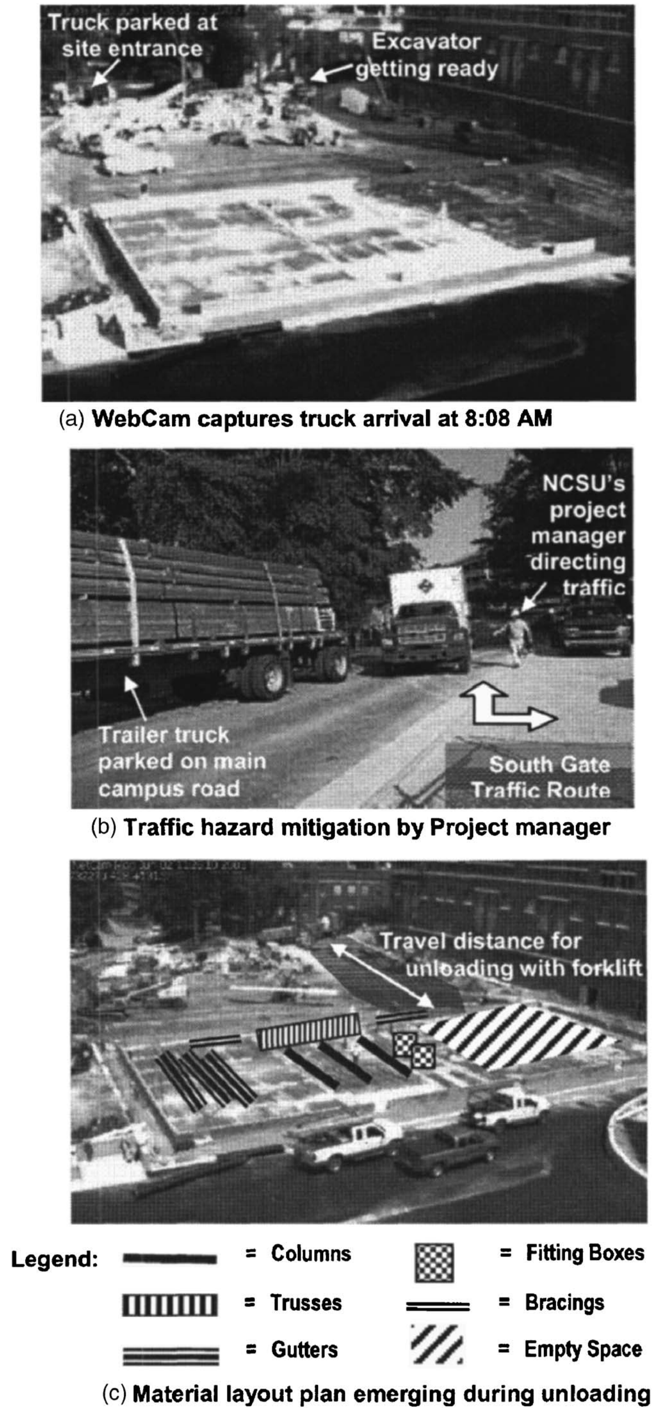

Fig. 8. Multipurpose utilization of live Web-cameras

terial management system results in 6% improvement in craft labor productivity, and an additional 4–6% can be expected when a sophisticated computer control is implemented (CII 1986). Inefficient management of construction material is considered a major cause of production delays and non-value-added activities (e.g., rehandling). The first shipment of greenhouse material was planned for Monday June 2, 2003. The network camera on the roof of Garner Addition building was set to take and store one picture every minute starting at 6:30 a.m. The delivery truck arrived exactly at 8:08 a.m., along with a six-member crew. Unfortunately for the crew, another contractor had begun an excavation job that closed the only access path to the first greenhouse until 9:21 a.m. However, the truck still could not enter the site because two passenger cars that belonged to a subcontractor obstructed the entrance. Since the truck arrived, the truck had been waiting for 2 h, 11 min before it was able to begin unloading, which lasted a mere 1 h, 33 min. From 358 images that were stored, a video clip was created that allowed the easy establishment of an event line, shown in Fig. 7. It is apparent from reviewing the event line that each event, starting with the arrival of the truck [shown in Fig. 8(a)], the end of the excavation, and the final parking of the truck on the site [shown in Fig. 8(c)] are all events that are very easily recognizable on Web cam. Potential use of the visual information available online are manifold to include: (a) remote preplanning of work crews with real-time data (e.g., readiness of foundation and access road); (b) real-time replanning by a remote subcontractor if conditions change (e.g., no access to site via main entrance); (c) creation of training videos of skillful work processes (e.g., layout of material); and (d) automatic creation of "as-it-was-built" visual documents.

