THE USE OF MOBILE COMPUTING IN CONSTRUCTION INFORMATION MANAGEMENT

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Construction work sites are the places where actual construction activities are carried out. However, onsite information communications are hardly supported by information technology. The advance of mobile computing gives the construction industry a powerful potential to extend the boundary of information systems to construction work sites. This paper describes an ongoing doctoral research that is aimed at exploring the potential benefits and barriers of applying mobile computing in improving onsite information communication. The specific focus of the research is on users' perspectives, such as users' requirements and preferences. The proposed methodology consists of three steps: (a) a pilot study; (b) a survey to investigate the information needs of onsite users and the current approaches to information communication; and (c) an experimental research to explore users' perception of using mobile computing within a real construction context. After comparing and analyzing results from the primary study, findings will be used to assess the barriers between people and technologies, the perception of users, and the potential opportunities of mobile computing in onsite information management.

Keywords: construction site, information communication, mobile computing.

INTRODUCTION

The construction industry is an information intensive industry which utilises vast amounts of information throughout the construction process. The efficiency of the industry depends, in part, on the efficiency with which correct and timely information is exchanged between the different stages, and participants involved in a project. The development of Information Technology (IT) gives the construction industry a powerful potential to increase the efficiency and effectiveness of information exchange and therefore bring productivity benefits to the construction process. Current IT support has been extended to construction site offices, but much progress is still needed to ensure that actual work sites also benefit from advances in IT. The emergence of mobile computing has the potential to enlarge the boundary of information systems from site offices to actual work sites and ensure real time data flow to and from the construction sites.

This paper presents an on-going doctoral research which is aimed at investigating the potential benefits of mobile computing on construction information management. Developments in mobile computing and the nature of construction information management are described. An example scenario is then given to illustrate the possibilities for applying mobile computing in the construction industry. Following a review of previous research in the area of mobile computing in construction, the

Chen, Y and Kamara, J M (2005) The use of mobile computing in construction information management. *In:* Khosrowshahi, F (Ed.), *21st Annual ARCOM Conference*, 7-9 September 2005, SOAS, University of London. Association of Researchers in Construction Management, Vol. 1, 581-90.

objectives, methodology and preliminary findings from the doctoral research, which is the subject of this paper, are then presented and discussed.

DEVELOPMENT OF MOBILE COMPUTING

Advances in computer networking since the mid 1970s have brought about the reality of distributed computing, which offers the possibilities for multiple computers and users to communicate and share remote information resources over networks. Satyanarayanan (2001) has summarised the key research areas in distributed computing, including remote communication, fault tolerance, high availability, remote information access and security, and indicated this body of knowledge is now well codified in textbooks.

With the advent of laptop computers, wireless networks and the integration of cellular technology with the Web, a need has arisen for researchers to design distributed systems for mobile users. Mobile computing that applies many basic principles of distributed system design, and which also extends these theories to meet mobile users' requirements, provides a basic infrastructure in which users can access the same point in the network from different computer devices at anytime. However, compared with distributed computing, mobile computing has four key constraints that restrict the development of specialized mobile computing technologies (Satyanarayanan, 1996). These constrains are: the limited local computational resources resulting from size and weight restriction, more vulnerability to loss or damage with regard to security considerations, the variety of connectional performance and reliability, and the concern of power consumption. Satyanarayanan (2001) further pointed out that mobile computing is still on the way of growth, and so far the achievements can be classified into the following areas: mobile networking, mobile information access, support for adaptive applications, system-level energy saving techniques, and location sensitivity.

In 1991, an inspired vision of computing was proposed by Weiser (1991), who said that "*the most profound technologies are those that disappear. They weave themselves into the fabric of everyday life until they are indistinguishable from it.*" This vision is the base of the concept of ubiquitous computing, now also called pervasive computing, which proposes a new way of thinking about computers and the new relationships between computers and users. Saha and Mukherjee (2003) compared the goals of pervasive computing and mobile computing, and concluded that pervasive computing is a superset of mobile computing. In addition to the goal of mobile computing which is recognized as "anytime anywhere", a reactive approach to access information, pervasive computing aims to be "all the time everywhere", which is the proactive concept that users can have seamless access to computing whenever they need it.

