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CONSTRUCTION PROGRESS CONTROL (CPC) APPLICATION FOR SMARTPHONE

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SUMMARY: *In order to stay within schedule and budget limits, construction projects require fluent communication and information exchange between the collaborating parties. Unnecessary project delays and rework are often caused by missing or outdated information. Easily available, accurate and up-to-date information on project status can improve work efficiency and quality. Such information can be efficiently shared between project parties in electronic form, but recording the information on-site and transmit it to the office requires mobile devices and wireless communication. This paper presents a prototype smartphone application called Construction Progress Control (CPC) that can record on-site progress in different activities, convert this information into a format that can be imported to a project management software (e.g., Primavera P6) and send this information to a PC where the project management software picks up this information and updates the schedule accordingly. The efficiency of construction projects can be improved by collecting and recording progress information at the worksite using electronic devices, by providing schedulers in the office with accurate and up-to-date progress information, and by updating the work schedule in a timely fashion, hence allowing the project manager to make decisions without delay.*

KEYWORDS: *construction scheduling, progress control, smartphone applications*

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1 INTRODUCTION

Much effort has been spent to improve the efficiency and quality of construction projects with the help of information and communication technologies. These technologies support traditional tasks, ease communications, speed up processes, and manage information. Unfortunately, the construction industry remains behind other industries and is still relatively in the early stages of adapting to these technologies (Klinc et al., 2010; Shen et al. 2010).

A vast amount of information is generated in all phases of a project. This information ranges from drawings produced in the design phase to different project reports prepared during the construction phase. Thus, the efficiency of information management is crucial to the construction industry and has been recognized as an important competitive advantage by construction companies (Chen and Kamara, 2008). Even though the utilization of information and communication technologies in the preconstruction planning process has made great advances through the use of systems such as Building Information Modeling (BIM), the use of information and communication technologies in on-site information management has been limited. Part of the lower productivity on construction sites can partly be explained by the fact that information and communication needs in the construction phase are not adequately met.

On-site information management is critical because it is the fundamental element of successful project management (Tsai, 2009). In order to stay within schedule and budget limits, construction projects require fluent communication and information exchange between on-site inspectors and schedulers in charge of progress control. Unnecessary project delays and rework are often caused by missing or outdated information. Easily available, accurate and up-to-date information on project status can improve work efficiency and quality. However, the construction industry has not found appropriate solutions for the problem of information communication and exchange on construction sites.

Traditionally, the main type of information that on-site construction personnel receive and transfer is paper-based files, which include documents such as drawings, data collection forms, correspondence, progress information and specifications (Bowden et al., 2004). The limitations of paper-based files constitute a major constraint in on-site information communication and exchange. Ineffective on-site information communication can result in construction personnel overlooking important issues that require a quick response and often cause on-site decisions to be deferred (Singhvi and Terk, 2003). Coordination of activities and management of operations on a construction site raises numerous queries and requires numerous interactions between project participants, which need to be handled quickly and efficiently to avoid downtime, rework, waste, and cost overruns (Miah et al., 1998).

Advances in information technologies create opportunities for increased efficiency of information exchange between an inspector on the construction site and a scheduler in the office. Advances in affordable mobile devices, increases in wireless network transfer speeds, and improvements in mobile application performance provide opportunities for enhancing information management (Chen and Kamara, 2008). Developing a simple and functional mobile application that can benefit the construction industry by streamlining on-site information flow to the scheduling office is now possible.

The objective of the research presented in this paper is to develop a prototype smartphone application called Construction Progress Control (CPC) that allows an on-site inspector to record on-site progress in different activities, convert this information into a format that can be imported to a project management software (e.g., Primavera P6) and send this information to a PC where the project management software picks up this information and updates the schedule accordingly. The efficiency of construction projects can be improved by collecting and recording progress information at the worksite using electronic devices, by providing schedulers in the office with accurate and up-to-date progress information, and by updating the work schedule in a timely fashion, hence allowing the project manager to make decisions without delay.

2 ON-SITE INFORMATION MANAGEMENT

The construction industry is characterized as one which inevitably generates vast amounts of information. Effectively managing such an immense volume of information to ensure its accuracy and accessibility in a timely manner is crucial to the successful completion of any project. Inaccuracies or holes in information can readily lead to project delays, uneconomical decisions, or even the complete failure of a project. It is for these reasons, therefore, that the efficient collection of onsite construction information and the timely communication of that information is a critical concern for all parties involved in the construction industry (Cox et al., 2002).