Accident Prevention

The location of the installed cameras on the roof of adjacent buildings or poles offers the viewer a birds-eye look at the situation. Web cams available on the market allow for panning and powerful zooming to observe even small details. This characteristic led to an unexpected but highly effective use of V-IWS.

When the trailer truck with the greenhouse material arrived and could not enter the site, it had to park alongside one of the main entrances to the campus. This led not only to many complaints from professors and students rushing to classes, but it also impeded the work of a survey crew whose line-of-sight connection with their control point was obstructed by the truck; most importantly, the truck caused a traffic hazard reducing a two-way road to a one-way road right after an incline in the road and right before a gate that had to be activated via an RFID. The university

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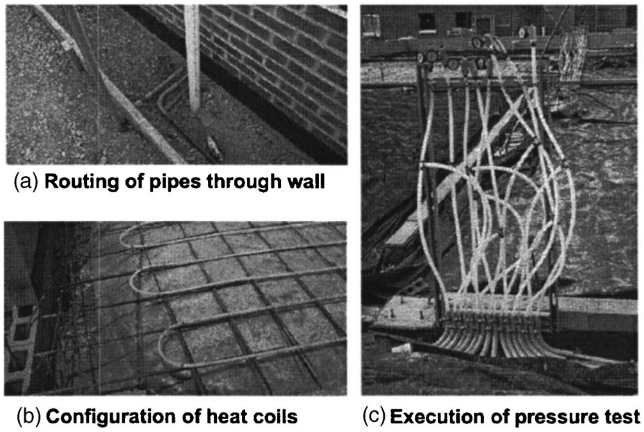

Fig. 9. "As-it-was-builts" create value for the user

project manager was reviewing plans in his office, located at a different building on campus and saw the situation, which had led to complaints by the campus police before. As shown in Fig. 8(b) he ended up directing traffic around the truck himself. This example seems to indicate that accident prevention and safety training would benefit enormously from a well equipped V-IWS. At the same time, stored images would allow a contractor to document the efforts that were made to prevent accidents as well, as they could possibly be used to understand what did lead to an accident, should one happen.

Visual "As-It-Was-Builts" for User and Skill Training

Some key project participants were the future users of the greenhouse facility, mainly teachers and researchers working in Horticultural Science. As part of this study, one of these professors was interviewed and allowed access to the Web cameras during construction, which led to some important new observations. It became immediately evident that the user was fascinated with the opportunity to receive visual "as-builts" that show how the greenhouse was put together, which led to the new term "as-it-was-builts." Rather than receiving drawings that show the location and sizes of valves and hoses, the V-IWS provided visuals of the actual locations of heating coils before they were encased with concrete, as shown in Fig. 9. Images that show the location and the appearance of utilities before they are covered up [see Fig. 9(a)], or procedures and tools used to pressure test pipes [see Fig. 9(c)] are invaluable pieces of information for somebody who will be occupying and maintaining the building. It was found that pictures of components and systems during construction are far more useful to the user than CAD-drawings filled with trade-specific symbols. In addition, the time-lapse video of the greenhouse erection process can be used as teaching material in the classroom.

The subcontractor was yet another participant who felt intrigued by the possibilities of visual "as-it-was-builts." He had to use a totally new crew for the work since all his other crews were working on different projects. Even the superintendent and foreman had never built greenhouses before. Everybody wanted to get copies of the video clip of the entire process of building the first greenhouse for the sole purpose of having a visual record to study and find opportunities to improve and, most importantly, to train a future crew. For the readers who have experience with time-lapse movies the desire of using video clips for these two purposes makes immediate sense. As mentioned earlier, V-IWS allows users not only to program the storing of pictures at predetermined intervals, but also to easily create and play videos that look exactly like the time-lapse movies of the past.