CONSTRUCTION INFORMATION MANAGEMENT

The construction industry is known as an information intensive industry. Construction information can be generally grouped into three categorises: technical information, commercial information, and management and control information (BT, 1995). Because of the intensity and diversity of construction information, the efficiency of information management is crucial to the construction industry, and has been recognized as an important competitive advantage to construction companies. However, the current state of information management in construction still has many problems, such as high error rates of data collection, the improvement of data exchange, and the need for automatic audit trails (Bowden et al., 2004). From several case studies, Gyampoh-Vidogah and Robert Moreton (2003) identified the following problems of information management in construction companies: the inability to develop information management policy, culture issues in the adaptation of new technology in construction, the restrictions in moving from the main communication medium (paper) to IT adoption, unconsidered business process techniques, and inability to reassess new IT systems.

As indicated by Rebolj et al (2001), one of the features of the construction industry is the fact that construction activities are dispersed and site locations frequently change. The infrastructure of computers has been transferred to site offices, but not to the construction work sites, which leads to problems with onsite IT support. On construction sites, information that people need to support their works include: requests for information, materials management, equipment management, cost management, schedule and means and methods, jobsite record keeping, submittals, safety, QC/QA, and future trends (de la Garza and Howitt, 1998). Bowden et al (2004) pointed out that the main type of information that onsite construction personnel receive and transmit is paper-based, and include documents such as drawings, data collection forms, correspondences, progress information and specifications. The limitation of paper-based documents has remained a major constraint on site information communication and exchange. Ineffective onsite information communication can result in construction personnel overlooking important issues that require quick response and often cause onsite decisions to be deferred (Singhvi and Terk, 2003).

AN EXAMPLE SCENARIO

The above section has simply introduced the historical development of mobile computing and problems in construction information management. In order to illustrate the potential and forecast the possible way of developing mobile computing in the construction industry, the following example scenario within the construction context will demonstrate some key concepts of mobile computing and pervasive computing and describe how construction personnel can work in an environment with mobile computing.

At 10:00 am, David who is a construction project manager leaves his site office with his wireless PDA. Since he is preparing for a site meeting at 12:00 am, in which attendees include architects, client consultants and subcontractors, David needs to go around the construction work sites and compare the actual progress with the project schedule. From location tracking service, the pervasive computing system detects that David is going to Field A where the task of concreting the foundation walls is in progress, and reviews his calendar that he needs to check progress, hence the system automatically transfers the schedule of this task from the database to his PDA. When David arrives at Field A and checks the progress, the system retrieves the weather forecasting service and informs David that there will be heavy rain that afternoon. Therefore David discusses this status with the labour supervisor and confirms the delay of schedule. Following the confirmation, a notation email is automatically sent to the concrete supplier to cancel that afternoon's delivery. From the equipment tracking service, the pervasive computing system detects that a heavy equipment is moving to Field B. The system also detects that David is leaving Field A and on the way back to the site conference room. After checking David's calendar for the meeting time and calculating the required time to walk back to the conference room, it finds *that there is enough time for David and suggests that he goes to Field B to check the safety requirements and the status of the heavy equipment. When David finishes the visit to Field B and is on his way to the site meeting, he edits the new data for his presentation for the site meeting by using a multi input method like voice and touch pad. As he walks to the conference room, the system starts to transfer the updated schedule and new status of equipment from his PDA to the computer he will use for his presentation. Finally, David commences his presentation and provides the audience the real time information he collected that morning.*

At first glance, this scenario seems like science fiction rather than reality, but it is noteworthy that all the component technologies are actually available today, such as the hardware technologies including PDA, wireless networks and software-controlled appliances, and the software technologies including location tracking, online weather forecasting, online calendars and speech recognition. The reason it looks like science-fiction is because the systematic integration is much better than the simple sum of the individual components.