The information needs at the construction site are varied. Personnel in the field require information to make decisions about the construction processes. Also, many different types of construction information are typically collected in the field, often on a daily basis. These different information sets can be categorized as follows (Cox et al., 2002):

- Chronological files of project correspondence and memorandums, including RFIs
- Change order and submittal requests
- Quality control and assurance records
- Construction field activity and progress logs
- Resource and inventory logs, including tracking of labor, equipment, and materials

Organizing construction project documents can be very difficult and time consuming. Especially for large construction companies with multiple simultaneous projects, the management of plans, specifications and drawings can be challenging. Providing access and presenting these documents to project team members is a must, but how best to go about it can be a real challenge. Traditionally, onsite data are recorded through the use of paper forms. Once an on-site inspector has collected this information, these forms are usually sent back to the office where they are manually sorted. Additionally, forms can be further processed by copying the desired information from multiple forms into one form or even into a computer spreadsheet. A calculator or a spreadsheet program may be used to further analyze the data to produce reports. Some type of filing method for the collected information usually follows. Forms are most often categorized and stored in a cabinet, ready for retrieval at a later date. However, time spent in collecting, filing, and distributing paper forms in this manual process raises many concerns. A practical solution to this problem is to transfer the information collected from the site immediately to a computer database at the office where it can be viewed, manipulated, updated and distributed electronically. Moreover, using electronic data collection and access can improve efficiency and reduce the probability of human error.

3 MOBILE APPLICATION SYSTEMS FOR MANAGING ON-SITE INFORMATION FLOW

Construction work is mainly fieldwork. Delivering the necessary information to the construction site or the data collected back to the office has been problematic and slow. Communication in the construction process needs to be simplified and speeded up. Usage of affordable mobile technology alongside the latest generation of communication infrastructure could be beneficial to this process (Bowden et al., 2006). Indeed, mobile technology devices have the potential to revolutionize the management of constructing civil infrastructure and buildings. The advantage that mobile technology devices offer is their ability to integrate many technologies into one device. Cameras, GPS, and data processing, among many other things, can all be united into one powerful hand-held device. Hand-held devices used on the construction site allow for information to be readily accessible to the construction team and related parties and indirectly reduce the cost and improve timeliness of the construction project. Smartphones and tablets, when used correctly, could be very useful tools to personnel such as project managers, engineers, architects, and subcontractors.

In recent years, with rapid change in mobile technology and Internet communication, research activity in this field proliferated. Since the early 1990's, the academic and industrial sectors have been investigating the use of hand-held devices for developing applications used in field data collection. A sample of these developments is presented here in chronological order. McCullouch and Gunn (1993) studied the possible automation of construction data collection with pen-based computers. Their study covered employee timekeeping, materials purchasing functions, and a daily report form. McCullouch (1997) also demonstrated the benefits of using pen-based computers in road maintenance operations. Nathawani et al. (1995) designed a PDA-based (Personal Digital Assistant) data collection application for maintenance inspection, and Repass et al. (2000) developed an application for a Palm handheld device that gives users access to schedule information and enables users to record schedule information electronically once they return to the office. Cox et al. (2002) described an application that automates the collection, recording, processing, and distribution of field inspection data relative to quality compliance using Pocket PCs. Kimoto et al. (2005) developed a PDA-based mobile computing system that lets construction managers record inspection reports, access drawings and specifications, check the position of structural members, and monitor progress. Wang et al. (2007) presented an RFID-based (Radio Frequency Identification) supply chain control system for the construction industry that allows engineers to collect data using PDAs, providing dynamic operation control and management. Vilkko et al. (2008) developed a smartphone application that enables collecting and accessing precast concrete element data at the worksite. Dong et al.'s (2009) telematic digital workbench captures digital images of a defect with a note regarding the defect, defines the location of the defect, and sends the information to an off-site database. Irizarry and Gill's (2009) iPhone-based "Construction Equipment Finder" application finds the equipment rental location closest to the jobsite, whereas their "Be Safe" application provides access to safety-related information. Venkatraman and Yoong (2009) developed a mobile collaboration tool that functions as a phone, fax, e-mail, and canvas for drawings, and demonstrated that the application was efficient in dealing with dynamic changes to site drawings and approvals at remote construction sites. Yammiyavar and Kate's (2010) mobile phone-based graphical user interface provides construction workers with access to information on job vacancies.