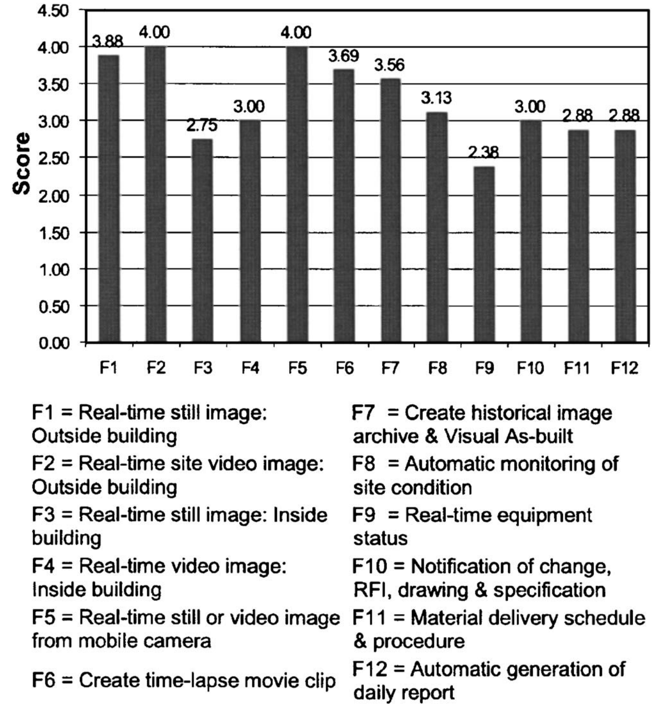

Fig. 10. Value assessment of system features

Overall Value Assessment

At the end of the field test, users who were given access to the V-IWS were asked to evaluate the system by filling out tailored questionnaires. The survey showed that all project members, except managers working for the general contractor on-site, used the V-IWS daily. It was thus no surprise that users who had their offices off campus, such as the mechanical design engineer from Charlotte, felt that the system did reduce many of their non-value-added activities (e.g., site visits.) The NC State University's project manager used the system every day to monitor overall work progress and site conditions. The greenhouse subcontractor also used the system daily to monitor the erection progress from the home office in Asheville. This was crucial since the crew was new for this type of greenhouses. As mentioned earlier, the user of the facility thought it was extremely valuable to have all the visual documents on a CD.

Part B of the questionnaire asked the users to rate the level of importance for 12 features of the system (listed in Fig. 10) by assigning a number to each between 1 and 5 (5 meaning most important and 1 of little or no importance). The features included such things as: (1) still image; (2) live video; (3) visuals from outside the building; (4) visuals from inside the building; and (5) visuals from a wireless mobile camera. The results and the list of all 12 features are shown in Fig. 10. As can be seen from the graph, the most important features ranked by the respondents are: (1) real-time site video image taken from outside building; and (2) real-time still or video images from a wireless mobile camera. The surveyed users felt that potential benefits from these features include increased productivity, quality control, security, and problem solving. The top five highest ratings for features that utilize either real-time photo or video technology. The ability to keep

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Table 1. Cost-Benefit Analysis for 66% Meeting Substitution

Item		Cost ($)	Benefit ($)	
Hardware		2,857		
ISP Fees	12 months · $250			
		3,000		
Maintenance	52 hours · $50/h	2,600		
Time spent online (10 min/day/person)	26 participants · (250 work days · 10/60) × $50/h	54,167		
Total Cost				−$62,624
Person-hours for weakly meetings	34 meetings · 6 participants · [(3 hours · $50/h) + $40 travel]		38,760	
Fixed cost/meeting	34 meetings · $80		2,720	
Person-hours for monthly meetings	8 meetings · 20 participants · [(4 hours · $50/h) + $40]		38,400	
Fixed cost/meeting	8 meetings · $80		640	
Total benefit				$ 80,520
Overall savings				$ 17,896

visuals as historical records was very highly rated by the owner and the user of the building, who both found it useful especially for nontechnical persons who are not familiar with two-dimensional construction drawings and all technical terms. A less important feature was monitoring real-time equipment status.