As introduced in the previous section, the major difference between mobile computing and pervasive computing is *proactivity*. In this scenario, proactivity was illustrated in many instances: transferring the schedule for concreting the foundation walls to David's PDA when the system detects he is going to Field A, sending an email to the supplier after the delay is confirmed, suggesting to David to check the safety of the heavy equipment after reviewing his calendar and calculating the time to walk back to the site office, and transferring the updated schedule to the presentation computer. However, in a proactive system, it is possible that the system pro-acts some suggestions or functions that are useless to users or even annoy users. Therefore, another major ability of this system is to precisely track *user intent*. Within this scenario, before transferring the schedule to David's PDA, the system knows exactly his intent is to check the progress of the concrete foundation walls. In order to precisely track users' intent, the key issue is *context awareness*, which implies the environment surrounding a particular user. Abowd and Mynatt (2000) suggested that "five W's" elements can compose a necessary context environment, including who, where, what, when and why. The value of "context-awareness" is the ability of a system to adjust or modify its behaviour by perceiving the information of users' state and surroundings. There are two main ways to obtain context information: from user's personal computing space, and from user's environment (Satyanarayanan, 2001). A user's computing space may consist of personal calendars, address books, contact lists, and to-do lists. Real-time information that can be obtained from a user's surroundings includes position, other users nearby, and locally observable objects and actions. In the above example scenario, the system knew David's intention to check the progress of concrete foundation walls because this computing system knows he is the project manager (Who) from his login of system; he is going to Field A (Where) from location tracking system, and he will check the construction progress (What) in the morning (When) from his calendar.

Moreover, this scenario also shows the idea of *self-tuning*, which means that the system can modify behaviour to fit circumstances, for example, David can edit data on his PDA by using voice or touch pad outdoor rather than by mouse and keyboard inside his office. The communication of *cross diverse platforms* has been illustrated by the ability to transfer data from PDA to presentation computer. The concept of *smart space* is shown by services and systems on the construction site: online weather forecasting service, online calendar system, location tracking system, and equipment management system.

MOBILE COMPUTING IN THE CONSTRUCTION INDUSTRY

From the construction industry perspective, this example scenario includes many construction information management issues, such as the collection of project progress information, the management of material and equipment information, and safety information check. In fact, there are a number of research initiatives that have applied these new concepts and ideas in the domain of the construction industry.

With respect to context awareness, the most important element of context in construction is location. Other factors include user identification, device or equipment identification, surrounding information of users, situation on the site, user activities, time factors and project status. Singhvi and Terk (2003) described the software architecture of a context-awareness system − Prophet, which enables construction personnel to maintain continuous access to data and services as they move around the construction site by utilizing the knowledge of a user's context. The major element of context in the Prophet System is the user's position which is handled by using a GPS service when outdoor and by a modified RADAR system when inside a building. According to the example scenario, equipment tracking can be found in the Tele-earthwork system (Oloufa et al., 2003), which takes into account the situational awareness of construction equipment and aims to utilizing Differential Global Positioning System (DGPS), wireless and web-based technologies for equipment tracking and collision detection. Menzel et al (2002) discussed the usage of multidimensional data management and agent technology to achieve a context-sensitive process and data representation. In their paper, they classified the context-sensitivity parameters, defined the concepts of multi-dimensional data management by using the metaphor of a data cube, and finally proposed a system architecture for context-sensitive presentation of process and data management.

The voice input technology mentioned in the example scenario has been introduced into the domain of the construction industry through the use of speech recognition in bridge inspection (Sunkpho and Garrett, 2000), and the navigation through drawings by using speech commands (Reinhardt and Scherer, 2000). The challenge of cross platform communication has been discussed by Liu et al (2003) who present a software infrastructure that supports universal accessibility of devices to construction information services. Other research focusing on mobile devices include the usability testing of hand held computing in construction (Bowden et al., 2003), 3D visualization on pocket PC (Fairuz Shiratuddin et al., 2002) and the test of PDAs within real construction scenarios (Magidc et al., 2002). An assessment of the wireless networks has been conducted by de la Garza and Howitt (1998). A review of the current state-of-the–art in mobile computing in the construction industry by Aziz et al (2004), identified the following problems: the weak integration of mobile computing applications with existing desktop based ICT infrastructure, the less integration of mobile computing technologies with construction work environments, the simplicity of collaboration support for mobile workers, and the piecemeal fashion in which mobile computing is applied in the construction sector.