Haas et al. (2002) conducted an extensive literature review covering a wide range of topics dealing with the implementation of mobile devices in construction, primarily on project management, schedule management, facility inspection, and field reporting applications. Haas et al. (2002) found that mobile devices have potential benefits in terms of time savings and improved information accuracy. However, achieving those benefits depends on a proper implementation strategy. Haas et al.'s (2002) study also showed a lack of interest in mobile devices on construction managers' part and a lack of interest in developing applications for the construction industry compared to other industries. Since 2002, i.e, since Haas et al.'s (2002) study, various researchers started experimenting with mobile devices on the jobsite for processing CAD/BIM, inspecting field activities, monitoring progress, eliminating defects, improving quality, setting up the site layout, and locating construction equipment (Cox et al. 2002, Kimoto et al. 2005, Vilkko et al. 2008, Chen and Kamara 2008, Dong et al. 2009, Irizarry and Gill 2009). However, due to the relative novelty of mobile devices in construction, there have been very few commercialized applications such as P6 Team Member (https://itunes.apple.com/us/app/p6-team-member/id457533019?mt=8) that is developed for the iOS platform only, and Project Inspector by FACS (http://www.facsware.com/) that involves quite a few other functions in addition to progress reporting.

4 CONSTRUCTION PROGRESS CONTROL (CPC) APPLICATION

Maintaining a current construction schedule is critical to effective project planning and control, but schedules frequently are not consistently maintained. This is likely due in large part to reliance on manual methods, which are tedious, time-consuming, and prone to error. It is not convenient for on-site inspectors to record the information directly on notebooks in the harsh construction environment. The schedule updating process can be improved by automating the process using advanced computer technology. However, desktop and laptop computers and the construction environment are incompatible. New smaller and portable computer technologies such as mobile phones appear to be more compatible with the rough construction environment. Most construction personnel are already familiar with using mobile phones and are more likely to accept them as tools.

A mobile application called "Construction Program Control" (CPC) was developed to allow for the collection of on-site progress data that can immediately be accessed by a project management program in the office. The iterative prototype development approach recommended by Fox and Sheldon (2008) was adopted in designing and developing the mobile application: it involves conceptualization, design/development, and testing.

4.1 Conceptualization

The main aim of the conceptualization stage is to research design requirements for developing the application, and to set up a roadmap for development and testing. The objective was to create a prototype that allows a project manager to record the status of an activity, attach evidence, and instantaneously send it back to the office so that the work schedule can be updated. Figure 1 shows the setup of the mobile application prototype. There were several requirements that needed to be considered when developing this prototype:

- The inspector should be able to record progress information on site, attach photos/videos and comments relative to progress, and forward this information to the scheduler as soon as the progress evaluation process is completed

- The inspector should be able to use a smartphone for this activity
- The inspector should be able to easily use this application with little training
- The scheduler should be able to access the progress information and import it into a commercially available project management program
- The construction manager should be able to view progress, photos/videos, comments, and updated information of construction activities in the office or at jobsite, immediately after progress is recorded
- The construction manager should be able to take appropriate actions immediately regardless of one's location

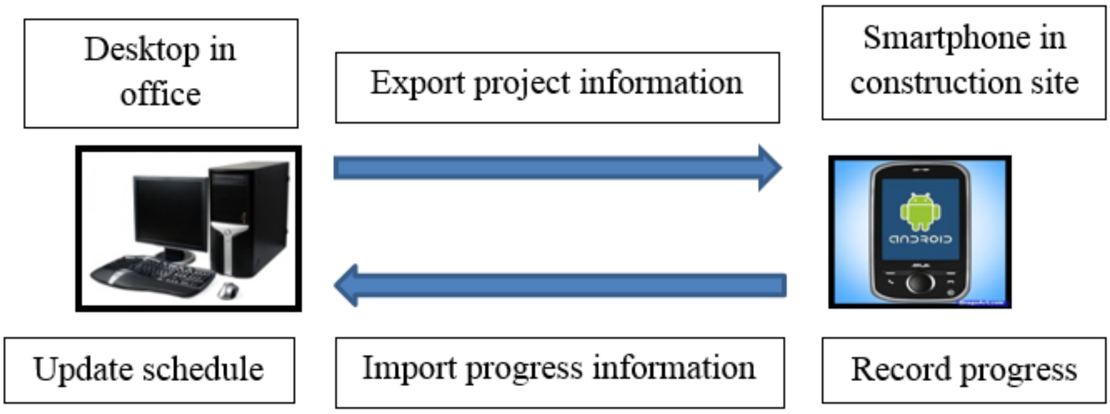


FIG.1: Setup for CPC Smartphone Application Prototype.

4.2 Design and Development

The choice of programming platform is an important consideration in the design of an application. Table 1 presents some of the most common operating systems being used in the marketplace. The systems that are currently available for smartphones include Android, iOS, BlackBerry OS, Symbian OS, Windows Phone, Linux, and others, but the ones that are mostly used are Android and iOS (iPhone) with a market share in the second quarter of 2012 of 68.1% and 16.9%, respectively (Table1). The application was developed using the Android operating system because this platform has the highest market share in the world and also because Android follows an open source philosophy. The development process is faster with Android because examples of source codes for Android applications are readily available on the Internet.