Costs-Benefit Analysis of the V-IWS

This section presents the costs and benefits of the V-IWS system. Due to the fact that the system is extremely flexible and expandable, finding the exact costs of the system is not easy. Once the core system has been set up, hundreds of network devices, such as network cameras and humidity and temperature detectors can be added into the system as needed depending on the size of the project. Estimating the benefits of the system in terms of dollar amount is even more difficult. In order to put cost-benefit comparisons into perspective, the costs of the system were based on the system implemented in this research and were compared with direct cost-savings due to site meeting reduction.

Fixed System Costs

The costs of the V-IWS system implemented at the USTL project can be broken down into three parts as follows:

1. The hardware used in this system consists of one computer, one router, two repeaters (access points that support repeater mode), two high-gains antennas, and three network cameras are as (the cost of the laptop computer used for measuring the wireless signal is not included);
2. The software used to develop the system (Microsoft XP); and
3. The ISP fees for broadband Internet connection, which vary from $110 to $250 per month (for business with fixed IP address). In this research, the system is connected to the Internet through the University's network.

The cost listed above are of the prototype system used for research purpose. The costs do not include the researcher's time and efforts to develop and maintain the system. If the system were about to be used for business the cost of design and development will need to be considered.

System Benefits

Direct cost-savings achieved by implementing the system is due to reducing the need for "unnecessary site visit" and "too many meetings." In addition to time for face-to-face discussion, time for traveling can be significant for project team members whose offices are not local. The latest model of mobile wireless cameras also transmit sound while permanent devices allow a remote viewer to control pan, tilt, and a very powerful zoom from their office. New Wi-Wi applications are becoming easily installable to include solar-powered sensors for humidity, temperature, wind, rainfall, RFIDs, and density. Automating the reading and/or downloading of the many data-streams provides value for a very small extra effort.

Cost-Benefit Analysis

Following assumptions for a hypothetical project were used for an basic cost-benefit analysis:

1. In a 12-month period, 34 weekly and 8 monthly meetings can be eliminated (66%);
2. An average weekly meeting consists of six members (five subs + one general contractor representative), and a monthly meeting has 20 participants (representatives for the owner, architect, engineers, quality control, general contractor, etc.);
3. Average time for meetings, included traveling time, is 3 h for the weekly and 4 h for the monthly meetings;
4. Average cost per man-hour of a meeting participant $50; overhead and average traveling cost per trip is $40 (fixed);
5. Cost savings per meeting due to reduced paperwork and time to prepare meeting minutes and meeting agendas is $80;
6. The V-IWS requires 52 h per year for maintenance at the cost of $50/h; and
7. Each system's user spends an average of 10 min per working day on the system as a substitute for lost weekly and monthly meetings time (=2,500 min/year).

Table 1 presents the resulting calculations that show that the estimated cost for a 66% meeting reduction is $62,624, mostly due to the 10 min the 26 individuals spend online each day ($54,167) in place of canceling two out of three meetings. However, the cumulative time saved is equally significant translating into a cost saving of $80,520 leading to an overall saving of

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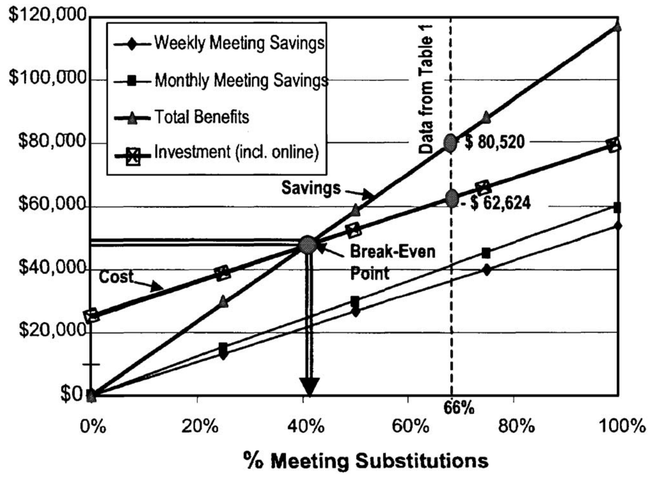

Fig. 11. Break-even point as a function of meeting substitutions

almost $18,000. It is most interesting to see what a minimum change in the traditional meeting schemes would be needed to justify the investment. Fig. 11 highlights how the cost savings vary with the amount of weekly and monthly meeting substitution. As shown, the cost curve consists of a fixed and a variable component where the minimum includes not only the hardware, maintenance, and fees but also an absolute minimum of 3 min per workday that a meeting participant spends online. It is also assumed that meeting time can be replaced with the online approach, thus leading to a linear function. As indicated, the minimal average time a person spends online increases linearly until it reaches 10 min, when 66% of the meeting time is substituted. The presented graph indicates that for the assumed situation the break-even point is at approximately 42%. This outcome has to be considered conservative since it excludes any other benefit that might accrue from having an IWS installed and available. It is believed that indirect benefits may outweigh the shown cost saving.