Although there are many research efforts in the area of applying mobile computing in the construction industry, it still has a long way to achieving the goal of mobile computing or even pervasive computing, such as "anytime anywhere" or more proactivity "all the time everywhere". Weiser (1993) pointed out that the whole goal of pervasive computing is to provide applications to service users' needs. This indicates the fact that any research in using new technologies or designing new systems should concern users' perception and find users' requirements. Some questions like who needs this new system, how this system is expected to be used, what kinds of functions users need, what kinds of activities users are engaging in with the system, and how users will employ these new technologies in the future, should be carefully identified and answered through user-centric research with well-designed methodology. Especially in the construction industry, research in employing new information technologies to improve the efficiency of communication or productivity of construction management should take into account the characteristics of the industry and the preferences of construction personnel. The ongoing doctoral research introduced in the following sections will focus on users' perspective in the application of mobile computing for construction site information communication.

THE DOCTORAL RESEARCH

According to current developments in mobile computing technology and the characteristics of the construction industry, the potential opportunities of mobile computing are best deployed in the area of onsite information communication. In this research, a construction site is considered to comprise two main components: construction work site and site office. Construction work site refers to the areas of material storage spaces, actual operation places, equipment locations and other field operations outside the site office. Construction site office is the headquarters for managerial personnel, such as the project manager, foremen, and engineers. The reason of dividing construction site into two components is based on the consideration of the information flow boundary between work site and site office. The site office is an information intensive environment where all types of documents, contracts, drawings and specifications are stored. The work site is the area where actual construction activities are carried out. Onsite people need to retrieve adequate information to sustain their operations and meanwhile transform sufficient information back to managerial people for project monitoring and control.

The topic of mobile computing on construction sites may involve lots of research themes. The proposed research focuses on users' perspective in terms of the identification of potential users, gaps and relationship between users and technologies, users' perception and preferences, and issues of human computer interaction. The communication links between the work site and site office or even with head-office are also considered in this research. The main aim of this doctoral research is to identify barriers between users and mobile computing, and explore opportunities in construction site information communication that can significantly benefit from the use of mobile computing. The findings from this research, it is hoped, will assist more construction companies to adopt mobile computing in their operations. Insights into users' perception in terms of requirements and preferences can also provide relevant information in the design of design future mobile computing information systems in the construction industry.

RESEARCH METHODOLOGY

In order to achieve the objectives of this doctoral research, an appropriately designed methodology is necessary. The strategy employed in this doctoral study contains three steps: a pilot study for the first stage, a survey that will investigate the information needs of onsite users and the current mechanism of information communication, and finally an experimental research that will explore users' perception of using mobile computing devices in a real-life construction environment.

Before commencing the primary study, a pilot study was conducted to obtain general and practical ideas for the proposed research area. The main aims of this pilot study were to identify onsite construction personnel, classify their information needs, and current state of onsite IT support. A case study approach was adopted for this pilot study, using a combination of personal observations and interviews.

The investigation of user's information needs (the second stage of the research) will use a Web-based questionnaire to survey users' needs. The survey will aim to answer two basic questions: what are the user's information needs and how do they receive and transfer information. Questions listed in the proposed questionnaire will be grouped and focused on the following issues: respondents' status, their onsite information needs, the nature of this information, the mechanism of onsite information communication, their experiences in using mobile computing, and their viewpoints on onsite information management. The data obtained from questionnaires will be rigorously and statistically analysed using statistical software, and the results will be used to depict the current status of information communication on construction sites and clarify users' requirements to improve the efficiency of information exchange.

The third stage aims to investigate users' perception of applying mobile computing in managing onsite construction information and will attempt to answer two major questions: what people do and what people prefer. Tenopir (2003) pointed out that what people do can be measured in experimental research by testing what they do in specific situations, and what people prefer can be measured by testing what people actually do within a given context rather than what they say they prefer. Therefore, an experimental research will be used to assess the users' perception of using mobile computing on construction sites. The results from the previous stage can be used to build the theoretical framework for designing the proposed experiment scenario. Construction professionals will be invited to attend this experiment in which they will be asked to perform a number of tasks including information retrieval, data collection and information transfer in a real-life construction site context. As indicated by Wang (1999), verbalization technique is the only method to obtain the data of participants' thoughts while they perform specific task in experiments. Hence, each participant will be interviewed after the experiment in order to identify users' requirements and preferences.