TABLE. 1: Top Smartphone Operating Systems in the Second Quarter (Q2) of 2012.

Operating System	Q2 2012 Shipments (million units)	Q2 2012 Market Share
Android	104.8	68.1%
iOS	26.0	16.9%
BlackBerry OS	7.4	4.8%
Symbian	6.8	4.4%
Windows Phone 7 / Windows Mobile	5.4	3.5%
Linux	3.5	2.3%
Others	0.1	0.1%
Grand Total	154.0	100.0%

Source: IDC Worldwide Mobile Phone Tracker, August 8, 2012

Just like all hardware devices are not the same, neither are mobile applications. Antevy (2012) divided mobile applications into three categories: native, web-browser, and hybrid. Each has distinct advantages and disadvantages. Native is written especially for the mobile device and has full access to all the unique capabilities of the device and offers the richest user experience possible. Web-browser is also known as a mobile-enabled website or web app. The web-browser mobile app uses the mobile device's web browser to access the application's functionality through the Internet. A hybrid mobile application combines the rich user experience and functionality of a native application with the data access capabilities of a web application. For the purpose of this application, a native mobile application was developed that could utilize all the features and capabilities of the mobile device, such as taking pictures/videos by using the smartphone's camera. It could operate with or without a direct connection to the Internet, and maintain the security, data and business processes of the application. An upgrade to a hybrid mobile application is under development.

The CPC application involves acquiring the data, editing the data, and sending it to the PC in the office. The information received in the office is used by the scheduler to update the construction schedule, and by the project manager to take the corresponding decisions if necessary. Java was chosen to perform these tasks due to its broad, cross-platform support as compared to other mobile phone operating systems, such as Windows Mobile. A custom-made Java software can be installed and operated on a smartphone to provide graphical interface for entering activities' progress information, capturing digital images, transferring data to the PC in the office, as well as retrieving and viewing feedback from the office.

Figure 2 shows the progress monitoring process in the CPC application. Since the most popular software for construction project management in the U.S. is Oracle's Primavera P6, the CPC application formats the information for easy import to and use by Primavera P6. There are different ways Primavera can import data, but the easiest is using Microsoft Excel files. In the CPC application, the user records the information on the smartphone, the application formats it into an MS Excel file using a code specially written (Figure 3) for the customization of the spreadsheet with Primavera P6's standard user settings, and should be able to send this file to the PC in the office. The scheduler imports the MS Excel file into Primavera P6 to perform scheduling calculations on the PC. The same happens when the application acquires project information from Primavera P6 but in the opposite direction: the scheduler exports from Primavera P6 an MS Excel file with project information, and sends this file to the smartphone that reads it and shows the activity information to the user. The MS Excel files with the project information can be transferred between the Smartphone and the PC that houses Primavera P6 via USB cable, 4G mobile communication network, or Wi-Fi. The prototype used a USB cable.

Primavera P6 can export different types of information related to a project, such as activity names, durations, relations between activities, resources, costs, etc. But since the objective of the application is to update the status of the activities of the project using a smartphone, the application reads only the information related to activity names and durations and ignores any other information about the project. After reading the activity-related information from the MS Excel file exported from Primavera P6, information about an activity selected by the user is displayed by the application, including the name of the activity, the start and end dates of the activity, the resources used in the activity, the project to which the activity belongs, and the percentage of completion of the activity. At this time, the user updates the percentage of completion of the activity and adds comments and photos/videos related to the activity. Photos/videos can be taken with the smartphone's camera or selected from the files stored on the SD card of the smartphone. Comments and photos/videos are only for the information of the people planning the construction in the office, and not for Primavera P6. Primavera P6 works only with the updated percentages of completion of each activity as input by the user.

4.3 Testing

The MS Excel file with activity information generated by Primavera P6 can be transferred to the SD card of the smartphone using a USB cable, 4G mobile communication network, or Wi-Fi. The path of the file is:

/mnt/sdcard/Android/data/cpc.application/files/Project23.xls

When the file is in the indicated location in the SD card of the smartphone, the user opens the CPC application and selects in the main screen (Figure 4a) one of the following three options: read the application instructions, update the status of the activities, or add pictures of the activities.