Far-Reaching Indirect Benefits

The following presents eight indirect benefits that should be considered, between others, when making a decision on installing project Web site with a Wi-Fi site network: (1) improved information flow on construction project in terms of timeliness and richness; (2) reduction of time needed for solving complex/visual problems on-site (having Wi-Fi network cover the entire jobsite allows wireless cameras to deliver real-time images to engineers and managers anywhere; cellphones and laptops can be used to exchange other information directly to the location where problem is being viewed); (3) reduction of rework and increased quality due to 24/7 access for remote CFSC members to allow continuous visual verifications and inspections by architect and owner; (4) accident reduction and theft due to 24/7 remote access for safety inspector and automated surveillance; (5) drastically enhanced supply chain integration; (6) improved training of work crew (video clips of exemplary work can be made available online); (7) creation of historical records of visual as-builts; and (8) use as a marketing tool.

Summary and Conclusion

Today's information logistics in construction relies mostly on well-tested channels of communications channels such as phone, two-way-radio, fax, express mail, and face-to-face meetings to ask for or distribute information. Recently, e-mail has become a "new kid on the block." As a whole, the litigious and highly visual nature of the business require verifiable "paper-trails" as well as direct observations of work status or work problems. Modern IT technologies offer rugged alternatives to the traditional methods used in construction but have not found much use. The integrated wireless site (IWS) model presented in this paper was designed to go beyond providing basic information and real-time bird's-eye-view pictures of the jobsite. Its aim was to test the efficacy and ruggedness of state-of-the-art Internet and Wi-Fi technologies.

In order to test the model, a prototype system called visual-based IWS (V-IWS) was implemented on a site for a new laboratory located on NC State University's main campus. The tests showed that modern Wi-Fi networks are not only affordable, but are technically sophisticated systems that can be used effectively on an active construction site today. Meshing signal repeaters extend the limited coverage area of a transmitter and offer the capability to meet most every corner of jobsite, including the inside of a structure. From questionnaires filled out by many project participants, such as the project manager, user, mechanical engineer, and greenhouse contractor, it was learned that the experimental system was actually used and proved to benefit every user differently. Some of the highly valued benefits included: (1) simultaneous video broadcasting of different areas on the jobsite; (2) remote monitoring of material delivery; (3) safety improvements; and (4) creating automatically visual "as-it-was-builts" for training and nontechnical users. Another interesting observation gleaned from the survey data was the fact that the off-site project team members came to depend on the system, using it on a daily basis. Heavy users were the project manager, architect, and engineer who had their offices off-site, thus eliminating their need for site visits (a nonvalue added activity), while keeping informed about progress in real-time.

The lessons learned gained from installing the wireless network underlined the importance of planning since the location of access points, repeaters, and all Wi-Fi devices must be placed strategically (they might be relocated as the building grows). In addition, appropriate procedures following local restrictions on the use of wireless networks while ensuring highest levels of network security need to be strictly followed. Advanced planning and pretests are imperative for success.

Having machines interact with machines, combined with the capability to make decisions autonomously, is still more a dream than a reality. The ongoing research project led by World Wide Web Consortium (W3C) called "semantic Web" promises to be the next generation of the Web that we know today. The semantic web provides a common framework in which information is given well-defined "meaning" (W3C 2004). For construction, the semantic Web, together with telematic devices, will allow construction equipment located at different locations—such as tower crane at the jobsite, delivery truck on the road, and forklift at the supplier's yard—to interact and to work together by exchanging information to make decisions that they would offer to an operator (e.g., deciding on the best spot to shake out a truck of steel elements.) The semantic Web concept presents the future frontier for research in construction communication and management.

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