FINDINGS FROM PILOT STUDY

The pilot study was conducted in February 2005. It involved visits to three construction sites with varying project types. The projects were: a theatre refurbishment project, a sports centre extension project, and a water supply project. The observations of construction sites concentrated on the following aspects: the working condition of onsite personnel, their movements and activities, and the different roles of labourers and management staff. With the permission of the project manager, a number of site personnel were interviewed. Interviewees were asked questions based on a pre-designed interview schedule. A tape recorder was used during the interviews with the permission of respondents. A number of factors, such as available time by respondents, interview accommodation, etc. affected the interview process with respect to quality, depth, and usefulness of information obtained. However, the data obtained from this case study was enough to allow a preliminary exploration of the potential difficulties and limitations of onsite studies and to provide insights into how best to design of the following primary study.

Onsite respondents were firstly asked to identify their roles in each project. Roles identified in this case study included project manager, quantity surveyor, general foreman, civil engineer, site engineer, quality administrator, officer manager, demolition manager, ground work foreman, and labourer. The varieties of roles on construction sites are normally affected by project stages, types and sizes. Since the theatre refurbishment project was in the early stages of demolition and ground work, onsite construction personnel included not only project manager, civil engineers and general foreman, but also demolition manager and ground work supervisor. In the sports centre extension project, the original buildings needed to be extended and decorated by particular construction personnel who can perform these types of construction activities. Project size is another factor to affect construction personnel on sites. For example, the general foreman in the limited size project of the theatre refurbishment has to be responsible for site safety issues, which were explicitly taken into account by a safety manager in the water supply project.

The main information that construction personnel need to support their onsite works is drawings. From interviews with civil engineers, they said they have to spend lots of time in analysing and checking construction drawings, and even necessarily carry them to construction sites to assist their works. Management staffs who are concerned with various aspects of the project require multiple types of information, such as drawings, specifications, documents, and site records, to help them to make decisions. In addition, information required by construction personnel is not separated and independent; construction information is also exchanged between functional departments to meet different requirements.

From the observation of construction work sites and site offices, the impression with regards to IT support is that middle-level managers have their own computer, usually laptops, in site offices. In the Sports Centre extension project, site computers had Internet connections to head-office, design teams, and other planning department. Construction information including drawings, documents, and contracts, are transferred via the Internet from head office to the site office. However, none of these three projects use mobile computing technologies to assist any information management tasks. A viewpoint about mobile computing from one of the project mangers interviewed was that: "The size of a PDA screen is too small for construction drawings. We prefer to use paper-based drawings that can be hung on the wall, so it is easy to discuss any construction details." This case study illustrates the fact that construction work sites hardly have sophisticated IT support and that mobile computing is still a very new concept to construction personnel.

CONCLUSIONS

The aims of this paper were to discuss the application of mobile computing in the construction industry and to report the progress of an ongoing doctoral research. The development of mobile computing has three major steps: distributed computing, mobile computing, and pervasive computing. Computer infrastructure has been transferred to site offices, but not to the construction work sites, which leads to inadequate onsite IT support. The concepts and ideas of pervasive computing, the next stage of mobile computing, has great potential to support site information communication and the ability of systemic integration for different devices, technologies and services. From the review of previous research, it was found that most studies in the area of mobile computing in construction are focused on the aspects of technologies or information systems rather than the human factors. The focus of this doctoral research is on users' perspectives, and the exploration of opportunities in site information communication that can benefit from the use of mobile computing. The proposed methodology consists of three steps: a pilot case study, a Web-based survey and a well-designed experimental scenario. The completed pilot study has identified key roles on construction sites, classified their information needs, and suggested current state of onsite IT support. Findings from this case study can be used to explore the potential difficulties and limitations of site-based research and provide insights into the design of the survey.

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