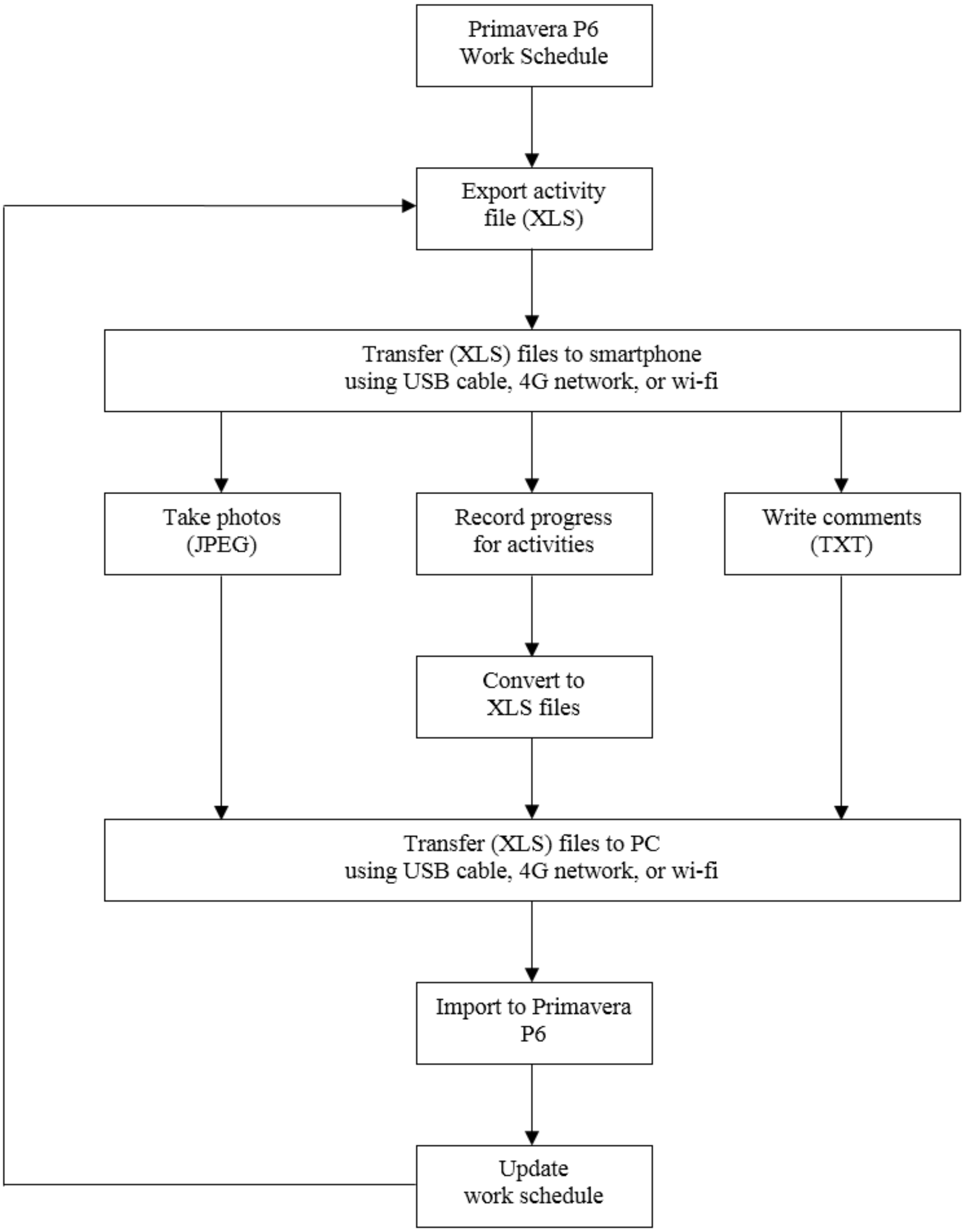


FIG. 2: Progress Monitoring Process in the CPC application.

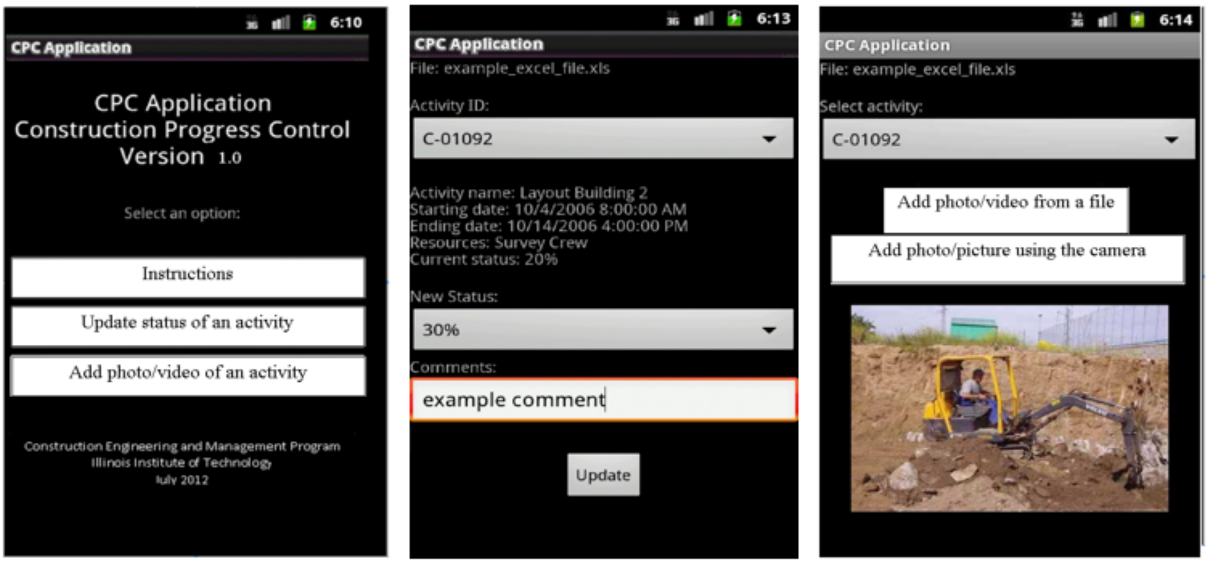
```
private void createLabelUD(WritableSheet sheet)throws WriteException {
WritableFont times10pt = new WritableFont(WritableFont.TIMES, 10);
times = new WritableCellFormat(times10pt);
times.setWrap(true);
CellView cv = new CellView();
cv.setFormat(times);
cv.setAutosize(true);
addCaption(sheet, 0, 0, "user_data");
addCaption(sheet, 0, 1, "UserSettings Do Not Edit");
addCaption(sheet, 0, 2,
```

FIG. 3: Code for Customizing MS Excel Sheet to Comply with Primavera P6's Settings.

When the user clicks on the "Instructions" button on the main screen in Figure 4a, the user sees information about how to export the MS Excel files from the PC to the smartphone before heading out to the jobsite, how to import the MS Excel files from the smartphone to the PC after collecting the activities' progress, and also brief descriptions about how to use the CPC program.

When the user clicks on the "Update Status" button on the main screen in Figure 4a, the user sees a drop-down menu that lists of the activities in the project, selects one of them, sees the information about the selected activity, updates the percentage of completion, and adds comments related to the status of the selected activity (Figure 4b).

If the user clicks on the "Add Photos/Videos" button on the main screen in Figure 3a, the user can select one of the different activities in the project, and add photos/videos about the selected activity by using the smartphone's camera or by selecting the files from its own database (Figure 4c).



4a. Main Screen	4b. Updating activity status and adding	4c. Adding photos/videos of activities

FIG. 4: CPC Application Interface.

Given the requirements of the Occupational Safety and Health Administration (OSHA 2007), workers need to wear protective equipment including hand protection. Gloves can make it difficult to operate touchscreen devices. However, site engineers rarely use protective gloves on construction sites, mainly because unlike laborers, masons, iron workers, and electricians, they are not in direct contact with materials and components that can create dangerous situations. However, Davies and Harty (2013) observe that site engineers can use a stylus to navigate a tablet application in case they need to wear protective gloves. Using a stylus is as easy with smartphones as it is with tablets.

Once recording all activities' status is completed, the smartphone stores on its SD card the activity-related information and comments in an MS Excel file and photos in jpg files. The user then transfers these files to the PC in the office that hosts Primavera P6 by USB cable, 4G mobile communication network, or Wi-Fi. Primavera P6 ignores the comments and the pictures, but uses the updated percentages of completion to rerun the schedule.

4.4 Limitations of the System

CPC is a prototype, and as such, it has limitations and some room for improvement. A pilot application is certainly necessary in a real-life project to identify any problems or challenges that can be encountered during implementation. One of the expected challenges relates to overcoming company culture that favors traditional methods. Implementation of systems such as CPC is likely to create resistance on the part of companies that have comfortably been using traditional pen-and-paper methods. Overcoming deep-seated cultural practices and motivating schedulers and site engineers may be quite critical to the successful implementation of a system such as CPC.

The current version of CPC requires that some updating tasks be performed manually. These tasks include exporting activity information from P6 to an Excel file, and then transferring the Excel file to the smartphone; and transferring progress information from the smartphone to the office computer, and then importing this file to P6 for updating the work schedule. However, it should be possible for CPC and P6 to communicate with each other automatically and seamlessly.

The main reason why CPC was developed for the smartphone is the popularity of smartphones compared to tablets. According to Heggestuen (2013), one in every five people in the world owns a smartphone compared to one in every seventeen owning a tablet. Also, 68% of smartphones use the Android operating system. That is why the CPC prototype presented in this paper was developed for smartphones that use the Android operating system. However, it is important that future versions also operate with the iOS, Windows and other operating systems in order to ensure widespread use, possibly with tablets too.

Security issues have not been considered in the development of this prototype. In the CPC application, schedule information is retrieved by the inspector's smartphone from the scheduler's computer in the office, and progress information is transferred from the inspector's smartphone to the scheduler's computer by Wi-Fi or a telephone network. Unfortunately, it is possible for this information to be intercepted by other parties. One can prevent this from happening by using encryption technology. These technologies are widely available but require expert programming talent and become obsolete quite fast. Given the fact that the information in question is not really very sensitive, using encryption may not be justified because it is expensive, short-lived, and in this case, may be superfluous.

The current prototype of CPC does not address the situation where government or industrial projects of sensitive nature prohibit photography on site. However, it is always possible to disconnect the camera from the smartphone, hence preventing inspectors from taking pictures or videos, but this may be difficult to achieve.

5 CONCLUSION

The use of smartphones with various capabilities, and the development of mobile applications that address various consumer needs are currently growing at a fast rate, extensively impacting almost every part of modern society. The main reason for developing a smartphone application in this study as opposed to a tablet application is the fact that one in every five people in the world owns a smartphone compared to only one in every seventeen owning a tablet (http://www.businessinsider.com/smartphone-and-tablet-penetration-2013-10). There are many opportunities for using smartphone applications, but the construction industry has been slow noticing these possibilities. Successfully developing an application is dependent on quick development and on correctly identifying the needs in the industry.

The Construction Progress Control (CPC) application supports electronic data collection from a construction jobsite and easy information exchange between a smartphone and the PC that houses a project management program in the office. The CPC application was developed for Android smartphones but can easily be extended to work with other systems such as iOS. It enables an inspector to access a project's schedule, record different activities' progress at the construction jobsite, and send the progress information to the office as soon as progress evaluation is complete. Even though CPC can easily be used by anyone who owns a smartphone, CPC is designed for use by on-site engineers in charge of inspecting the work and recoding progress, rather than laborers or trades people. The scheduler in the office can then update the project's schedule accordingly and the project manager can take appropriate action immediately. Accessing, collecting, recording and updating a project's progress information by using electronic means helps ensure the data is accurate and is processed in a timely fashion. The advantage of the system lies not only in improving the efficiency of recording progress information for on-site engineers, but also in providing a quick and automated updating of the work schedule and quick and reliable decision-making for on-site solutions to delays.

Work is underway to let Primavera P6 automatically import the uploaded MS Excel file and update the schedule accordingly. Developing this application for other platforms like iOS and extending the use of the application to tablets are to be explored in future work. Also, security can be an issue in sensitive construction sites and encryption technology needs to be explored to make sure the information does not land in the wrong hands.

6 REFERENCES

Antevy, J. (2012). "Choosing mobile applications for construction management (part 1 of 3)." *e-Builder*, < http://www.e-builder.net/blog/choosing-mobile-applications-construction-management-part-1-3> (Dec. 15, 2012).

Bowden, S., Dorr, A., Thorpe, A., and Anumba, C. (2004). “Mapping site processes for the introduction of mobile IT.” *eWork and eBusiness in Architecture, Engineering and Construction,* Proceedings of the 5th European Conference, Product and Process Modeling in Building and Construction Industry, (2004), Istanbul, Turkey, 491-499.

CEM (2000a). "Mobile inspection assistance." *CEM's Emerging Construction Technologies,* < http://rebar.ecn.purdue.edu/ect/links/technologies/other/mia.aspx> (Dec. 17, 2012).

CEM (2000b). "Palm estimating." *CEM's Emerging Construction Technologies*, < http://rebar.ecn.purdue.edu/ect/links/technologies/other/palmest.aspx> (Dec. 17, 2012).

CEM (2000c). "UpdaterTM: Mobile schedule tracking sofware." *CEM's Emerging Construction Technologies*, < http://rebar.ecn.purdue.edu/ect/links/technologies/other/updater.aspx> (Dec. 17, 2012).

Chen, Y., and Kamara, J. (2008). “The mechanisms of information communication on construction sites.” *FORUM Ejournal*, 8(1), 1-32.

Cox, S., Perdomo, J,. and Thabet, W. (2002). “Construction field data inspection using pocket PC technology.” *International Council for Research and Innovation in Building and Construction*, Proceedings of CIB w78 Conference, Aarhus, 243-251.

Davies, R., and Harty, C. (2013). “Implementing ‘site BIM’: a case study of ICT innovation on a large scale hospital project.” *Automation in Construction*, 30(2), 15-24.

Dong, A., Maher, M.L., Kim, M.J., Gu, N., and Wang, X. (2009). “Construction defect management using a telematic digital workbench.” *Automation in Construction*, 18(6), 814-824.

Fox, S., and Sheldon, B., (2008). "Professional office business application development: using Microsoft Office SharePoint Server 2007 and VSTO", *Office Business Application Development,* Wiley, Indianapolis, IN.

Haas, C.T., Richard L.T., Kamel S.S., and Nicole A.B. (2002). "The value of handheld computers in construction." *Proceedings to International Symposium on Automation and Robotics in Construction*, 557-562. Diss. The University of Texas at Austin, US.

Heggestuen, J. (2013). “One in every 5 people own a smartphone, one in 17 own a tablet.” *Business Insider*, <http://www.businessinsider.com/smartphone-and-tablet-penetration-2013-10> (February 27, 2014).

IDC (2012). "Android and IOS surge to new smartphone OS record in second quarter, According to IDC." *International Data Corporation*, < http://www.idc.com/getdoc.jsp?containerId=prUS23638712#.UM9tEG-CnD8> (Dec. 14, 2012).

Inglesby, T. (2000). “Handheld computing: in the field, handhelds can make a difference.” *ConstrucTECH*, <http://www.constructech.com> (Dec. 17, 2012).

Irizarry, J., and Gill, T. (2009). “Mobile applications for information access on construction jobsites.” *Computing in Civil Engineering*, Proceedings of the 2009 ASCE International Workshop on Computing in Civil Engineering, Austin, Texas, 176-185.

Kimoto, K., Endo, K., Iwashita, S., and Fujiwara, M. (2005). “The application of PDA as mobile computing system on construction management.” *Automation in Construction*, 14(4), 500-511.

Klinc, R., Turk, Z., and Dolenc, M. (2010), “ITC enable communication in construction 2.” *Pollack Periodica*, 5(1), 109-120.

McCullouch, B. (1997). “Automating field data collection in construction organizations.” Proceedings of Construction Congress V: Managing Engineered Construction in Expanding Global Markets, (1997), Minneapolis, MN.

McCullouch, B.G., and Gunn, P. (1993). “Construction field data acquisition with pen-based computers.” *Journal of Construction Engineering and Management,* 119(2), 374-384.

Miah, T., Carter, C., Thorpe, A., Baldwin, A., and Ashby, S. (1998). “Wearable computers – an application of BT’s mobile video system for the construction industry.” *BT Technology Journal*, 16(1), 191-199.

Nathawani, S., Shroff, A., Romack, G., and Ricezz, M. (1995). “PDA-based field data collection for Pontis.” *International Bridge Conference,* Pittsburgh, PA, 342-346.

OSHA. (2007). “Personal protective and life saving equipment.” Part Number 1926, Subpart E, U.S. Department of Labor, Occupational Safety and Health Administration (OSHA), Washington, DC. <https://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=10658> (February 27, 2014).

Tsai, M.K. (2009). “Improving communication barriers for on-site information flow: an exploratory study.” *Advanced Engineering Informatics*, 23(3), 323-331.

Repass, K.A., de la Garza, J.M., and Thaber, W.Y. (2000). “Mobile schedule tracking technology at the jobsite.” *Construction Congress VI*, Proceedings of Construction Congress VI: Building Together For a Better Tomorrow in Increasingly Complex World, Orlando, FL.

Shen, W., Hao, W., Mak, H., Neelamkavil, J., Xie, H., Dickinson, J., Thomas, R., Pardasani, A., and Xue, H. (2010). “System Integration and Collaboration in Architecture, Engineering, Construction, and Facilities Management: A Review.” *Advanced Engineering Informatics*, 24(2), 196-207.

Songer, A., and Rojas, E. (1996). “Field inspection data collection using personal digital assistants and digital cameras.” *Computing in Civil Engineering*, Proceedings of the Third Congress on Computing in Civil Engineering, Anaheim, CA.

Singhvi, V., and Terk, M. (2003). “Prophet: a contextual information system framework.” Proceedings of the CIB W78’s 20th International Conference on Construction IT, Construction IT Bridging the Distance, CIB Report 284, Waiheke Island, New Zealand.

Venkatraman, S., and Yoong, P. (2009). "Role of mobile technology in the construction industry – A case study." *International Journal of Business Information Systems*, 4(2), 195-209.

Vilklo, T., Kallonen, T., and Ikonen, J. (2008). "Mobile fieldwork solution for the construction industry." 16 International Conference Software, Telecommunications and Computer Networks, September, Split, Dubrovnik, Croatia, IEEE, 269-273.

Wang, L.C., Yin, Y.C., and Lin, P.H. (2007). "Dynamic mobile RFID-based supply chain control and management system in construction", *Advanced Engineering Informatics*, 21(4), 377-390.

Yammiyavar, P., and Kate, P. (2010). "Developing a mobile phone based GUI for users in the construction industry: a case study." *IFIP Advances in Information of Communication Technology*, 211-223.